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L. Ribeiro, A. Chambel & M.T. Condesso de Melo Eds.

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Campus Universitário de Santiago
3810-193 Aveiro
PORTUGAL
Tel: +351 91 647 11 02
Fax: +351 234 370 605
E-mail: info@iah-2007.com

Preface

Ecosystem services are defined as the goods and benefits provided to people by ecosystems, including provision of food, fuel, wood and water; regulating services; supporting services such as soil formation and nutrient cycling and cultural services such as opportunities for recreation and spiritual experience.

A recent study of the *Millennium Ecosystem Assessment* has concluded that many of the Earth's ecosystem services are seriously affected by overuse and exploitation of resources. In fact, groundwater resources are facing increasing pressure from consumption in various socioeconomic activities, the most dramatic of which is the general rise in water demand. On the other hand, climate changes have contributed to the decrease in groundwater availability, especially in some sensitive regions such as arid and semi-arid areas and coastal/ estuarine zones. All these anthropogenic changes pose a significant threat to the health of the groundwater ecosystems and negative modifications on the services provided by them.

During the last two decades, groundwater ecology has very rapidly developed as a new research area, originating important concepts such as *Groundwater Dependent Ecosystem (GDE)*. These ecosystems totally or partially rely on groundwater to maintain their species composition and natural ecological processes. Furthermore, their characterization is regulated by the level of dependency on groundwater.

Subterranean ecosystems reveal specific fauna and show high biodiversity and habitat heterogeneity at spatial and temporal scales. Besides, the biological component of subterranean ecosystems provides an important ecosystem service of water purification through microbial degradation of contaminant compounds.

In conclusion, there is a growing need to develop interdisciplinary methodologies in order to properly analyse and understand the complex interrelationships in all these specific ecosystems; and geology, hydrogeology, geochemistry, biology, economy, geomathematics play an essential role in the process.

Implementation of the *European Water Framework Directive (WFD)* and the complementary 'Directive on the Protection of Groundwater against Pollution' [European Union Groundwater Directive] demands an initial characterization of all groundwater bodies.

The initial main criterion for the Directives was the definition of the groundwater status from the point of view of quantity and quality (chemical). However, due to its relevance, the ecological perspective was also introduced in the Groundwater Directive, recognizing the importance of the ecological functions of groundwater and their interactions with GDEs.

The *International Association of Hydrogeologists (IAH)* has set up a *Commission on Groundwater Dependent Ecosystems*, acknowledging the important ecological role of groundwater in rivers, wetlands and other coastal and terrestrial environments. The main goals of this GDE Commission are:

- To promote wider understanding of the ecological role of aquifers and the impacts of groundwater abstraction to decision makers.
- To provide a forum to promote, link and coordinate research in terrestrial, aquatic and marine Groundwater Dependent Ecosystems (GDEs) between IAH members.
- To connect IAH with other organizations active in ecohydrology and related disciplines.
- To potentially attract a new group of groundwater scientists to IAH.

And, UNESCO has also included the concept of GDE in the Ecohydrology theme of the International Hydrological Programme.

The objectives of this *XXXV IAH Congress*, the first one organized by IAH dedicated to *Groundwater and Ecosystems*, are:

- To experience exchange of knowledge on integral groundwater management with dependent ecosystems.
- To propose methods of defining, preventing, controlling and mitigating negative environmental impacts related with groundwater on the ecosystems.
- To discuss specific issues such as climate changes, groundwater quantity and quality as well as threatening processes in dependent ecosystems, biological aspects of groundwater dependent ecosystems and

management and economic tools to protect groundwater, etc.
- To communicate with the general public and with non-groundwater specialists.
- To consider the importance of sustainable development of groundwater, with social, ecological and economic implications.
- To present recommendations to administrators and professionals of water resources management.

The Editors
Luís Ribeiro
António Chambel
M. Teresa Condesso de Melo

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Keynotes

Expanding concepts within eco-hydrology to accommodate the hydrodiversity of groundwater dependent ecosystems (or how do aquifers make ecosystems lazy, inefficient and vulnerable?)

Christine COLVIN

Natural Resources and the Environment, CSIR, Stellenbosch, South Africa.
E-mail: ccolvin@csir.co.za

ABSTRACT

Whilst hydrogeology studies the flow of water through the lithosphere, ecology studies the biologically mediated flow of energy through the biosphere. We currently lack a generic conceptual framework to examine the water-energy interface of groundwater linked ecosystems. Eco-hydrology has emerged as a trans-disciplinary area of study over the last 2 decades in an attempt to consider water links to ecosystems more holistically. However, currently two domains are evident within this field: soil-moisture driven terrestrial systems and surface-water driven aquatic systems. Groundwater dependent ecosystems (GDEs) exist in a diverse range of habitats, spanning both aquatic and terrestrial systems, and their study encourages thinking towards a more inclusive and holistic earth-system model. Much of the previous (valuable) work on GDEs has considered individual case studies (eg Doñana wetlands) or types of habitats (in-aquifer systems), and studies have adopted a bi-disciplinary approach, linking hydrogeology to ecology, ecophysiology or hydrology. Predominantly bi-disciplinary studies have resulted in some confusing and conflicting applications of terminology.

This paper proposes some clarifications for terminology, particularly groundwater dependent ecosystems and aquifer dependent ecosystems. It proposes that ecosystem water requirements should be considered in terms of hydrotopes at the landscape and ecosystem scale. Hydrotopes may be delineated in specific habitats with characteristic spatial and temporal patterns of water provision from precipitation, soil moisture, surface water, groundwater, tidal and oceanic sources. The Trigger-Transfer-Reserve-Pulse (TTRP) model of landscape ecology, is incorporated and expanded to account for the variable storage-transfer functions of different hydrological pathways. The interplay of (typically) soil-moisture/ surface water/ groundwater transfers to an ecosystem define the *hydrodiversity* and *hydroperiodicity* of an ecosystem. Special attention is given to aquifer dependent ecosystems (ADEs) in water controlled (semi-arid and arid) environments, with an illustration of hydrotope typesetting examples in Southern Africa. Semi-arid zone ADEs typically represent keystone ecosystems at ecotones with characteristic hydrotopes of biologically mediated aquifer discharge. Linear and discrete spatial discharge patterns of fractured and alluvial aquifer systems contribute to ecosystem heterogeneity and 'patchiness'. The larger (volume) and more sustained hydrodiversity of aquifer fed hydrotopes sustain relatively high productivity during seasonal periods of relative dormancy in neighbouring soil-moisture dependent hydrotopes. Both terrestrial and aquatic ADEs in these environments are believed to have greater hydrological resistance to disturbances in water inputs and contribute resilience to the surrounding ecosystem. However, ADEs have a relatively low resilience (ability to recover) following changes to the aquifer flow regime beyond natural minima and maxima, and are more vulnerable to irreversible alteration by disruption of aquifer flow. Typically ADEs subsidise neighbouring non-ADEs through trophic cascades. Linked to their smoothed hydroperiodicity, it is expected that ADEs have a lower water efficiency in primary productivity ($gC.H_2Omm^{-1}$) may show net mean annual productivity equivalent to their more 'flashy' episodic neighbours, who have high productivity during the shorter periods of water availability.

In a nutshell – ADEs in water controlled environments have a greater hydrodiversity and characteristic smoothed, longer hydroperiod due aquifer-fed baseflow, than neighbouring hydrotopes, reliant predominantly on surface water or soil-moisture. The additional water budget available to ADEs, slowly released from aquifer reserves, effectively lubricates slower and more prolonged productivity. Whilst ADEs are typically net exporters of ecological services to surrounding non-ADEs, they tend to be lazy, inefficient and vulnerable!

Keywords: ecohydrology, groundwater dependent ecosystems, hydrotopes, hydrodiversity.

Water management and ecosystems – Living with change

Malin FALKENMARK

Stockholm International Water Institute, Drottninggatan 33, SE 11 51 Stockholm, Sweden
E-mail: malin.falkenmark@siwi.org

ABSTRACT

Awareness of ongoing change
In view of the ongoing Great Transition in the developing world, driven by population growth, economic development and increasing expectations, proper awareness has to be paid to criteria for an environmentally sustainable development. This should be interpreted as a development that is not undermining the life support system, i.e. does not involve degradation of ecosystems to such a degree that they cease to contribute vital functions.

Basically, ecosystems are mixes of organisms living in a certain physico-chemical environment. The organisms which belong to different main categories, having different functions (respectively producers, consumers and decomposers) are interacting internally. In this way ecosystems contribute a lot of beneficial functions in the biosphere. Water's role of bloodstream of the biosphere, makes it a key component of ecosystems. At the same time, water is on the one hand influenced by human activities, while it is on the other hand possible to manage.

Terrestrial ecosystems are land-based: forests, grasslands and croplands are supported by soil moisture/green water (Fig. 1), whereas wetlands may be supported by many different forms of water: precipitation, inundating surface water, groundwater, or a mix. Aquatic ecosystems are water-based and may be fluvial or coastal. They dwell in water bodies with blue water forming their habitat.

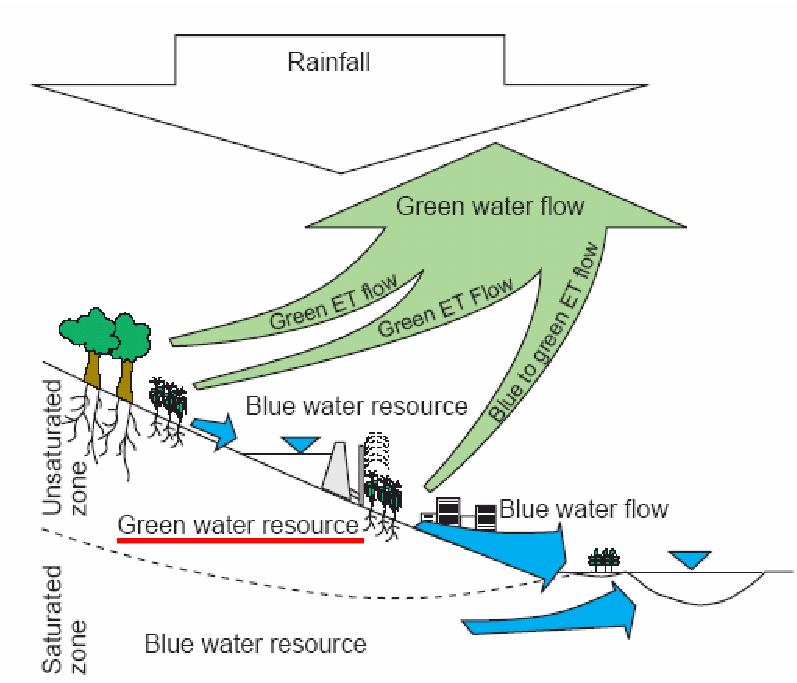

Fig. 1. There are two types of water resources: the blue liquid water in rivers and aquifers, and the naturally infiltrated precipitation or green water in the soil

Protection of ecosystems
In recent years, the earlier focusing among environmentalists on environmental preservation has increasingly been replaced by focus on *conservation of the ecosystems*. Such protection raises three questions: why, what and

how. *Why* is the issue of understanding and convincing of the beneficial functions and usefulness of ecosystems, often expressed in terms of "ecological services" in an effort to reach decision makers and the general public. *Wha*t to protect is a quite difficult question to answer. It tends to refer to either an appreciated landscape component such as an iconic site, a certain forest, a beautiful lake, a certain wetland, etc. that should be protected already for its social value. But it may also be interpreted as the catchment as a whole, referring to certain crucial functions, such as groundwater recharge, to be protected for their ecological value.

Also, *how* to protect an ecosystem is a demanding question to answer. Water's many parallel functions (Fig. 2), its integrating capacity and role in linking land and water, upstream and downstream, humans and ecosystems, invites the possibility to make use of this capacity within integrated water resources management (IWRM). This makes water an interesting entry point for ecosystem protection and IWRM an interesting tool.

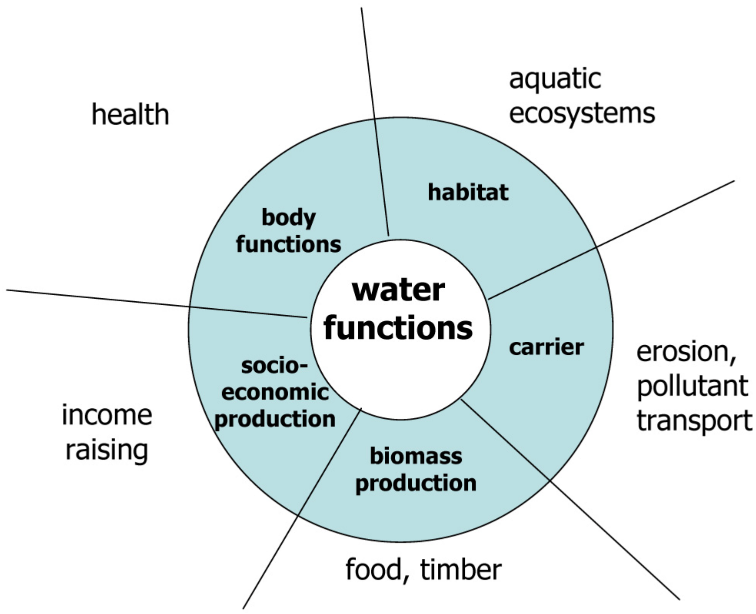

Fig. 2. Water's many parallel functions.

<u>*Focus on ecosystem water determinants*</u>

Attention has then to be directed to the water determinants of the particular ecosystem in focus: what water supports the particular ecosystem, where it comes from, how it might be protected, and what response time one should expect. Terrestrial ecosystems are often linked to the rainwater partitioning process which directs focus to land use and its management. Other such systems may be groundwater-fed, directing focus to where that groundwater was recharged and how far and for how long time it has travelled. Aquatic ecosystems on the other hand dwell in a habitat formed by streamflow, representing a mix of water components with different history. Groundwater is generally a component of that mix and may have travelled short distance or long distance, quickly or slowly. Wetlands, finally, represent a highly diffuse type of ecosystem, which can be anything from a highland bog to a sea shore. Its water determinants – what water keeps the wetland wet – can therefore have very different origin.

As a consequence of water's deep-going involvement in ecosystem life, ecosystem management can, as already indicated, make use of water's potential role as an entry point and be entered into an integrated water resources management (IWRM). For this purpose, however, IWRM would have to be developed into ILWRM where L stands for land use, and water incorporates both blue and green water.

In order to proceed along this path it will be essential to develop a joint understanding between ecologists and hydrologists, both those with focus on water behaviour in a river basin and those with focus on groundwater transported in deep aquifers. Core questions will include issues such as where does the water come from and where does it go? How long has it been on route before arriving at the surroundings of the particular ecosystem. And what can be done in terms of management?

It will be quite important to develop a *meta-language* that can be used for all the discussions required to enter protection of vital ecosystems into integrated water resources management. Since the ILWRM process will involve a lot of trade off striking in terms of balancing humans and nature in efforts to be moving towards sustainable ecosystem management, such meta-language will have to be understandable also by all the stakeholder groups involved in the trade offs.

Interactions between Ground Water and Surface Water and the Hydro-ecology of Streams and Rivers

Judson W. HARVEY

U.S. Geological Survey, Sunrise Valley Drive, Reston, VA 20192, USA, E-mail: jwharvey@usgs.gov

ABSTRACT

Interactions between surface water and ground water influence the quality of water as well as the quantity and timing of water flow in streams and rivers. Although hydrogeologists have long described interactions between surface water of river channels and ground water in surrounding alluvial aquifers, more recently it was ecologists that first demonstrated the importance of very shallow surface-subsurface water interactions that substantially influence water quality of streams and rivers. Flow of water and solutes back and forth between channel flow and the shallow subsurface beneath and to the sides of streams is now commonly referred to as the hyporheic flow. The physics of hyporheic flow have proven difficult to study because many of the fundamental processes, such as the hydraulic forces that drive the flow, not only vary spatially at fine scales (centimeters to meters) but they also respond rapidly to changes in both surface and subsurface flow in ways that are hidden from detection with typical sampling protocols. Another key aspect of the study of hyporheic zones involves the chemical transformations that solutes undergo during transport across the streambed interface. The flow of surface water into the subsurface hyporheic zone replenishes oxygen, carbon, and nutrients that stimulate very high rates of microbial metabolism in hyporheic zones. Consequently, many biogeochemically reactive solutes undergo rapid transformation during transport through hyporheic flow paths. Hyporheic-zone reactions that transform or sequester contaminants include 1) precipitation of iron and manganese oxides in the hyporheic zone that adsorb large quantities of more toxic trace metals such as cadmium, 2) removal of high-levels of in-stream nitrate by hyporheic-zone denitrification, and biodegradation of organic contaminants such as toluene and ethanol. Over the past two decades the study of hyporheic flow has advanced substantially due to interdisciplinary efforts of hydrologists and ecologists working together to combine their measurements in ways that reveal both the fundamental processes and the cumulative effects of hyporheic flow on drainage-basin water quality.

Landscape modelling for the assessment of a nuclear waste repository in Sweden: Integration of hydrological and ecological modelling

Ulrik KAUTSKY, Sten BERGLUND, Jan-Olof SELROOS, Tobias LINDBORG

Swedish Nuclear Fuel and Waste Management Co. (SKB), Box 5864, SE-102 40 Stockholm, Sweden,
E-mail: ulrik.kautsky@skb.se, sten.berglund@skb.se, jan-olof.selroos@skb.se, tobias.lindborg@skb.se

ABSTRACT

The Swedish Nuclear Fuel and Waste Management Co. (SKB) currently investigates two sites in Sweden as potential locations for an underground disposal of spent nuclear fuel. The site investigations cover geological, chemical, hydrological and ecological factors. A strong emphasis has been put on the characterisation of properties and processes affecting the water-born transport and the retention of radionuclides along flow paths from repository depth (c. 500m below ground surface) to the surface, as well as the dispersal and accumulation in the surface system. In the modelling performed to support the site descriptions and the safety assessments, a wide range of hydrological tools have been utilised. These include tools primarily developed for modelling groundwater flow in fractured rock, as well as hydrological modelling tools that handle surface and subsurface flows, water uptake in vegetation and the interactions with the atmosphere. The couplings between the hydrogeology, the near surface hydrology and the surface ecosystems have been especially important for this integrated modelling.

We utilised a landscape approach where the different ecosystems were interconnected through the surface hydrology (i.e., the surface water and near-surface groundwater flows) and the landscape was subdivided by the catchments. Radionuclide transport was modelled in an evolving landscape starting from a marine ecosystem over a coastal to a terrestrial landscape over a period of 20,000 years. The modelled development of the landscape was affected by land uplift after the latest glaciations, sea-level changes, infilling of lakes, and succession of vegetation. The terrestrial landscape includes lakes and rivers that successively develop to mires and potential agricultural land. The discharge of groundwater from repository depth seems to affect low-lying parts of the landscape primarily, which usually contain wetland ecosystems that can be used as agricultural areas in the future.

In this paper, we focus on the description of the interconnection of the hydrological and landscape modelling, and present results from characterisation and modelling performed to support the assessment of potential radionuclide discharge from the rock to the surface ecosystems. Specifically, relatively large-scale groundwater flow models extending well below repository depth are used to identify discharge areas, and hence the potentially affected objects at the surface, whereas hydrological models with a more detailed representation of the surface and near-surface processes provide direct inputs (e.g., residence times and water balance components) to the modelling of transport in the surface system. At the surface the additional flows of organic carbon are included in the modelling of fluxes that gives exposure to humans and the environment.

Estimating groundwater discharge to lake and wetland ecosystems using environmental tracers

[1] Peter G COOK, [2]Cameron WOOD, [2]Troy WHITE and [3]Craig T SIMMONS

[1] CSIRO Land and Water, PMB 2 Glen Osmond SA 5064, Australia, peter.g.cook@csiro.au
[2] Flinders University, GPO Box 2001 Adelaide SA 5001, Australia
[3] Flinders University, GPO Box 2001 Adelaide SA 5001, Australia, craig.simmons@flinders.edu.au

ABSTRACT

Wetland hydrology is considered the most important influence on wetland ecology, development and persistence, and plays a crucial part in understanding and evaluating wetland functions and processes. Wetland hydrology however, is both poorly understood and difficult to characterise. Amongst the hydrologic concerns related to wetlands, the direct interaction between surface water bodies and the groundwater system is one of the most difficult components to quantify. However the groundwater component, even if it is relatively small, can be of crucial importance in wetland processes.

Environmental tracers are often preferred for quantifying groundwater – surface water interactions because their use requires little in the way of field instrumentation, and because of shortcomings of other methods. Wetland and lake ecosystems are often characterised by highly complex stratigraphy, making hydraulic approaches very difficult to apply (due to large uncertainties in hydraulic gradient and hydraulic conductivity values). Water balance methods for estimating groundwater inflow rely on accurate estimates of other water balance components, and are likely to be inaccurate when groundwater inflow is a small component of the water budget.

An ideal environmental tracer is usually considered to be one which is easily-measured, is largely non-reactive and has low background concentrations. These conditions are best met for three tracers: the chloride ion, the stable isotopes ^{2}H and ^{18}O, and radon (^{222}Rn). Of these, radon is least widely used. It is a naturally occurring radioactive element with a half life of 3.82 days; it is a decay product of radium-226, which is present in all rocks and soils in varying concentrations. After groundwater containing radon discharges to surface water bodies, radon activities begin to decrease due to radioactive decay and exchange with the atmosphere (which is low in radon). If the rate of gas exchange can be considered constant, then changes in radon activity within the surface water over time can be used to infer changes in the groundwater inflow rate.

The rate of change of the volume of water in a wetland may be described by a simple water balance:

$$\frac{\partial V}{\partial t} = PA + I_s + I_g - Q - EA$$

where P is precipitation falling directly on the lake (m/day), I_s is the surface water inflow (m^3/day), I_g is the groundwater inflow (m^3/day), Q is combined surface water and groundwater outflow (m^3/day), E is evaporation (m/day) and A is the wetland surface area (m^2). The solute balance can be expressed:

$$\frac{\partial cV}{\partial t} = PAc_P + I_s c_s + I_g c_g + FA - Qc - EAc_E - kAc - \lambda Vc$$

where c_P, c_s and c_g are solute concentrations in precipitation, surface water and groundwater inflow; c is the mean concentration within the wetland, c_E is the concentration lost in evaporation, k is the gas transfer velocity across the water surface (m/day), λ is the radioactive decay constant (day^{-1}) and V is the water volume (m^3), and F is any solute contribution via diffusion from underlying sediments. k and λ are zero for chloride, ^{2}H and ^{18}O, while $c_E = 0$ for chloride and radon. c_s and c_P can also be assumed to be zero for radon.

Assuming steady state conditions (ie. no change in volume over time), the above equations may be combined and rearranged to solve for I_g. Usually, this is done by eliminating Q in the substitution. Groundwater inflow can then be estimated if all other parameters are known. The accuracy of the estimate will depend upon the accuracy of the estimates of the other parameters, and the accuracy of the steady state assumption.

The rest of this paper describes the use of radon (^{222}Rn) to assess patterns and magnitudes of surface water - groundwater interactions in a shallow wetland in southern Australia. Radon activities were been measured in the wetland, and in the surrounding groundwater between May and October 2006. Over this time, the mean water

depth in the wetland fluctuated between approximately 0.15 and 0.25 m, and the surface area ranged between 3500 and 5500 m^2. No surface water inflows were observed over this period. Additionally, gas exchange rates between the wetland and the atmosphere were measured by deliberate injection of SF_6, and radon production within the subsurface was measured on wetland sediment samples.

Figure 1 shows radon activities measured in the wetland in late July 2006. Values range from 0.06 to 1.05 Bq/L (mean 0.32 Bq/L) and appear generally high along the southern and eastern edges. Similar maps were made in May and October 2006, and showed the same pattern of higher radon activities along the eastern and southern boundaries. (Mean activities were 0.32 and 0.28 Bq/L in May and October, respectively.) The results suggest that discharge is occurring primarily along these edges of the wetland. The relative uniformity of radon activities over time, suggests that groundwater inflow is relatively constant.

Results from gas injection experiments using SF_6 gave a gas exchange rate of $k = 0.15 \pm 0.003$ m/day, and the mean radon production rate within the underlying sediments was estimated to be 1.5 mBq/cm^3/day. Based on the measured production rate and an assumed diffusion coefficient, the mean diffusive radon flux from the sediments was estimated to be $F = 11$ Bq/m^2/day, and the radon activity within the wetland that would arise with no groundwater inflow was estimated to be approximately 0.09 Bq/L. Thus, while diffusion may account for some of the lower values observed in the western part of the wetland and in the reed bed, the higher values suggest an additional source of radon, most likely advective flux from groundwater inflow.

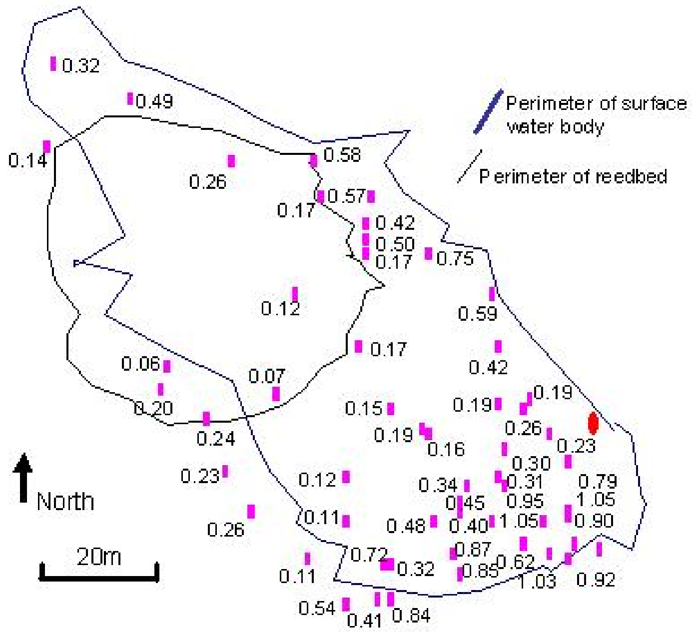

Fig. 1. Radon activities (Bq/L) in surface water on 25 July 2006.

Because of the short residence time of radon, it is reasonable to use a steady state approach to estimate groundwater inflow from the measured radon activity. In the five days prior to 24 May, the mean precipitation rate was 0.6 mm/day and the mean evaporation rate was 1.0 mm/day. Based on a measured lake area of 3500 m^2, this gives precipitation inflow of 2.1 m^3/day and evaporative outflow of 3.5 m^3/day. Assuming $c_g = 15$ Bq/L and $V = 525$ m^3 (mean depth of 0.15 m), and that there is no surface inflow at this time, the measured radon activity of 0.32 Bq/L gives a groundwater inflow rate of 11 m^3/day. Twenty percent uncertainties in P, E or F have negligible effect on the estimated groundwater inflow rate. Similar uncertainty in V causes only a 5% uncertainty in I_g, while a 20% uncertainty in A, k and c_g also causes a 20% uncertainty in I_g. In late September – early October, the lake area was 5500 m^2, and the measured mean radon activity was 0.28 Bq/L. In the five days preceding radon measurement, the mean precipitation rate was 0.26 mm/day and the mean evaporation rate was 4.8 mm/day, giving a precipitation inflow of 1.4 m^3/day and evaporative outflow of 26 m^3/day. Assuming c_g = 15 Bq/L and $V = 1160$ m^3 (mean depth = 0.21 m), gives $I_g = 16$ m^3/day.

Keywords: wetland, radon, isotopes, groundwater, water balance

Modeling of geochemical transport along fresh and salt water mixing zone developed in a coastal aquifer

[1]Kenji JINNO, [2]Keigo AKAGI, [3]Yoshinari HIROSHIRO, [4]Tosao HOSOKAWA, [5]Jun YASUMOTO

[1,2,3,5]Institute of Environmental Systems, Graduate School of Engineering, Faculty of Engineering, Kyushu University, 744 Motooka Nishi-ku Fukuoka, 819-0395 JAPAN, E-mail: jinno@civil.kyushu-u.ac.jp
[4]Department of Civil and Urban Design Engineering, Faculty of Engineering, Kyushu Sangyo University, 3-1 Matsukadai 2-chome, Higashi-ku, Fukuoka, 813-8503 Japan

ABSTRACT

Saltwater intrusion into coastal aquifers is one of the groundwater problems that occurs in many parts of the world. For many years much research has been done on this subject and it is therefore considered that not many new interesting aspects remain. However, geochemical properties and related species transportation, particularly along the fresh and salt water mixing zone, have not yet been studied sufficiently.

In closed seawater areas such as bays and inlets where water exchange is limited, nutrients such as phosphates, nitrates and organic carbons are discharged along the fresh and salt water mixing zone of aquifers. This results in eutrophication inducing deterioration of the aquatic environment and the marine products industry. Recently, it has been reported that nutrients transported by groundwater flow play a significant role in the marine environment.

The authors have been working on the oxidation and reduction geochemical processes coupled with mass transport modeling in coastal aquifers. When porous material is contaminated by organic carbons, oxidized manganese and iron, nitrate can be denitrified and anaerobic groundwater will be discharged. On the other hand, reduced divalent iron will be oxidized while mixing with oxygen rich fresh or sea water. Accordingly, the groundwater quality and marine spring water quality may not be always similar. Such transformation through coastal aquifer has not been discussed sufficiently. The present paper discusses the geochemical and biochemical reaction processes along the mixing zone between fresh water saturated by oxygen and reduced saltwater in coastal aquifers. By comparing the numerical solution with the experimental observation for the iron precipitation along the mixing zone, the validity of the present model was confirmed. The developed model was also applied to the actual aquifer formed at the sand spit. The model is verified by the comparison with observed data in which the salt water in the sand spit was highly reduced at this site.

Microbial ecology and geochemistry of biodegradation in porous aquifers – new concepts for limitations and stimulations

[1]Christian GRIEBLER, [1]Robert, BAUER, [1]Bettina ANNESER, [1]Christian WINDERL, [1]Tillmann LUEDERS, [1]Piotr MALOSZEWSKI, [1]Florian EINSIEDL, [1]Willibald STICHLER, [2]Massimo ROLLE, [2]Sebastian BAUER, [2]Christina EBERHARDT, [2]Peter GRATHWOHL, [3]Lars RICHTERS, [1]Rainer U. MECKENSTOCK

[1] GSF – National Research Center for Environment and Health, Institute of Groundwater Ecology, Ingolstädter Landstrasse 1, 85764 Neuherberg, Germany, e-mail: christian.griebler@gsf.de
[2] ZAG – Center of Applied Geosciences, University of Tuebingen, Sigwartstrasse 10, 72076 Tuebingen, Germany.
[3] Stadtwerke Düsseldorf AG, Höherweg 200, 40233 Düsseldorf, Germany.

ABSTRACT

The biodegradation of organic pollutants in groundwater systems may be limited by the depletion of essential nutrients, the low number of degraders and specific biokinetics. However, the main problem seems to be the insufficient mixing of e-donors and e-acceptors. Main degradation activities in contaminant plumes should therefore be located at their fringes. We call this working hypothesis the 'plume fringe concept'. In order to investigate if biodegradation in porous media is mixing-controlled and to elucidate the ecological role of pollutant degrading microbes, lab and field investigations were performed. These comprised (1) experiments in 2-D aquifer model systems, (2) retrieving of intact sediment cores at a former gasworks site and (3) installation of a novel high-resolution multi-level well.

1) To assess the importance of individual abiotic (e.g. mixing, toxicity, nutrients) and biotic (e.g. cell distribution and activity, redox tolerance) parameters for biodegradation under well controlled lab conditions, contaminant plumes were generated in 2-D aquifer model systems, and subsequently inoculated with aerobic and/or anaerobic bacterial strains to investigate biodegradation at high spatial resolution. The collection of empirical data was accompanied by state of the art reactive transport modelling.
2) For the linkage of processes involved in biodegradation and the respective microorganisms, fresh sediment samples were collected repeatedly from a sandy tar oil-contaminated aquifer. The total microbial community structure as well as the distribution of functional marker genes were correlated to prevailing physical-chemical sediment characteristics.
3) To elucidate the importance of scale in relation to biodegradation activities in porous media, a high-resolution multilevel well was installed. This well allows the simultaneous withdrawal of groundwater samples from the contaminated zone with a vertical spatial resolution of up to 3 centimetres.

The 2-D microcosms and the investigated aquifer biodegradation of contaminants was followed by vertically resolved concentration measurements, compound-specific stable isotope ($^{13}C/^{12}C$, $^{34}S/^{32}S$ and $^{18}O/^{16}O$) analysis, the identification of signature metabolites, the spatial distribution of microbial biomass, and specific degraders via marker genes indicating potential degradation activities.

Major outcomes so far may be summarized as follows:

- Dispersion in porous aquifers controls contaminant transformation to a high degree, but in anoxic environments further processes (most probably coupled to biokinetics) limit anaerobic biodegradation.
- Sediment heterogeneity and transient hydraulic conditions exhibit a significant positive effect on the overall biodegradation.
- The fringes of contaminant plumes display small scale and steep physical-chemical gradients in the range of centimeters to decimeters. These gradients are the hot spots of biodegradation.
- At these hot spots the relative abundance of specific degraders was highest. Up to 50% of the cells present in sediment samples from the fringe zone could be shown to carry degradation-specific functional genes.

Keywords: biodegradation ecology, plume fringe concept, small-scale gradients, high-resolution sampling, mixing-controlled biodegradation, spatial and temporal dynamics

Ecohydrology, phreatophytes and groundwater dependent ecosystems

[1]O. BATELAAN and [2]J.P.M. WITTE

[1]Vrije Universiteit Brussel, Dept. Hydrology and Hydraulic Engineering, Belgium, e-mail: batelaan@vub.ac.be, also at: K.U.Leuven, Dept. Geography-Geology
[2] Kiwa Water Research, PO Box 1072, 3430 BB Nieuwegein, The Netherlands, e-mail: Flip.Witte@kiwa.nl

ABSTRACT

Ecohydrology has been discovered, and embraced, as a new scientific discipline throughout the world. Several authors have stressed its importance to the progress of hydrology and ecology. However, there appears to be a wide range of ideas on which topics ecohydrology should include. We describe the history of ecohydrology and distinguish the different ecohydrologic schools. One of the roots of ecohydrology is based on the dependence of certain plants on groundwater, as was already recognized by Henry Philibert Gaspard Darcy. Oscar Edward Meinzer introduced the term 'phreatophyte' (Meinzer, 1923). He defined it as a plant that habitually obtains its water supply from the zone of saturation, either directly or through the capillary fringe. In the first half of the 20th century plants hydrologists regularly used plants as indicators in groundwater investigations, especially in the semi-arid regions of the U.S.A. Here the relation between vegetation and groundwater availability is obvious. After the first half of the 20th century hydrogeologists seemed to lose their interest in the use of phreatophytes in groundwater studies, but ecologists continued the study of their habitat requirements (Londo, 1988; Ellenberg, 1991). In more recent times the general interest in phreatophytes has been revived, following the interest in groundwater dependent ecosystems.

In this paper, the ecohydrological schools are reviewed as well as the role of phreatophytes in ecohydrology and in assessment of groundwater dependent ecosystems. Case studies are used to demonstrate the benefits, limitations and complications of using phreatophytes in hydrological studies. Groundwater and particle tracking models, hydrochemistry and remote sensing are used to understand the distribution of plants and the composition of vegetation. These all contribute to understanding biodiversity and the functioning of groundwater dependent wetlands. In addition, phreatophytes may be helpful when designing groundwater models. In stable conditions, they reflect average long term hydrologic conditions, which can be assessed quite easily. It is argued that the well balanced use of 'soft' phreatophytic information can be complementary to 'hard' groundwater data and analysis techniques. This will result in a better understanding of groundwater dependent ecosystems.

Keywords: Ecohydrology, phreatophytes, groundwater dependent ecosystems

Science-policy integration linked to the implementation of the European Union Water Framework Directive (WFD) and its daughter directives

Philippe QUEVAUVILLER

European Commission, Environment DG, Office: BU9 3/142, B - 1049 Brussels.
E-mail: Philippe.Quevauviller@ec.europa.eu

ABSTRACT

The need for a better science-policy integration linked to the implementation of the European Union Water Framework Directive (WFD) and its daughter directives, in particular the new Groundwater Directive 2006/118/EC, is being discussed since 2004 in multi-stakeholders' forum. The sharing and exchanges of views between scientists, policy-makers and experts from NGOs and professional associations have highlighted that, at the present stage, knowledge generated by several research and demonstration projects is not reaching policy-makers in an efficient way. On the other hand, the consideration of research results by the policy-making community is not straightforward, mainly for political reasons and difficulties to integrate the latest research developments in legislation. The difficulty is enhanced by the fact that the policy-making community is probably not defining its role as "client" sufficiently well. In other words, the dialogue and communication are far from being what one would hope to ensure an efficient flow of information. It is now generally recognised that improvements could be achieved through the development of a 'science-policy interface', ensuring a structured information exchange among different actors concerned. This would enable R&D results to be synthesised in a way that could efficiently feed the implementation and further reviews of the policies and ensure a timely identification of short, medium and long term research needs.

The 'Policy Session' of the IAH Groundwater & Ecosystems Conference is at the heart of these discussions, providing examples of research projects and case studies that are linking scientific progress to EU groundwater policy developments.

Perceptions, Economic Values and Water Policy

Gregory L. POE

Department of Applied Economics and Management, Cornell University,
Ithaca, New York 14853 USA. E-mail: glp2@cornell.edu

ABSTRACT

As evidenced by the debate over Arsenic Drinking Water Rule in the United States, public policy with respect to water quality is based, to a large extent, on science, but is perhaps more greatly influenced by human perceptions and values. Notably, in the United States significant environmental rules promulgated by executive agencies such as the US Environmental Protection Agency require an evaluation of benefits and costs as part of the regulatory impact analysis. Quantification of the benefits associated with regulatory intervention are typically based on the economic concept of society's "willingness to pay" for improvements in environmental quality. Often these values are measured using the contingent valuation method, a survey technique that elicits individual willingness to pay measures for environmental improvements.

Drawing from a meta analysis of groundwater quality valuation studies and the individual studies contained in this data set, this presentation will identify themes that have emerged from existing contingent valuation research in the United States. The role that contingent values from these studies played in the Concentrated Animal Feeding Operations (CAFO) Rulemaking will be highlighted: interestingly the original proposed CAFO rule had to be revised, in part because the estimated benefits of the original proposal did not exceed the costs.

The aforementioned research and policy have been directed toward assessing the benefits of reduced exposure and health improvements for humans, which has been facilitated by the fact that the scientific community has been able to provide meaningful endpoints or outcomes that can be used in economic analyses. Lessons learned from this research, as well as more recent results from behavioral economics, are extended to the challenges of valuing impacts on ecosystems.

The economic challenge to integrated groundwater and ecosystem protection

Roy BROUWER

Institute for Environmental Studies, Vrije Universiteit, De Boelelaan 1087, 1081 HV, Amsterdam, The Netherlands. E-mail: roy.brouwer@ivm.vu.nl.

ABSTRACT

The Water Framework Directive (WFD) is the first European Directive to explicitly recognize the importance of the interdependency between aquatic ecosystems and their socio-economic values and provides a more integrated catchment approach to water policy. Investments and water resource allocations in river basin management plans have to be guided by cost recovery, cost-effectiveness criteria and the polluter pays principle. The plan formulation and assessment process must furthermore include a meaningful consultative dialogue with relevant stakeholders. Such a dialogue will inevitably raise socio-political equity issues across the range of interest groups and therefore affect the management strategies.

Although groundwater resources are an integral part of catchment wide aquatic ecosystems, their position and role are not well defined in the WFD. Hence in 2007 the adoption of specific measures to prevent and control groundwater pollution in the new European Groundwater Directive (GWD). The GWD complements the provisions already in place in the WFD and in the existing Groundwater Directive 80/68/EEC, which will be repealed in 2013 under the WFD. In order to support the process of determining future groundwater quality threshold values for European groundwater bodies, the social and economic aspects and implications of specific threshold values, (e.g in relation to sensitive ecosystems), were considered as part of the EC Directorate-General Environment commissioned 2005-2006 project Background cRiteria for the IDentification of Groundwater thrEsholds (BRIDGE).

The role of economics in establishing groundwater threshold values is comparable to the role of the economic analysis in the implementation of the WFD, where environmental objectives can be lowered or delayed in time if the costs of reaching the objectives are considered ‘disproportional’. In order to be able to evaluate and assess whether the economic costs of reaching environmental groundwater threshold values are disproportional, an important step is to evaluate and assess the cost and effectiveness of possible management measures to reach these threshold values. This includes their distribution across various stakeholders, and then to compare these with the corresponding environmental, social and economic benefits. Researcher and policy-maker confidence in the estimated costs and benefits associated with different groundwater threshold values is an important criterion in this decision.

Risk and uncertainty are key concepts in the environmental and economic assessment of different groundwater quality threshold values. The ecological and human risks of groundwater quality are surrounded by uncertainty about the correct dose-pathway-effect relationships. The risk of not meeting a threshold value is highly dependent on the limited available data and information and the confidence the analyst and policy-maker have in these data and information. In principle, economics also has a role to play here: in the development and design of alternative groundwater quality monitoring systems to inform policy makers and groundwater managers about the appropriate course of action. In the case of setting up new monitoring systems or modifying existing monitoring networks, the economic value of additional information plays an important role. Here the economic costs of extra monitoring will be weighted against the additional benefits of more sustainable groundwater management, including their impact on dependent aquatic and terrestrial ecosystems. In other words, economic criteria are expected to be an integral part of the actual adoption and implementation of any groundwater monitoring and management plan.

In conclusion, economic criteria and considerations are expected to play an increasingly important role in the actual implementation of sustainable groundwater management based on threshold values now and in the future. So too, the design of groundwater quality monitoring systems, to inform policy makers and groundwater managers about the appropriate course of action to be taken.

Ecohydrology and groundwater dependency of water limited ecosystems

Maciek W. LUBCZYNSKI

ITC, P.O. Box 6, 7500 AA Enschede, The Netherlands, e-mail: lubczynski@itc.nl

ABSTRACT

With climate change, population growth and also increasing awareness of the interdependencies between plants and water, the role of ecohydrology, particularly related to ecosystem groundwater dependency, is rapidly increasing.

In water limited environments, that cover a large part of the earth, plants are the main users of rain water. They are typically well adapted to large water stress conditions, being efficient not only in uptaking surface and unsaturated zone water but some tree species can also uptake groundwater from depths exceeding even 70 m! In water limited environments, characterized by very low recharge, this can affect the groundwater balance significantly.

Tree transpiration can be estimated based on sap flow measurements of individual trees. Spatial variability and patterns of tree transpiration can be derived through upscaling of sap flow measurements, either by field surveys or by remote sensing. For spatio-temporal tree transpiration, additional long-term sap flow monitoring needs to be done on a number of different size trees for all species types present in the study area. Such spatio-temporal transpiration provides ecohydrological characteristic of an area investigated, but also an input for ecohydrological models.

In order to map groundwater dependency of ecosystems, for example isotopic partitioning of tree transpiration for each species present in the study area can be applied. Once such partitioning is done, i.e. the proportion of the groundwater uptake versus total transpiration is known per species, the spatio-temporal mapping of groundwater uptake can be defined, modifying total transpiration maps accordingly.

The results obtained from the Kalahari research indicate, that plants uptake the majority of the rain water. Besides, some specific tree species for example *Boscia albitrunca,* uptake a large amount of groundwater from a great depth. In water limited environments, such as Kalahari with low recharge <10 mm/y, the impact of plants upon groundwater is therefore of critical importance so cannot be neglected in regional groundwater resources evaluations.

TOPIC 01

Groundwater/surface-water water interactions and their importance for the sustainability of river and spring base flow, and associated wetlands

A classification scheme for pollutant attenuation capacity of the groundwater-surface water interface

[1]Jonathan WN SMITH, [2]Tracey GOODWIN, [3]Julian C ELLIS, [4]David N LERNER

[1] Environment Agency, Olton Court, Solihull, UK, e-mail: jonathan.smith@environment-agency.gov.uk
[2] CEH, Crowmarsh Gifford, Wallingford, Oxfordshire, UK, e-mail: tgo@ceh.ac.uk
[3] WRc plc, Blagrove Road, Swindon, Wilts., UK, e-mail: julian.ellis@wrcplc.com
[4] Catchment Science Centre, Sheffield University, Sheffield, UK, e-mail: d.n.lerner@sheffield.ac.uk

ABSTRACT

The groundwater – surface water interface is a critical transitional zone between terrestrial and aquatic environments. Chemical and temperature gradients are frequently present that have been shown to enhance the cycling of carbon, nutrients and energy, and to create a dynamic ecotone. These conditions can result in the attenuation of certain pollutants, including a number of priority pollutants under the EU Water Framework Directive (WFD). Assessment of the interactions between groundwater and surface waters is a requirement for assessment of groundwater chemical status, and for analysis of the impact of groundwater bodies on surface-water body ecological status.

A classification scheme has been developed that describes and categorises the potential for pollutant attenuation within sediments at the groundwater – surface water interface. It is constructed at WFD surface water body-scale, and includes data describing:

- Sediment supply and thickness;
- Stream power;
- Sediment permeability;
- Sediment geochemistry

Nationally available datasets have been used to develop a regional-scale classification scheme that is implemented via a GIS. It is used to aid prioritisation and integrated catchment management where groundwater – surface water interactions are a significant component of the hydrological dynamics of a catchment. The classification scheme categorises around 6000 surface water bodies in England and Wales into one of nine attenuation classes (Fig. 1)

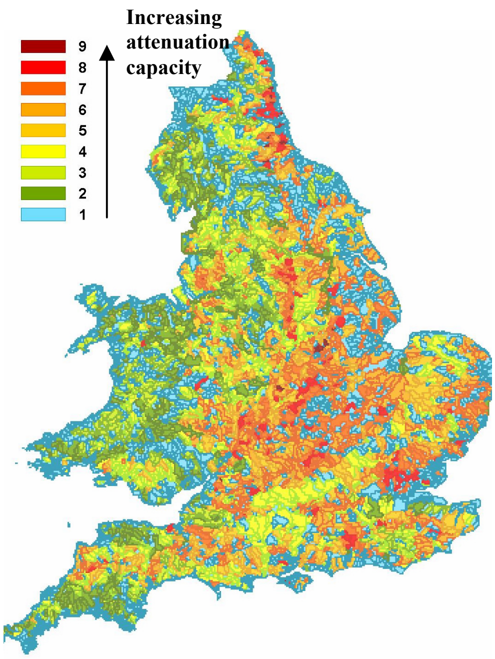

Fig. 1. Attenuation capacity of hyporheic sediments in surface water bodies in England and Wales.

The classification scheme has been tested using groundwater and surface water nitrate data, previously collected as part of the designation process for Nitrate Vulnerable Zones in England and Wales. Using multiple regression analysis, the explanatory powers of the various pollutant attenuation criteria were tested for predicting the nitrate concentration in rivers. The explanatory powers of the classification axes were each found to be statistically significant ($P>0.001$) in predicting river nitrate concentrations, and improving the overall model's performance by about 7%, to $R^2 \sim 0.6$.

The use of the attenuation classification scheme will be illustrated for designing risk-based catchment management responses in nutrient enriched-catchments. It will be shown how the classification can help catchment managers design more technically- and cost-effective programmes of measures for nutrient pollutant groundwater-fed rivers.

Keywords: GW-SW interactions, attenuation, classification, management

An Assessment of Groundwater Dependent Ecosystems in the Burnett River Groundwater area, Queensland, Australia.

[1]Richard EVANS, [1]Steve PARSONS, [2]Tony O'GRADY, [3]Andrew BOULTON

[1] Sinclair Knight Merz, 590 Orrong Road, Armadale, VIC, 3143, Australia, revans@skm.com.au
[1] Sinclair Knight Merz, 590 Orrong Road, Armadale, VIC, 3143, Australia, sparsons@skm.com.au
[2] Research Fellow, School of Plant Science, University of Tasmania, Hobart, TAS, 7001, Australia, Tony.O'Grady@ffp.csiro.au
[3] Professor, Ecosystem Management, University of New England, Armidale, NSW, 2351, Australia, aboulton@une.edu.au

ABSTRACT

The Burnett River Groundwater Area is located near the eastern coast of Australia in Central Queensland, near the city of Bundaberg. This is an area of significant groundwater use where about 70,000ML/yr is used, predominantly for irrigation of sugar cane. Groundwater development in the Coastal Burnett Groundwater Area commenced in the early 1900s and grew slowly but steadily until around 1960. The 1960s sugar boom, combined with advances in drilling triggered rapid development of groundwater resources in the area, and an estimated 900 irrigation bores were installed by 1968. This led to over extraction and saline intrusion along the coastal areas and a lowering or elimination of river baseflow in some areas. A groundwater management plan is being developed with the aim of controlling further expansion of groundwater use and also to stop sea water intrusion. As part of the development of the plan, there is a legislative requirement to consider the impact of groundwater use on groundwater dependent ecosystems (GDE) and hence minimise these impacts as part of the implementation of the plan. This paper describes the assessment undertaken to determine the environmental water requirement of the following GDE types.

1. Terrestrial and Riparian GDEs

Groundwater dependence was assessed by considering ecosystem structure, climate, depth to groundwater and soils. Eleven regional ecosystems were identified as being potentially groundwater dependent. Of these, eight are considered to be highly dependent and the remainder are considered to be proportionally or opportunistically dependent. Rainfall and stored soil water probably meets the water use requirements for most regional ecosystems for most years where depth to groundwater is greater than 3 m. However, the frequency of groundwater use increases in communities where groundwater is shallow (1-3 m). Environmental water requirements for highly, proportionally and opportunistically dependent communities were determined based on the frequency of groundwater use measured as the number of years over the period of rainfall record, where the soil water balance at the end of the dry season was zero.

2. River Baseflow Systems

The Elliott River is a highly dependent GDE during the dry season based on the baseflow separation analysis. Baseflow analysis indicated that on average over the past 30 years groundwater contributed more than 50% of flow to the Elliott River for 5 months of the year (June to October), peaking in July when the contribution is 70%.

It is proposed that the average frequency of flows less than 2 ML/day be adopted as the environmental water provision for the Elliott River. Based on modelling of natural flows in the river it is estimated that on average 30 days per year occur with flow less than 2 ML/day.

3. Wetlands

Potential wetland groundwater dependence was assessed using depth to watertable maps, nearby bores and associated water level and salinity data, soils maps, and hydrology and available ecological descriptions.

4. Aquifer Ecosystems

A preliminary survey of stygofauna was conducted which formed the primary data source for this assessment. Based on the survey results, the key groundwater attributes that correlated with high stygofauna abundance were:

- depth to watertable (less than 11 m below ground), and,
- water quality: dissolved oxygen (between 0.5 - 5 mg/L, conductivity less than 200 µS/cm, and total organic carbon 0.25 - 3.2 mg/L).

5. Submarine Groundwater Discharge (SGD) Systems

Three ecosystem types can be considered as significant spatial entities including seagrass communities, open system communities, and estuarine systems. The estuaries can be expected to be highly dependent on groundwater. Australian coastal waters are relatively depauperate in nutrients, such as nitrogen and phosphorus, as a result of limited upwelling along the continental shelf margin and localised (in space and time) terrestrial discharge. The emergent paradigm is that SGD is usually enriched with nitrogen, phosphorus and often silica so that even if SGD flows are low, the relatively high nutrient concentrations combined with the longitudinal dimensions of aquifers ensure a disproportionately large significance for groundwater inputs to the coastal sea and its ecosystems. It is likely, therefore that both the seagrass communities and the deeper coastal open system communities adjacent to the shoreline boundary of the Burnett Basin groundwater region are proportionately or highly dependent on related SGD. The shallow intertidal ribbon and deeper coastal open systems are probably best considered to be of opportunistic or proportional dependency on SGD.

6. Fauna

A major turtle rookery in the area supports the largest concentration of nesting marine turtles on the eastern Australian mainland and is the most significant loggerhead turtle nesting population in the South Pacific Ocean region. Available evidence suggests groundwater dependency is high and the key attributes to the saturated sands that comprise this GDE are groundwater level and possibly groundwater quality. While the necessity for saturated sediments for loggerhead viability is unquestioned, the exact association of this with groundwater dynamics and sources is less clear. Assuming that there is a high dependency between groundwater and egg/hatchling survival in the nesting chamber, the likely response function to groundwater level is a threshold response where the watertable sustains capillary sediment moisture but is not so saturated that free water enters the nesting chamber and drowns the eggs. The primary environmental water requirement is that groundwater levels beneath the dune during the nesting period (wet season) are sufficiently elevated so that the capillary zone is at least within 0.5 m below surface of the main hatching area.

Keywords: Burnett River, Australia, groundwater dependent ecosystems

An integrative approach to sustainable groundwater and associated groundwater-dependent system management in arid karst aquifers: Cuatrociénegas Basin, Mexico

[1]Brad D WOLAVER, [2]John M SHARP, Jr., [3]Juan M RODRIGUEZ, [4]Dean A HENDRICKSON

[1] Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX 78712-0254, U.S.A., email: brad_wolaver@mail.utexas.edu

[2]Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX 78712-0254, U.S.A, email: jmsharp@mail.utexas.edu

[3]Department of Geohydrology and Geophysics, Faculty of Civil Engineering, Universidad Autónoma de Nuevo León, San Nicolás de los Garza, Nuevo León, México, email: lampazos54e94@yahoo.com

[4]Section of Integrative Biology, The University of Texas at Austin, School of Biological Sciences, 1 University Station R4000, Austin, Texas 78712, U.S.A, email: deanhend@mail.utexas.edu

ABSTRACT

The Cuatrociénegas Basin, Coahuila, Mexico, in the central Chihuahuan Desert, is a UNESCO Biosphere Reserve with a suite of approximately 500 springs and associated groundwater-dependent ecosystems, called ciénegas, a Spanish term for wetlands. The reserve protects over 70 endemic species of fish, turtles, mollusks, snails, and other endangered biodiversity, as well as a diversity of globally extremely rare, active freshwater stromatolites. Springs vary widely in discharge rate and timing, temperature, and salinity. In the southwest U.S. and Mexico, many similar groundwater-dependent wetlands have dried due to groundwater overdevelopment, highlighting the need for conservation of existing ciénega ecosystems. Lines of springs occur in the Cuatrociénegas Basin on either side of the Sierra San Marcos, a 2,600-m Cretaceous carbonate highland with extensive visible karst development that divides the 1,200 km^2 valley into west and east sub-basins. The west sub-basin contains fracture-controlled springs with relatively high and constant discharge, elevated temperatures, and high total dissolved solids. The east sub-basin is comprised of dozens of stratigraphically-controlled small springs that occur at the fringes of alluvial fans. East sub-basin springs generally have lower temperatures and fresher waters than west sub-basin springs. Springs in the east sub-basin have relatively low discharges that fluctuate in response to precipitation. Hypothesized fault and fold control on these springs was discounted by gravity profiles. Aquatic species and a deep basin outlet canyon at Puerto Salada suggest that the Cuatrociénegas Basin was part of a large regional surface water drainage. Elevated travertine deposits and remnant alluvial fan deltas suggest a lake system filled the Cuatrociénegas Basin, or surface and groundwater discharge was much greater during past pluvial periods.

Water development in the Cuatrociéngas Basin region has substantially reduced groundwater-dependent ecosystem size. The formerly closed basin included large playa lakes and extensive ciénega ecosystems. Natural discharge from the Cuatrociénegas Basin was evapotranspiration and possibly surface and groundwater outflows, but there is no historically documented interbasin surface or groundwater flow to the La Madrid valley to the east. Radiocarbon dating indicates groundwater-dependent ecosystems in the Cuatrociénegas Basin have existed for at least 30,000 years. Archeological remains in caves show that humans fished valley wetlands since well before pre-Columbian times. Spaniards settled the Cuatrociénegas Basin in the 1760s, attracted by the riparian wetlands of the spring-fed Río Cañon, which they used to irrigate gardens, orchards, and vineyards. Now, canals convey spring discharge out of the formerly closed basin through the Puerto Salado gap to irrigate the La Madrid valley. French drains have lowered shallow groundwater for grazing and further reduced wetland size and the unique stromatolites associated with the former Río Garabatal. Groundwater level existed close to the ground surface (manifesting as seasonal phreatic playas in some locations) as late as the 1970's in upgradient valleys to the north and south, prior to large-scale agricultural groundwater development for alfalfa in the mid-1980s (exasperated by long-term regional climatic drying), that caused over 20 m drawdown in the Hundido Valley to the south and drying the Río Cañon to the north (in the 1960s spring discharge was approximately 0.25 m^3/sec, but the Río Cañon now rarely flows). In light of the adverse environmental effects of water development projects, wetland restoration is occurring. Pronatura Noreste, a Mexican non-governmental conservation organization, has purchased water rights from farmers to restore wetlands – the first such purchase in Mexico.

Reserve managers are also exploring the possibility of diverting canal flow through the now dry Río Garabatal to restore wetlands.

Continued groundwater overexploitation in upgradient basins to the north, west, and south basins endangers spring-fed wildlife habitat in the Cuatrociénegas Basin. This research project: 1) delineates recharge areas to Cuatrociénegas Basin springs; 2) evaluates of the effects of regional groundwater management decisions and climatic variation on Cuatrociénegas Basin spring discharge; and 3) communicates these results to Mexican water resource managers using a user-friendly groundwater simulation model for rapid water-use analysis. Ultimately, the procedures developed by this research will present Mexican water resource managers information needed to develop effective water management policies to protect Cuatrociénegas Basin groundwater-dependent ecosystems from unsustainable development. We test the hypothesis that a combined local and regional flow system provides water to Cuatrociénegas Basin springs and associated groundwater-dependent ecosystems using an approach that integrates disparate data types (spring discharge, temperature, water quality, etc.). A hydrogeologic model is developed that is the foundation of a numerical simulation model used to predict the effects of various water management and climatic scenarios on spring flow.

Spring discharge data (December 2002 to January 2007) indicate that Poza La Becerra, the largest spring in the west sub-basin, has a relatively constant discharge (720 to 840 L/s, $Q_{average}$=580 L/sec), suggesting a strong regional flow component. The Santa Tecla Canal integrates dozens of springs in the east sub-basin and shows that discharge decreased from 320 to 250 L/s ($Q_{average}$=190 L/sec) over the period of record, reflecting drying in a primarily local Sierra San Marcos recharge source. Anecdotal evidence suggests that east sub-basin terminal wetlands are the largest in 10 years, due to heavy late-2006 Cuatrociénegas Basin precipitation. However, west sub-basin spring outflow is unchanged, supporting regional recharge sources there. Spring temperature data were collected continuously in west and east sub-basin springs during a summer monsoon season from June to July 2006. Temperature data show that west sub-basin spring temperature is constant and elevated (33.90°C). East sub-basin spring temperature is lower (30.55°C) and decreased 3 to 7°C in response to two heavy precipitation events. Temperature data indicate a local recharge component and a shallower groundwater flow system in east sub-basin springs. West sub-basin springs reflect a significantly deeper, regional flow component. Spring water total dissolved solids data (as measured by electrical conductance, EC) were collected during 2004 and 2005 sampling events. EC ranges from 2,360 to 2,550 µS in the west sub-basin and is approximately 1,390 µS in east sub-basin springs. Higher EC values in west sub-basin springs suggest more highly evolved groundwater indicative of regional flow. Lower EC values in east sub-basin springs suggest a greater influence of less-evolved local flow derived from Sierra San Marcos recharge.

An integration of discharge, temperature, and water quality data demonstrate a hydrogeologic conceptual model with springs of two distinct hydrogeologic character: locally- (east sub-basin) and regionally-derived (west sub-basin) recharge. In order to understand recharge sources, groundwater catchments are delineated based on surface topography (700 to 3,025 m) using geographic information systems (GIS) for the Cuatrociénegas Basin and surrounding 18,300 km^2 region, including four major valleys upgradient to the Cuatrociénegas Basin. Chloride mass balance recharge estimates show that groundwater flowing to springs is recharged in the mountains surrounding neighboring upgradient valleys. A relatively small catchment area in the mountains surrounding the largest spring in the basin also indicate a strong regional flow component. A groundwater simulation model is constructed using the hydrogeologic model and catchments delineated in GIS. The model is coarsely-descritized (seven basins) to permit rapid run times for stakeholder participation and is calibrated by varying permeability (based on analogous karst terranes), recharge (using precipitation extrapolated by elevation from valley floor gauges and mountain top vegetation), and basin hydrogeologic connectivity until modeled spring discharge matches measured values and groundwater heads are correct (both measured and anecdotal evidence). Model users can change pumping scenarios and climatic conditions using a simple graphical user interface (GUI) to understand management effects on spring discharge.

We have developed an integrative approach to characterize the regional arid karst aquifer system and groundwater-dependent ecosystems of the Cuatrociénegas Basin, Coahuila, Mexico. Results of this research should permit water resource managers to develop effective policies to protect, conserve, and restore groundwater-dependent ecosystems in the Cuatrociénegas Basin. Similar procedures may be used to balance groundwater development with wetland protection in similar arid karstic settings globally.

Keywords: Arid regions, Groundwater recharge/water budget, Groundwater/surface-water relations, Karst, Water-resources conservation

Assessing the Nitrogen Attenuation Capacity of a Hyporheic Zone in a Lowland River Catchment

[1]Nicholas P RIESS, [2,3] Wairimu A MUIA, [1,4]Jonathan WN SMITH,
[3]A Mark OSBORN, [2]Steven F THORNTON

[1]Catchment Science Centre, Kroto Research Institute, University of Sheffield, Broad Lane, Sheffield, S3 7HQ, UK
[2]Groundwater Protection and Restoration Group, Kroto Research Institute, University of Sheffield, Broad Lane, Sheffield, S3 7HQ, UK
[3] Animal and Plant Sciences, University of Sheffield, Western Bank, Sheffield, S10 2TN, UK
[4] Environment Agency, Olton Court, 10 Warwick Road, Olton, Solihull, B92 7HX, UK,

Under European Union legislation, (Water Framework Directive, Groundwater Directive) limits are being introduced for a range of chemical species, including nitrate (NO_3^-, 50mg/L) in ground and surface water bodies. High nitrate levels in surface water are associated with eutrophication and a subsequent reduction in water quality and biodiversity. Other nitrogenous species can also cause environmental problems such as nitrogen oxides (NO_x) which contribute to acid rain and nitrous oxide (N_2O) which is a potent greenhouse gas. Consequently, there is a need to improve understanding of the different processes controlling the form and flux of nitrogen (N) species into and out of river channels. In particular, the controls on attenuation of NO_3^- via denitrification (reduction of NO_3^- to gaseous dinitrogen, N_2) need to be better understood as this represents a permanent attenuation pathway, as opposed to the dissimilatory reduction of NO_3^- to ammonium (NH_4^+) (DNRA), whereby N is retained within the system.

The hyporheic zone (HZ) is the water saturated sediment surrounding a surface water channel and provides a uniquely reactive environmental compartment distinct from the surface water above and the groundwater below. The redox gradients which exist across the HZ allow a range of reactions such as nitrification (conversion of NH_4^+ to NO_3^-) and denitrification and DNRA to occur in localised areas. The influence that HZ geochemical and microbiological properties have on the formation and loading of N species to surface and ground waters needs to be understood to improve future risk assessments and inform management decisions concerning N pollutants in the environment.

In this study, a total of 24 sediment cores were taken from two contrasting sites (sandy bed/ slow flowing vs. gravel bed/ fast flowing) along a short reach of the River Tern, Shropshire, UK. The Tern is a tributary of the River Severn in western England which flows through a rural setting and receives agricultural inputs of N from runoff and groundwater flow. Each of the cores were sectioned and porewater chemistry sampled by diffusion. Chemical analysis of the porewater revealed geochemical profiles which vary greatly both within single cores and between cores. These profiles show that levels of NO_3^- are correlated with the lithology of the sediments, in particular the organic matter levels. The highly variable stratification within the cores results in levels of NO_3^- which can fluctuate across distances of a few centimetres, and sometimes exceed the levels permissible under the new EU legislation. The 2D data from each individual core have been combined to generate 3D models of the geochemical conditions at both study sites to provide spatial models for the geochemistry of the system and to identify those parameters that have a direct relationship with NO_3^- levels. These models are useful in providing a clear representation of how the properties of the system vary and have provided useful indicators as to how the system is behaving with respect to N transformation.

To complement the geochemical profiles, subsamples of the core sections were taken for molecular microbiological analysis. DNA, representing the total microbial communities present, was extracted directly from the sediments and 16S rRNA genes were amplified. Terminal-Restriction Fragment Length Polymorphism (T-RFLP) analysis coupled to DNA sequencing has been used to investigate variability in the composition of the bacterial communities both within and between cores. In addition, a suite of polymerase chain reaction (PCR) primers have been used to target genes encoding nitrate and nitrite reductases to investigate the functional potential for nitrate reduction and nitrogen cycling within the Tern sediments. In combination with the geochemical data this enables a model of the geochemical, hydrological and biological factors affecting nitrate attenuation to be constructed and provide better understanding of the key factors that will control NO_3^- levels entering water bodies.

Overall the data demonstrates the importance of the HZ for N attenuation and how this relates to the biological potential for denitrification. It is anticipated that the ongoing analysis will highlight the importance of the HZ properties on the form and flux of N entering receiving water bodies. By comparing bacterial denitrifier presence with geochemical conditions, in part by use of 3D geochemical models, the ability of the HZ to attenuate N can be viewed in the context of the interacting hydrogeological, physicochemical and microbiological properties of the system. By investigating the different facets of the HZ a clearer picture of HZ functioning is emerging.

Keywords: Hyporheic zone, nitrate, denitrification, attenuation

'Cabo da Boa Esperanca' – changing the course and impact of fertilizer contaminated groundwater seepage on an urban stream and wetland ecosystem

[1]Ritchie MORRIS and [1]Martin BURR

[1] Morris Environmental & Groundwater Alliances, PO Box 26870, Hout Bay, 7872. Tel: 021-790-5793.
Email: rd@megateam.co.za

[2] Heartland Leasing (Pty) Ltd, Pvt. Bag X101, Somerset West, 7129. Tel: 021-852-1154.
Email: martinb@heartland.co.za

ABSTRACT

Operation of any large industrial facility for an extended period will inevitably implant an 'environmental footprint', not only physically onto the actual site, but also socially and economically onto the surrounding community. Alteration of this footprint due to closure of the 40 year old operations requires attention to business, environmental, social and regulatory issues. This needed to be done in conjunction with the regulatory agencies who govern how the induced 'footprint' and related wastes from the demolition and rehabilitation exercise should be managed, given the intended future land use.

Closure of the old Kynoch Fertilizer production facility in Milnerton, Cape Town (Fig. 1), required a multi-disciplinary project team of both in-house and external specialists, assisted in their decision making by a number of local government authorities and public interest groups.

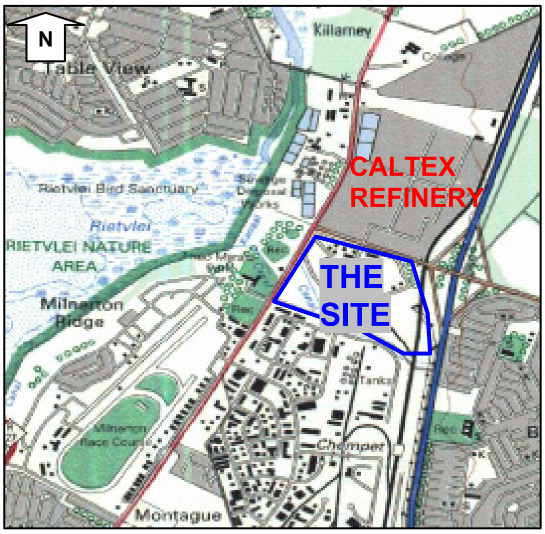

Fig. 1. Locality map

Industrial plant closure is a multi-faceted process requiring several years of preplanning followed by the actual physical demolition component and management of environmental impacts resulting from historical leaks, spillages, burial of wastes and inadequate housekeeping. Managing the closure process itself required specific attention to detail to avoid any further negative environmental impacts.

Fertilizer by its very nature is water soluble and will easily impact groundwater where shallow primary aquifer conditions prevail. The seepage of this groundwater as bank recharge to an urban stream traversing the Milnerton site required both interim (emergency) and, later, final intervention actions with a long term solution in mind. Actions included *in situ* aquifer flushing, cut-off barriers supported by subsurface interception drains for groundwater capture, storage and safe disposal of the captured groundwater and re-routing a stream over a section of about 0.5 km. This paper will provide guidance to operators of other large fertilizer manufacturing industrial sites on both ongoing operational and ultimate closure issues.

Keywords: Industry, Fertilizer, Groundwater, Stream, Seepage

Environmental effects of groundwater level changes in headwater boreal ecosystems

[1]Bjørn KLØVE , [2]Jens KVÆRNER, [3]Seppo GEHÖR and [3]Hannu ANSALA

[1] Water Resources and Environmental Engineering Laboratory, Department of Process and Environmental Engineering, 90014 University of Oulu, Oulu, Finland, email:bjorn.klove@oulu.fi
[2] Bioforsk - Norwegian Institute for Agricultural and Environmental Research, Soil and Environment Division, Frederik A. Dahls vei 20, N-1432 Ås, Norway, e-mail: jens.kvarner@bioforsk.no
[3] Department of Geosciences, 90014 University of Oulu, Oulu, Finland, email:seppo.gehor@oulu.fi; hannuans@mail.student.oulu.fi

ABSTRACT

In boreal catchments, potential hydrological changes to groundwater and surrounding ecosystems are often caused by intensive forestry, road construction, mining, groundwater use and climate change. In Norway and Finland environmental impacts of tunnel constructions and forestry drainage have recently received considerable attention after severe drawdown of groundwater and notable changes in surrounding ecosystems. Environmental effects noted include changes in lake and wetland water levels. The changes are typically most severe in headwaters.

Examples from case studies will be presented from Norway and Finland from different geological conditions. In Norway, road construction has had consequences on water levels in fractured rock. This has influenced lake and wetland water levels. For example in the Grua tunnel to Oslo airport a severe drawdown in groundwater was seen after construction (Kværner and Kløve 2003). Changes in wetland ecosystems have been noted after tunnel constructions and the changes are partly irreversible. Forest drainage has also influenced lakes and wetlands in boreal basins. An example from Finland show changes in water levels in an esker after drainage of surrounding peatlands and increased activity of construction. The drainage has caused changes in water levels in small lakes and affected the recreational value of these lakes.

Hydrogeological studies coupled to modelling are a valuable tool for vulnerability assessment. New results from fingerprinting methods with isotopes and other geochemical methodology will be presented. Also measurements related to hydrology for detecting changes in groundwater depended ecosystems will be presented. The results from detailed field investigations show that a key factor for understanding the environmental consequences of drainage and road construction is the understanding of hydrology of different landforms (Kværner and Kløve 2006). The factors that should be considered are:

- sources of base flow to vulnerable sites (lakes and wetlands)
- location and characteristics of major fracture zones in crystalline bedrock
- groundwater recharge and discharge areas at local and regional scale
- factors influencing increased discharge
- effects of different drainage activities

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Keywords: Hydrogeology, wetlands, peatlands, low flows, drainage

Groundwater abstractions and aquifer-river interaction in the Mancha Oriental System (Júcar River Basin, SE Spain)

[1]David SANZ-MARTÍNEZ; [1]Juan J. GÓMEZ-ALDAY; [1]Santiago CASTAÑO-FERNÁNDEZ

[1]Remote Sensing & GIS Group. Institute for Regional Development (IDR). University of Castilla-La Mancha (UCLM). Campus Universitario, s/n. 02071- Albacete, Spain.
e-mail: Santiago.Castano@uclm.es

ABSTRACT

The Mancha Oriental hydrogeological System (7,260 Km^2), is a multilayered carbonate aquifer that constitutes the unique groundwater source for the sustainability of 80,000 ha of irrigation crops and a total population of about 275,000 inhabitants.

The system is placed in the western edge of the Mancha Plain and belongs to the Jucar River European Union Pilot Basin. During the last thirty years, the development of extensive irrigation crops have resulted in a dramatic groundwater level lowering (c.a. 30 m). This affects not only the river-aquifer system but probably the evolution and the status of the river ecosystems as well.

To evaluate the response of the groundwater flow and the recharge mechanisms to the groundwater abstraction, the spatial and temporal (1982-2002) distribution of the irrigated surface and the groundwater consumption through the use of satellite images was determined. The piezometric surface changes show a decrease in the aquifer saturated thickness that is compensated by the river recharge. This fact is related to the modification in the grade of river-aquifer interconnectivity along the fluvial course.

Keywords: **G**roundwater, irrigation, recharge, aquifer saturated thickness, remote sensing

Groundwater and stream water interactions and salinity in the upper Hunter Valley, Eastern Australia

[1]Peter SOMERVILLE, [1]Ian WHITE, [1]Ben MACDONALD, [2]Sue WELCH, [1]Sara BEAVIS, [3]Richard BUSH.

[1]Centre for Resource and Environmental Studies, Building 43, Australian National University, Canberra ACT 0200, Australia.
[2]Department of Earth and Marine Sciences, Australian National University, Canberra ACT 0200, Australia.
[3]School of Environmental Science and Management, Southern Cross University, PO Box 157, Lismore NSW 2480, Australia.

ABSTRACT

Increasing stream salinity due to the altered hydrology of catchments resulting from changed landuses coupled to frequent ENSO-related droughts is a major threat to sustainable environmental management in Australia. The Hunter River catchment in eastern Australia is one of the region's most productive catchments with extensive coal mining, high quality wine production, horticulture, and grazing. Recent studies have suggested that stream salinities in the Hunter catchment are increasing. Replacement of deep rooted native trees with shallow rooted pasture and crops has been widely assumed to be the cause of rises in saline groundwater piezometric surfaces with increased saline discharge into streams. The salinity in the groundwater is presumed to be of meteoric origin from atmospherically advected sea salt accumulated in recharge. Shallow, fresh alluvial groundwater water systems overlying saline groundwater are extracted for use in farming and mining, and this may exacerbate salinity problems. This study in Widden Brook in the upper Hunter Valley, New South Wales investigates groundwater-stream water interactions and salinity in this catchment. One hypothesis being tested is that a significant source of salinity is mineral weathering of underlying coal measures. This paper presents preliminary results of groundwater and stream chemistry and groundwater-stream water interactions in the catchment.

Widden Brook flows from the Wollemi National Park in the upper Hunter and discharges into the Goulburn River, a right bank tributary of the Hunter River 40 km to the north. Lithology consists of Permian Wollombi and Wittingham Coal Measures, Triassic Narrabeen Sandstone and Tertiary basalt which outcrops in parts of the catchment. Shale deposits of the Denman Formation, which is a marine transgressive phase between the Wollombi and Wittingam coal deposition episodes, underlie Widden Brook at variable depths between 6-8m. The two main tributaries are Blackwater Creek, which drains the Triassic sandstones from the south-east, and Emu Creek, which flows from the south-west only after substantial rainfall. Widden Brook incises sodic floodplain terraces which can rise to 3 m above the stream and the alluvial sediments. The principal landuses in the catchment are the protected native forests in the National Park and grazing in the lower catchment with significant shallow alluvial groundwater extraction for pasture irrigation in summer.

Piezometers have been installed in sections of the catchment to complement existing groundwater bores and spear point wells. The groundwater network consists of five bore/piezometer transects in mid-catchment from which groundwater samples can be collected. Stream water samples were collected from twelve sites along the creek to reflect the input of groundwater from the Triassic sandstones and the floodplain terraces. All water samples were measured in the field for pH, electrical conductivity (EC), dissolved oxygen (DO), redox and alkalinity ($HCO3^-$). Concentration of ferrous iron and sulfate of selected samples were measured in the field spectroscopically. All water samples were filtered in the field using 0.45µm membrane filter and analysed in the laboratory for major cations (ICP-AES), major anions (IC) and trace metals (ICP-MS). Selected groundwater water samples were also analysed for stable isotopes of oxygen (δ18O) and hydrogen (δ2H).and strontium, which can be a tracer for weathering and the origin of salts.

Stream water salinity in Widden Brook is characterised by increasing concentration of sodium, chlorine and bicarbonate ions downstream (Figure 1). Drought conditions have prevailed in eastern Australia for the period 2005-2006. The results presented for November 2005 were for full flow in the Widden. Whilst the absolute concentrations vary, a similar and consistent trend was found for March and July 2006 when there was limited stream flow. Results indicate increasing EC (150-700 µS/cm) and alkalinity (50-150 mg/l) along Widden Brook. In the upper Widden Brook, EC is generally <300µS/cm due to groundwater input from the Triassic Sandstones. EC increases downstream as the Widden incises the sodic floodplain terraces but falls sharply at the confluence with Blackwater Creek (EC 90-120µS/cm) where fresh water discharges into the Widden. Stream EC increases again downstream (EC 500-700µS/cm) from the confluence as Widden Brook incises the floodplain terraces from the 17 km point in the catchment. The decrease in salinity at about 23 km appears to be from groundwater discharge from Triassic sandstone.

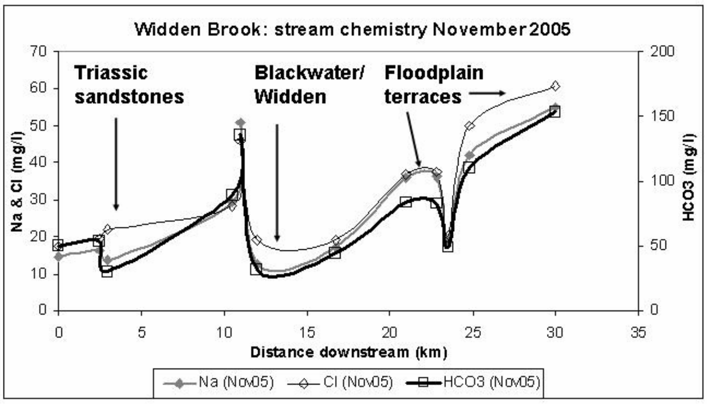

Fig. 1. Trend in salinity in Widden Brook.

Groundwater chemistry results indicate a clear contrast in salinity between the floodplain terraces and alluvial floodplains. In the floodplain terraces, electrical conductivity (EC) is 1200-1500 µS/cm, sodium >120mg/l and chlorine >100mg/l. In the alluvial floodplains, EC is 300-700 µS/cm, sodium 35-60 mg/l and chlorine 38-52mg/l. Sulfate concentrations generally reflect differences in oxidation state between the alluvial floodplains and floodplain terraces. In the alluvial floodplains, low concentrations of sulfate (<5mg/l) were recorded, whilst in the floodplain terrace, groundwater sulfate was an order of magnitude higher (>10mg/l). Spectroscopy analysis suggests low concentrations of ferrous iron (<1mg/l) in the alluvial floodplain groundwater and concentrations up to 17 mg/l ferrous iron in the floodplain terrace groundwater. Groundwater alkalinity is generally an order of magnitude higher (80-850 mg/l) than stream water concentration. The bicarbonate/chloride ratio (mmol/l) of groundwater is generally >> 1 which is significantly higher than the seawater ratio. This value suggests that the input of ions from mineral weathering (as a result of water-sediment exchange reactions) rather than aeolian deposition of salts is a major contributor of ions to groundwater and stream water. Concentrations of trace metals (Sr, Ba, Cr, Cu, Ni) in groundwater (~10-20 ppb) are an order of magnitude higher than in streamwater, reflecting weathering reactions at variable depths in the sub-surface sediments. Strontium isotope ratios $^{87}Sr/^{86}Sr$ of groundwater illustrate differences in the origin of salts in the floodplain terraces and alluvial floodplains. In the floodplain terraces, the $^{87}Sr/^{86}Sr$ ratio is in the range 0.7073-0.7078 reflecting a shale signature; in the alluvial floodplains the $^{87}Sr/^{86}Sr$ ratio is 0.7091-0.7099 reflecting either (1) marine input or (2) input from weathering of rubidium in the sands of the alluvial floodplain sediments.

Results indicate that groundwater in the floodplain terraces is oxidised and brackish with high sulphate and generally low ferrous iron concentrations. In the alluvial floodplains, groundwater is reduced and less brackish with generally low sulphate and high ferrous iron concentrations. Strontium isotope data indicate different sources of salts. The results indicate that mineral weathering is a major contributor to salinity in the upper Hunter, in addition to the often invoked models of (1) rising groundwater tables as a result of tree clearance which mobilise salts in the soil zone, and (2) aeolian deposition of salts. These alternative models pose a challenge for the management of salinity and productivity in catchments in south-east Australia. Proposals to increase agricultural productivity by constructing in-stream stuctures in Widden Brook in order to raise stream base level and to reinstate wetlands or 'chain of pond' systems may mobilise salts in the floodplain terraces and increase the concentration of salts in surface flows.

Future research is being undertaken on ^{18}O and ^{2}H of groundwater and stream water samples, sulphur isotope analysis and using Fe^{2+}-Fe^{3+} cycling as a tracer for groundwater-stream connectivity, PHREEQC analysis of ion exchange reactions and modelling of groundwater-stream water interactions.

Groundwater Dependent Ecosystems associated with Basalt Aquifers of the Alstonville Plateau, New South Wales, Australia

[1]Richard T GREEN , [2]Ross S BRODIE & [3]R Michael WILLIAMS

[1] NSW Department of Natural Resources, Grafton NSW, Australia, e-mail: greenra@mac.com
[2] Bureau of Rural Sciences (BRS), Canberra ACT, Australia
[3] NSW Department of Natural Resources, Sydney NSW, Australia

ABSTRACT

Water reforms in Australia recognise the environment as a legitimate user of a groundwater resource. This presented a challenge for scientists to determine the environmental dependency on groundwater from a Tertiary basalt aquifer in northern New South Wales (NSW) as part of an aquifer management plan. The Alstonville Plateau fractured rock basalt aquifer has a high degree of surface water connectivity, so associated rivers springs and wetlands were classified as groundwater dependent ecosystems (GDE's).

The greatest demand for groundwater on the North Coast of NSW is in the area around Alstonville, immediately inland from Ballina and about 700 km north of Sydney. The Lismore Basalt is a complex fractured rock aquifer, forming a plateau rising some 200m above the coastal plain. The low salinity groundwater is generally used for horticulture, town water supply, domestic and stock. Yields generally range from 1 to 15 L/s, with maximum yields of 38 L/s. The plateau was originally covered by rainforest, most of which was cut for hardwoods, followed by clearing for dairying during the early 1900's. From the 1970's, horticulture intensified and more recently a rapidly growing regional population has increased water demand and the need for more detailed aquifer management.

The Department of Natural Resources of NSW (DNR) administers the NSW Water Management Act (2000) which is the primary mechanism for managing groundwater on the Alstonville Plateau. The aquifer was classified as high risk in terms of overallocation and potential for contamination, so was selected as a priority region for a Water Sharing Plan. A collaborative project between the DNR and the Federal Government agency of the Bureau of Rural Sciences (BRS) was instigated to research the aquifer characteristics to allow for sustainable groundwater management.

The Lismore Basalt consists of a series of basalt flows which generally dip shallowly to the north-west, (Brodie and Green, 2002). Aquifers are comprised of medium to highly fractured or vesicular basalt, old soil profiles (paleosoil) or sediments deposited between flows. The Tertiary basalt sequence is capped by residual krasnozem soils which overlay weathered basalt to form a surficial aquifer. The krasnozems clays are poor sealing clays so readily allow rainfall infiltration. This is indicated by the rapid rise in bore hydrographs of the shallow watertable, immediately following rainfall events exceeding 100mm/week. The shallow aquifer discharges as hill-slope springs, valley seepages and baseflow to the plateau streams. The major streams are perennial and gaugings and hydrochemistry has shown them to be gaining systems reliant on groundwater. Isotope analysis of the groundwater indicate that the shallow groundwater is younger than the deeper groundwater (Williams 1998; Budd *et al*. 1999). The deeper confined aquifers within the vesicular or highly fractured components of basalt flows and interbedded fluvial deposits are generally found at depths exceeding 50m. The deeper aquifers discharge at lower levels in the landscape, typically as springs along the plateau escarpment.

The Alstonville Basalt groundwater source was found to contain three major categories of groundwater dependent ecosystems in the form of:

- **Wetlands** fringing vegetation and aquatic communities permanently or temporarily underwater or waterlogged by groundwater (Groundwater seepage zones eg springs);
- **River Base Flow Systems** riparian and aquatic ecosystems (including the hyporheic zone) within adjacent to stream fed groundwater flow;
- **Terrestrial Vegetation** communities that have seasonal groundwater dependency (eg Mapped rainforest remnants that access the shallow groundwater).

Over 1500 springs and numerous seepage zones have been mapped from aerial photography (Brodie *et al*. 2002). These wetland seepages can be dominated by Melaleuca and used as an over-winter food source for migratory birds, or by sedges or bull rush that provide important habitat. Groundwater discharge is also important in sustaining major plateau streams during extended dry times, which is critical for the aquatic

ecosystems. It is considered that the maintenance of baseflow and stream pools by groundwater discharge, is the main reason for a relatively high platypus population. There is also the potential for the shallow watertables to be accessed by native trees. Relative deep rooted rainforest trees such as Black Bean (Castanospermum australe) can have a seasonal or opportunistic dependency on shallow groundwater. This is of particular concern as there is very little of the Alstonville Plateau "Big Scrub" subtropical rainforest left. Isolated remnants total 140 hectares or about 0.4% of the management area. A map showing significant GDE's has been developed by BRS, based on National Parks and DNR data. This mapping was used as the basis for defining buffer zones around these ecosystems (Brodie *et al*. 2002).

The Water Sharing Plan for this aquifer was implemented in 2004, with a significant proportion of the sustainable yield (average annual allocation) reserved for the GDE's. As part of the increased management required under the Water Sharing Plan the DNR completed installation of additional monitoring bores in 2006. This was undertaken in order to enhance the groundwater network so that improved science would assist in the effective sustainable management of the aquifer.

Keywords: Groundwater/surface-water interaction, ecosystems (GDE's).

Groundwater/surface water exchange and its influence on stable water isotopic signatures along the Darling River, NSW, Australia.

[1]Karina MEREDITH, [1]Suzanne HOLLINS, [1]Cath HUGHES, [1]Dioni CENDON, [1]DavidSTONE.

[1] Australian Nuclear Science and Technology Organisation, Institute for Environmental Research, PMB 1, Menai NSW 2234, AUSTRALIA, e-mail: karina.meredith@ansto.gov.au

ABSTRACT

Stable water isotopes (SWIs) have been analysed in surface waters collected from the Darling River over the past five years (2002 to 2007). Run-of-River sampling results were compared with temporal SWI data from three gauging stations located along the river. Darling River surface water samples are generally enriched in heavy isotopes due to evaporation. Partitioning of distinctly labelled isotopic waters such as enriched surface waters and depleted groundwaters allowed for the identification of groundwater/surface water exchange. Preliminary results showed that large flood events recharge the shallow aquifer with fresh-enriched waters and during low flow conditions, saline-depleted groundwaters rebound towards the river. Consequently, during drought periods saline groundwaters discharge into the river system. The flux of saline groundwaters into the surface water system was found to not only increase the salinity of scarce fresh water supplies but also create the desired environmental conditions for cyanobacteria blooms in the Darling River.

Hydrochemical investigations of surface water groundwater interactions in a sub-catchment in the Namoi Valley, NSW, Australia

Martin S. ANDERSEN and Ian ACWORTH

Water Research Laboratory, University of New South Wales, Australia

ABSTRACT

Quantifying surface water and groundwater interactions over larger scales is often hampered by the lack of sufficiently detailed hydrogeological and stratigraphical data. In general, observed head gradients may indicate the potential for water flow between water bodies. However, hydraulic connectivity cannot necessarily be inferred from such data within a heterogeneous geology. Important clues about subsurface water flow and thus interconnectivity may be gained from studying the distribution of tracers, injected or natural. Natural tracers have the advantage of being far simpler to use than tracer tests, which may be expensive, time consuming and often only applicable on a relatively small scale. However, the use of natural tracers requires that there are natural contrasts in water chemistry between the water bodies of interest. In addition, a prerequisite for using reactive chemical species is that chemical reactions affecting these species can be understood and quantified. In order to test the use of hydrochemical tracers for studying connected surface water groundwater systems, an investigation was carried out in the Maules Creek catchment of the Namoi Valley, NSW, Australia. The flow in Maules Creek appears to be almost exclusively controlled by surface water groundwater interactions, which makes it a well suited field site.

Groundwater samples from monitoring piezometers (10-100 m deep) and surface water samples from Maules Creek and the Namoi River were collected in the beginning of August 2006. Redox-sensitive and volatile species (O_2, Fe^{2+}, H_2S and alkalinity) as well as pH, electrical conductivity (EC) and temperature were measured in the field. In the laboratory Dissolved Organic Carbon (DOC), major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+ , Cl^-, SO_4^{2-}, NO_3^-, Si) and trace elements (Fe-tot, Mn^{2+}, Sr^{2+}, Ba^{2+}, Li^+) were analyzed.

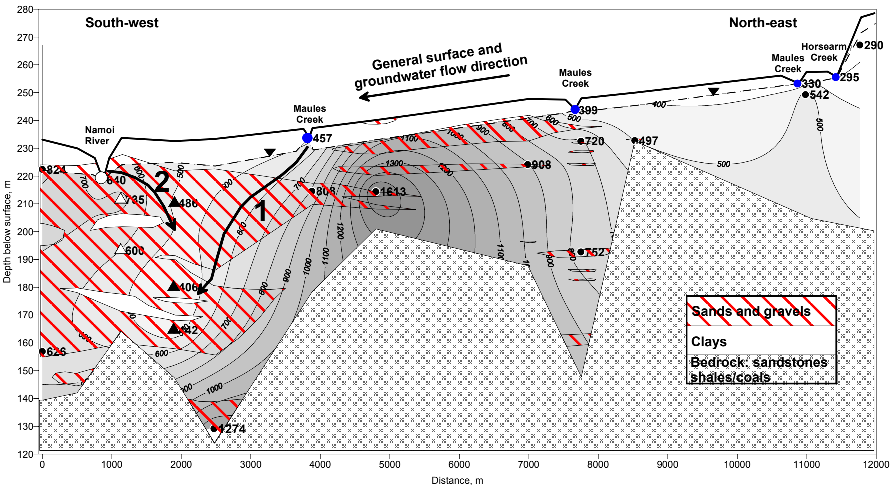

Fig. 1. Geology and distribution of EC (µS/cm) in a depth transect along Maules Creek. The Namoi paleo-channel is the large sand and gravel deposits found below the river Arrows infer possible flow paths. Symbols refer to Fig. 2.

The electrical conductivity (EC) as a general measure for total dissolved solids was found to vary in a complex pattern in the catchment, both reflecting sources of water of varying quality as well as water rock interactions within the aquifer. Generally EC was found to increase down gradient in the aquifer, but in some instances the reverse was found, as demonstrated in Fig. 1. EC-values in Maules creek increased from 295 to 457 µS/cm downstream indicating some interaction with groundwater of higher EC along its reach (see Andersen and Acworth, this issue). In contrast the EC of the groundwater below the creek increases much more rapidly down gradient up to 1613 µS/cm. The reason for this high EC appears to be related to Permian volcanics and Triassic coal-measures which occur immediately to the south of the study site. Interestingly, the down gradient low EC zone has values comparable with surface water samples in the lower portion of Maules Creek situated just above. The groundwater decrease in EC could thus be explained by infiltration of relatively fresh low EC surface water into the subsurface (see flow path 1 in Fig. 1). Another plausible explanation could be infiltration of surface water from the Namoi River in the west (see flow path 2 in Fig. 1) at times with either high groundwater extraction from the Namoi Paleo-channel or high river flow. However, this appears to be less likely based upon our available data as the EC of the Namoi River water was higher (640 µS/cm) in our study. Nevertheless lower levels are possible during flood flows and additional data collection is required to resolve this. Plotting the major ion composition of selected surface water and groundwater samples in a Piper diagram (Fig. 2) can give additional, although not conclusive, clues about the source of the low EC groundwater. In the Piper diagram the surface water samples from Maules Creek plot on a trajectory (circles in Fig. 2) largely indicating an increase in chloride down along the reach. The surface water sample from the Namoi River is situated further along this trend. The three groundwater samples from the low EC zone (solid triangles in Fig. 1) plot almost on the line in between the compositions of the Maules Creek and the Namoi River (arrow in Fig. 2). In contrast, the two groundwater samples from the zone between the Namoi River and the zone of low groundwater EC (open triangles in Fig. 1) are located further a field in terms of chemical composition, (curiously - in opposite directions). It therefore does seem less likely that the Namoi River is the source of the low EC groundwater (via flow path 2 in Fig. 1).

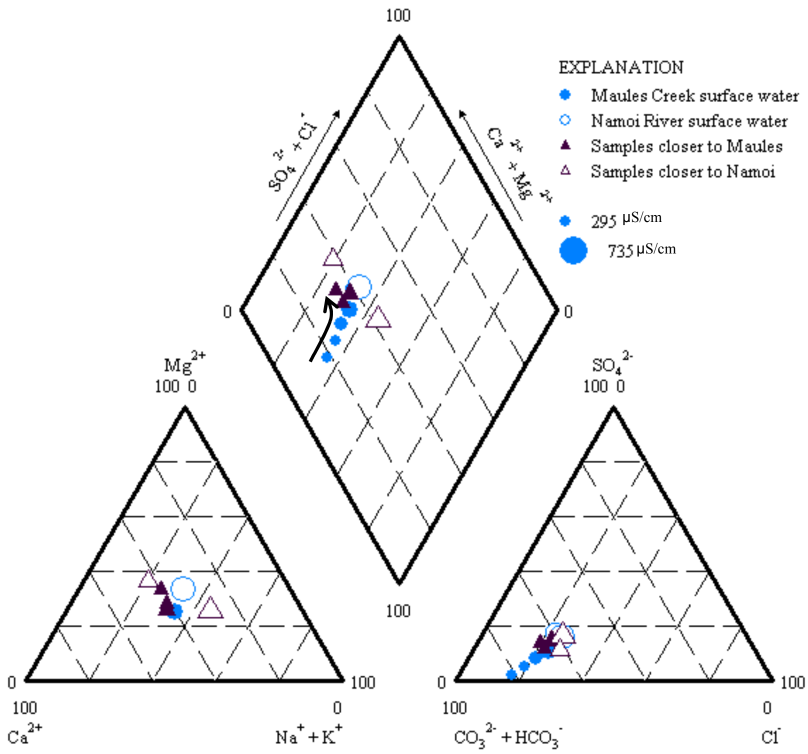

Fig. 2. Piper diagram showing the relative major ion composition of selected surface water and groundwater samples. The arrow indicates change in water composition down along Maules Creek and into the aquifer. For location of samples see symbols in Fig. 2.

Hydrochemical data along the Namoi River indicate that there may also be interactions between the Namoi River and the aquifer in the proximity of the river. In August 2006, two surface water samples were taken along the Namoi River showing a downstream decrease in EC (from 640 to 542 µS/cm). Such a decrease only seems possible with an influx of lower EC water to dilute the surface water EC. A zone of low groundwater EC (~460 µS/cm) was found near the Namoi River between the two sampling sites. It is quite possible that the flow direction reverses depending on river stage, seasonal groundwater abstraction and variations in the regional rain fed recharge of the aquifer.

Other hydrochemical data suggest that at times Namoi River water is in fact recharging the aquifer in some locations. Elevated levels of dissolved organic carbon (DOC) with an average of 1.4 mg C/L were measured in the groundwater in the vicinity of the river (~1-2 km) as compared to levels of 1.0 mg C/L in Maules Creek and 0.9 mg C/L in the upstream portions of the aquifer. In contrast the levels of DOC in the Namoi River (4.9 mg C/L) were found to be about 5 times higher than in the aquifer in general, possibly reflecting a higher level of pollution with sewage effluent and nutrients in the Namoi. In the same region as the elevated groundwater DOC samples, samples depleted in dissolved oxygen and nitrate and with increased levels of dissolved ferrous iron (Fe^{2+}) occurred. Infiltration of river water with high organic carbon content and subsequent oxidation in the river bed or in the aquifer could be a mechanism explaining such chemically reduced water quality. The organic carbon is firstly oxidized by electron acceptors dissolved in the water (O_2 and NO_3^-) and subsequently by iron oxides ($Fe(OH)_3$) present in the sediment. However, at this stage it cannot be ruled out that sedimentary organic matter deposited together with the sands and gravels could be causing the reducing conditions. More detailed studies as well as age dating of the groundwater are necessary to provide more definite answers.

In summary, this study shows how hydrochemical analysis of surface water and groundwater samples may provide important evidence of surface water groundwater interactions by revealing connectivity and delineating flow paths.

Keywords: Surface water groundwater interactions, hydrochemistry, water quality.

Interactions between groundwater and artificial ponds in the northern Botany aquifer, Sydney, Australia

[1]Wendy TIMMS, [2]Ian ACWORTH, [3]Ian TURNER

[1]Senior Engineer-Scientist, Water Research Laboratory, School of Civil and Environmental Engineering, University of New South Wales, King St, Manly Vale, 2093 AUSTRALIA
email: w.timms@wrl.unsw.edu.au
[2]Gary Johnston Professor of Water Management, School of Biological Earth and Environmental Sciences and School of Civil and Environmental Engineering, University of New South Wales, Kensington, NSW, AUSTRALIA email: i.acworth@unsw.edu.au
[3]Deputy Director - Research, Water Research Laboratory, School of Civil and Environmental Engineering, University of New South Wales, King St, Manly Vale, 2093 AUSTRALIA
email: ian.turner@unsw.edu.au

ABSTRACT

Quantifying groundwater/surface-water interaction is particularly important for effective management of irrigation and recreational water usage in city parklands. The Centennial Parklands in Sydney overlie a sandy aquifer up to 24 m deep, with a series of ponds (26 hectares) that provide irrigation supplies and recreational amenities. Detailed hydraulic testing was undertaken by de-watering a pond, and then aquifer pump testing of a new irrigation bore while monitoring surface and groundwater levels. Contrary to previous assumptions, it was found that leakage occurred out of the pond walls to the aquifer under typical conditions. Very low pond levels reversed horizontal, but not vertical hydraulic gradients, with about 80% of pond water from groundwater inflow. Hydraulic testing of a new irrigation bore confirmed close hydraulic interaction since drawdown was limited by a recharge boundary (ie. the pond). The evidence indicated that pond water and groundwater should be considered and managed as a connected resource.

Keywords: Pump test, hydraulic gradient, permeability, unconfined aquifer.

Management of stream compensation for a large conjunctive use scheme, Shropshire, United Kingdom

Martin G Shepley[1], Mike Streetly[2], Kevin Voyce[3] & Fiona Bamford[3]

[1] Environment Agency, Midlands Region, Olton Court, 10 Warwick Road, Solihull, West Midlands, B92 7HX United Kingdom, e-mail: martin.shepley@environment-agency.gov.uk
[2] ESI, New Zealand House, 160-162 Abbey Foregate, Shrewsbury, Shropshire, SY2 6FD, United Kingdom
[3] Environment Agency, Midlands Region, Western Area, Hafren House, Oxen Business Park, Shrewsbury, Shropshire, SY3 8BB, United Kingdom

ABSTRACT

The Shropshire Groundwater Scheme (SGS) is the largest conjunctive use scheme in the United Kingdom. The SGS operates in drought periods, pumping water from the Permo-Triassic Sandstone aquifer in Shropshire, England to regulate flows in the River Severn, alongside releases from conventional surface water reservoirs. This regulation increases the security of supply of major public water supply abstractions downstream. When fully operational the eight phases of the SGS will increase the available water resources of the River Severn by up to 225,000 m^3/d. The use of the SGS is controlled by storage levels in an upstream compensation reservoir (Llyn Clywedog, Wales) and the river flows measured at a downstream gauging station (Bewdley, Worcestershire). The SGS pumping is constrained by a ‘rolling’ licence with restrictions on quantities pumped in any one-year and five-year period.

An important operational consideration is the impacts SGS groundwater abstraction has on small streams that rise on the Shropshire Permo-Triassic Sandstone. Compensation boreholes have been installed to maintain flows during and after the operation of the SGS. In order to manage the operation of the SGS carefully, it is important to determine accurately the rate and duration of compensation pumping required because:

1. Compensation pumping needs to be sufficient to prevent deterioration of the ecological status of the stream;
2. The compensation pumping should not be too great as this will limit the amount of water that can be pumped into the River Severn under the five year rolling licence and that is available for water users further downstream in future droughts.

This paper shows how a groundwater model of the East Shropshire Permo-Triassic Sandstone has been used to estimate the required level of compensation flows for recent climatic conditions. This has involved using results of a large-scale surface water model of the River Severn to determine the periods when the conditions for operating the SGS are met at the upstream Llyn Clywedog reservoir and downstream Bewdley gauging station. The groundwater model has been used to prediction the number of times compensation is required and at what rate to maintain flows above the Q95 for the streams most at risk from abstraction impacts of the SGS. This allows a better estimation of the water available from the SGS for water users of the River Severn, while ensuring better protection of the aquatic environment of the streams most sensitive to the operation of the SGS.

Keywords: Conjunctive use, compensation pumping, predictive modelling

Mapping groundwater-surface water interactions and associated geological faults using temperature profiling

[1]Matthijs BONTE, [2]Josie GERIS,[2]Vincent POST, [3]Victor BENSE, [4] Harold van DIJK

[1] Witteveen+Bos. P.O. Box 10095, 1301 AB Almere, The Netherlands, e-mail: m.bonte@witteveenbos.nl
[2] Vrije Universiteit, Faculty of Earth and Life Science, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands
[3] University of East Anglia, School of Environmental Sciences, Norwich, NR4 7TJ, England
[4] Waterboard Aa en Maas, Pettelaarpark 70, 5216 PP 's-Hertogenbosch, The Netherlands

ABSTRACT

In this study temperature profiling was used as a mapping tool to investigate surface water-groundwater interactions associated with low-permeability faults in the southeastern part of The Netherlands. The faults are associated with the tectonically active Roer Valley Rift system and have a low permeability due to clay smearing and iron precipitation. Their reduced permeability causes the faults to have a significant influence on groundwater flow: Horizontal flow paths are diverted vertically and, as a result, groundwater discharges in drainage channels and streams. Water logging occurs in areas where drainage is absent.

The discharging groundwater is characterised by a distinct water quality: High Fe and low nutrient concentrations (N and P). The low nutrient concentration of discharging groundwater, sustains valuable aquatic and groundwater dependent ecosystems in an area characterised by widespread eutrophication of surface water due to agricultural land uses. Typical ecosystems of the groundwater seepage zones comprise phreatic grassland and swamp vegetation (Calthion palustris, Filipendulion, Caricion elatae), and groundwater dependent tree species (Alnion glutionosae).

Another distinct aspect of the groundwater seepage zones is their visual appearance: where groundwater discharges, the dissolved iron reacts with oxygen and precipitates as iron oxides giving locally land and water a distinctive reddish colour. The localized precipitation of iron has resulted in the development of iron concretions along the fault lines (ranging in size from several cm^3 to m^3). The distinct features of these seepage zones, makes them a scarce geological phenomenon in the Netherlands, locally known as *wijst* grounds. Figure 1 illustrates the appearance of a typical *wijst* ground.

Fig. 1. Typical coloration of drainage channel (left photo) and close up (right photo)

Because of the ecological and environmental value of these areas, the Waterboard Aa and Maas commissioned a regional mapping project of the *wijst* grounds. The project aimed primarily to accurately delineate groundwater seepage zones and the corresponding faults and secondly to assess the opportunities to restore or increase the ecological health of the seepage areas. In the study area, 39 locations were selected on the basis of 1) a GIS analyses of groundwater level and seepage data, soil data and fault locations inferred from seismic and drilling data, and 2) local knowledge brought in by inhabitants of region. These 39 locations were visited in a field campaign between October and December 2006.

Earlier studies have shown that the governing principle behind the use of temperature to map groundwater-surface water interactions is that the groundwater temperature is more constant through a year than the air and surface water temperature. In winter, the temperature of groundwater under a drainage channel or stream receiving groundwater discharge is higher than the surface water temperature. In summer the situation is inversed. Due to the contrasting temperatures of the groundwater and the surface water, zones of focussed groundwater discharge show up as temperature anomalies in the soil below the streambed.

This principle was applied in the field mapping of the groundwater seepage zone by measuring temperature profiling along a section perpendicular to faults. Measurements were taken at intervals varying between 5 to 25 meters, depending on the observed spatial variability in temperature. The temperature profiling was undertaken using a rod with a thermistor probe at its tip. The rod is pushed manually into the bed of a drainage channel or stream to a depth of 0.4 m below the bed. The temperature profiles showed very clear anomalies interpreted to be the result of groundwater discharge to the surface water. The method allowed for an accurate, fast and cost efficient, delineation of groundwater seepage zones and also for identifying areas where there was clearly no groundwater discharge. Figure 2 shows a typical example of a temperature anomaly observed at a groundwater seepage zone.

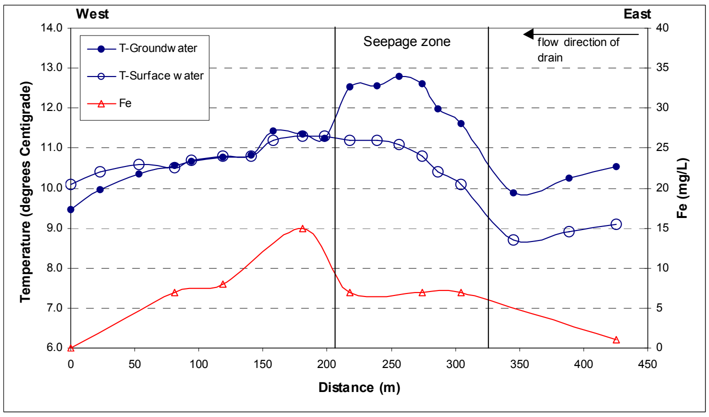

Fig. 2. Typical temperature profile along drainage channel

The field program provided adequate data to draw a regional map of the occurrence of the major groundwater seepage zones. The amplitude of the anomalies was used to qualitatively assess the magnitude of the groundwater seepage rates and to assess which areas are most suitable for ecological restoration. The fall of 2006 was relatively mild, with temperatures on average only two to five degrees below the annual average. It is expected that the accuracy of the measurements will increase when the measurements are taken after prolonged cold or hot periods.

Temperature profiling proved to be a very useful tool to investigate groundwater-surface water interactions and to map groundwater seepage zones during this project. The strength of using heat as a tracer is that it is very easily measured in the field using relatively low cost equipment. The use of heat as a tracer is therefore in our opinion an undervalued technique compared to for example hydrochemical of isotopic techniques.

Keywords: Hydrogeology, groundwater-surface water interactions, heat, temperature

Modelling Stream-Groundwater Interactions in Querença-Silves Aquifer System

[1] José Paulo MONTEIRO, [2] Luís RIBEIRO, [3] Edite REIS, [1] João MARTINS, [4] José MATOS SILVA

[1] Algarve Univ, CVRM, Campus de Gambelas, 8005-139 Faro, Portugal, e-mail: jpmontei@ualg.pt
[2] Inst. Sup. Técnico, CVRM, Av. Rovisco Pais 1049-001 Lisboa, Portugal, e-mail: pcnlrib@mail.ist.utl.pt
[3] CCDR Algarve, Rua José de Matos, 13, 8000-503 Faro, e-mail: ereis@ccdr-alg.pt
[4] Inst. Sup. Técnico, CEHIDRO, Av. Rovisco Pais 1049-001 Lisboa, Portugal e-mail: jmsilva@civil.ist.utl.pt

ABSTRACT

The concentration time for rivers in Algarve (southern Portugal) is always less than 24 hours. This is because of the relatively short length of the watercourses between their headwaters, in the north, and their mouths, at the southern coast. All major watercourses are hydraulically connected with the aquifers of the region and, therefore, these rivers are active during periods spanning from a few months until more than one drought year, in some reaches, as shown in the period 2004-2005.

Those headwaters constitute the upland reach of Algarve streams, where the drainage density *d* is high (more than 3.5 km/ km^2), with some values higher than 6.5 km/ km^2, due to the low infiltration rates in the local thick turbiditic sequence of shale and greywacke (Carboniferous in age). The mid-sections of the streams are located on Early- and Middle Jurassic karstic rocks, where infiltration rates are high and *d* stands between 0 and 2 km/ km^2. To the south, in the coastal strip, the infiltration rates are less important than in the karstic outcrops, because of the low permeability of Upper Jurassic and Cretaceous rocks and because Miocene carbonate and detritic aquifers are covered by low permeability Pliocene to Quaternary sediments. Thus, *d* values in these reaches are near 3.5 km/ km^2. Due to the complexity of the hydrogeologic factors controlling stream-aquifer interactions, a traditional rainfall-runoff model cannot take all the relevant factors into account, to simulate stream flow at the watershed-scale in a realistic way. This is especially true for the stream reaches in the area of the Jurassic karstic rocks. In these areas, the generation of stream flow cannot be described as the final destiny of overland flow, after the fulfilment of the processes of interception and infiltration. On the contrary, the generation of stream flow in the area where outcrops of Jurassic carbonate formations are present comes almost entirely from base flow, resulting from the recharge of karstic aquifers supported by these rocks.

The streams in hydraulic connection with Querença-Silves aquifer system (QS) include all the three types of the above-referred reaches: (1) upstream QS, in the low permeability Paleozoic rocks, where a rainfall-runoff surface water model provides a reasonable approximation for description of surface water flow; (2) the area of QS itself, where overland flow toward streams is negligible, due to the high infiltration rates and, therefore, stream flow is strongly dependent on hydraulic connection with groundwater in several influent and effluent stream reaches, and (3) the downstream reaches, where stream flow towards the sea occurs over areas with variable infiltration rates and, in some cases, established hydraulic connection with other aquifer systems. In this last case, some water is exported from QS aquifer system towards Albufeira-Ribeira de Quarteira and Quarteira Aquifer systems, throughout Ribeira de Quarteira River (Fig. 1).

The hydrological conditions described above are the result of a hydrogeological control on streamflow in the several influent and effluent stream reaches along QS area. Taking these conditions into account, a finite element flow model, implemented at the regional scale for QS, was used to investigate the river-aquifer interaction, specifically to evaluate the reliability of the use of a regional groundwater flow model to quantify the volume of water transferences between QS aquifer system and the stream network.

The approach used to simulate the hydraulic stream-aquifer relations was based on a sequence of operations started by the implementation of a bi-dimensional numerical representation of Querença-Silves aquifer system. The conductive parameter transmissivity (T) was estimated by inverse modelling for 32 zones, using the Gauss-Marquardt-Levenberg method. This was implemented in a non-linear parameter estimation software, coupled with a standard finite-element model based on the Galerkin method of weighted residuals.

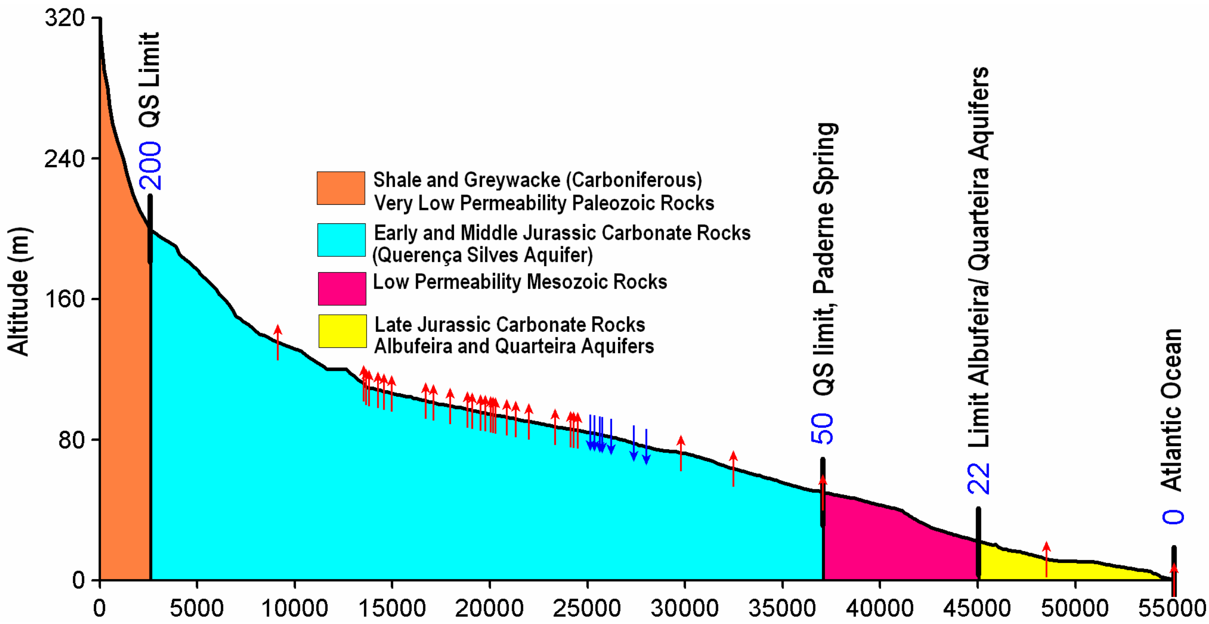

Fig. 1 – Schematic cross-section of *Ribeira de Quarteira River*, showing reaches with different river-aquifer relations, according to the lithologies. Arrows represent influent (blue) and effluent (red) reaches identified in the field.

The second phase of model implementation corresponded to the introduction of data related to human interference in the water balance, represented by wells used for irrigation and water supply. Additionally, this phase of the work was characterized by the implementation of a large set of variables related to the model validation. Finally, the third phase of the implementation of the model included the whole stream network present in the area of QS, and the simulation of the river-aquifer transferences. Fig. 2 shows the stream network in the area of the model and the identification of the simulated distribution of influent and effluent reaches of the rivers.

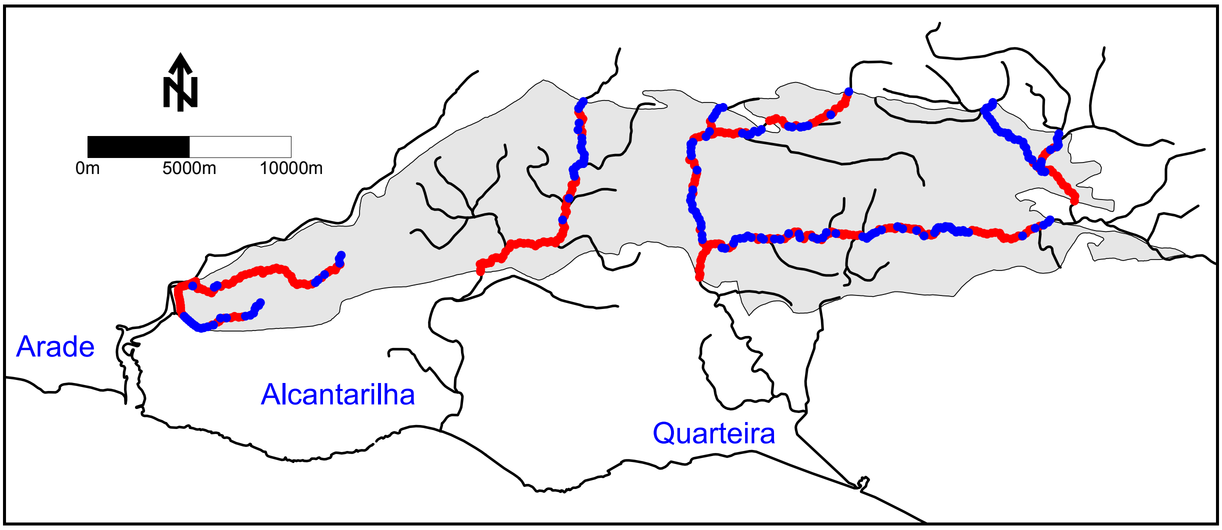

Fig. 2 - Stream network in the area of the model and the identification of the simulated distribution of influent (blue) and effluent (red) reaches of the rivers.

The introduction of the stream network in the model allows the identification and systematisation of the parameters and variables needed to improve the conceptualisation of the river-aquifer relations, specifically in terms of data collection and definition of boundary conditions.

Keywords: Inverse Modelling, Groundwater/surface-water interactions

Near surface hydraulic and geophysical detection of depth-sourced saline water, Duna-Tisza Interfluve

Szilvia SIMON

Department of Applied and Environmental Geology, Eötvös Loránd University of Sciences, Pázmány Péter stny 1/c, Budapest, 1117, Hungary, e-mail: szilvia.simon@gmail.com

ABSTRACT

Introducion and scientific background

The Duna-Tisza Interfluve (DTI) is one of the most densely populated regions of Hungary. The area between the two rivers is rich in groundwater- and thermal water-resources. Consequently the protection of the water supplies is very important in this region. This task needs to be based on a detailed knowledge of the groundwater flow systems of the area. This study attempts to contribute to a better understanding of the flow conditions as well.

According to Tóth and Almási (2001), two driving forces are prevalent in the Duna- Tisza Interfluve. There are gravity-driven flow systems situated near the surface, and these sit on deep, over pressured waters, which originate in the preneogene basinfill. Detailed hydraulic and hydrostratigraphic studies show that the deep-water component gets near to the surface in the Duna-valley, where – on the surface – there is a wetland area with highly saline lakes (Mádlné Szőnyi, Simon, Tóth, Pogácsás, 2005). According to our hypothesis, the high salt content of the lakes and soils derives from the water of the deep flow system, which signify ascending saline water (TDS:2-40000 mg/l). This hypothesis refutes the former theories, maintain that the high salinity is the result of the evaporation of the shallow groundwater in that area. The aim of this work – which is supported by the Hungarian OTKA grant T 047159 – was to verify our hydraulically based hypothesis in the case of Kelemen-szék lake and its close surroundings. According to the hydraulic results, the Kelemen-szék lake is situated in the discharge area of the deep system on the one hand, while on the other, from the east side of the lake the gravity sytem is prevalent. This study attempted to verify this hydraulic situation, the connection between the lake and the water of the deep system, and to examine the interrelationship between the two systems close to the surface (100-120 m). The results are probably not only new scientific issues, but are applicable in the management of the thermal water resources of the area, in the amelioration of sodic soils, in the water management and in the protection of the agriculture environment as well.

Applied methods

The segregation of the two systems is based on their different chemical composition. The TDS content of the over-pressured system could reach the 40000 mg/l value. Although it presumably reaches the surface diluted by the fresh shallow groundwater, it can still have higher TDS content than the "fresh" water of the gravity-driven systems. Based on this idea, higher values below the lake, and continuously decreasing TDS values towards east are expected in the groundwater. This distribution could be checked in points with examination of the chemical compositions of well waters and spatially by geophysical measurements. With the help of the geophysical resistivity measurements the different salt content of the pore water can be detected. In the study area the geological strata are horizontally bedded, so in a given layer the measured differences intermittently originate from the chemical difference in groundwater (the smaller resistivity values signify the higher TDS content). This way the distribution of the different watertypes in space and presence of a boundary between the two systems can be examined. In the course of the investigation electric (VES measurements, penetration: 100-120 m) and electromagnetic (RMT measurements, penetration: 18-25 m) methods too were used.

Chemical and geophysical results

The chemical study was carried out along the cross section of the hydraulic investigation. The TDS and the Cl^- contents were taken into consideration, because they are the most reliable components, and these can indicate the deep system. The values clearly show the presence of two different systems with different chemical compositions to a depth of 60-70 m (Fig 1.). Higher values were obtained below the lake (TDS: 2540-5750 mg/l, Cl^-:579-1016 mg/l), which decrease sharply to the east (TDS: 246-446 mg/l, Cl^-:6-31 mg/l), supporting the hydraulically based hypothesis. The chemical data prove the presence of the interface between the two systems as well.

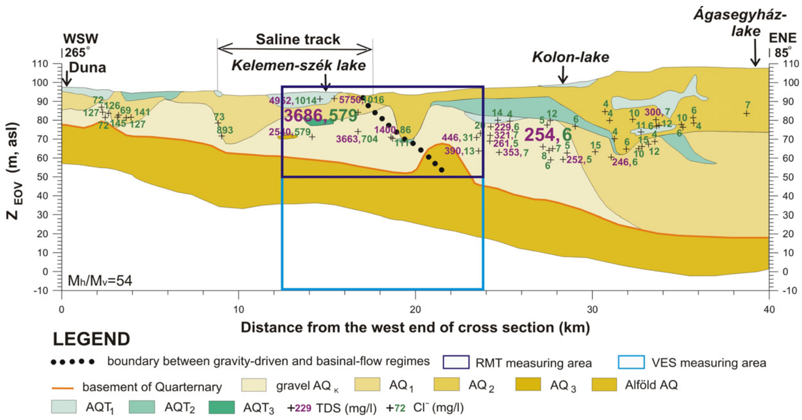

Fig 1. TDS and Cl^- content of the groundwater

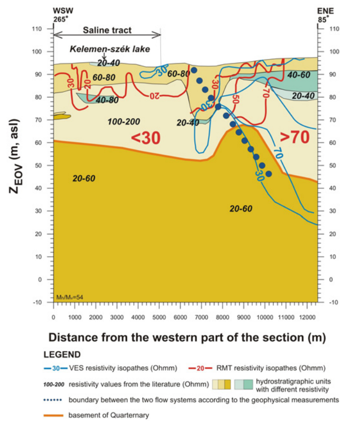

Fig 2. Geophysical results

The geophysical measurements were carried out in close vicinity to the hydraulic cross section. On that (Fig 1.) the bigger quadrangle shows the area and the penetration of the VES, and the smaller area of the RMT measurements. The results are represented on the area of the bigger quadrangle on Fig 1. (Fig 2.). The different, coloured layers signify different hydrostratigraphic units. The black numbers show the resistivity of the rocks, if these were filled by fresh water (2-300 mg/l). These values were obtained from the literature and are refined with the locally measured K (hydraulic conductivity) values. The distribution of the specific resistivity values are shown by isolines. The results of the RMT measurements (red isolines) and the VES measurements (blue isolines) show the same distribution. In every layer, west from the supposed boundary of the two systems much smaller resistivity values were measured, as if it were filled with "fresh" water (2-300 mg/l). The biggest differences were found in the lightest yellow gravel layer. This deviation can be seen in every layer to 100 m depth, which signify highly saline groundwater. To the east the values increase continuously and reach the black values. This means that the salinity of the groundwater is decreasing. The 30 Ωm, transition values could represent the boundary between the "saline" and the "fresh" water. According to this distribution, the measured values suggest that to a depth of 100 m highly saline water fills the pores in the surroundings of the lake, and that the "fresh water" of the gravity system dominates on the eastern part of the area. In addition the resistivity measurements support the presence of the interface between the two systems.

Conclusion

The hydraulic based hypothesis with the help of the interpretation of the chemical data and the geophysical measurements were verified. Namely, that the deep flow system dominates the surrounding of the lake, and that it reaches the surface. The results prove that this highly saline water discharges in the lake, providing salt source for the lake and the sodic soils. Also the investigations support the presence of the interface between the two systems.

The study confirms our former scientific observations on the groundwater flow systems of the Duna-Tisza Interfluve. The methods are applicable and results will be useful in the course of further investigations of the area.

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Keywords: groundwater-lake interaction, highly saline water, geophysical (VES and RMT) measurements

Quantifying groundwater dependence of wetlands in a volcanic plain, south-eastern Australia

[1]Annette B BARTON, [1]Jim W COX, [2]Peter G DAHLHAUS, [1]Andrew L HERCZEG

[1] CSIRO Land and Water, PMB 2 Glen Osmond SA 5064, Australia, email: annette.barton@csiro.au, jim.cox@csiro.au, andrew.herczeg@csiro.au
[2] Department of Geology, University of Ballarat Mt Helen Vic 3350, Australia, email: dahlhaus@netconnect.com.au

ABSTRACT

The Victorian Volcanic Plain region in the Corangamite catchment, south-west Victoria, Australia, is characterised by an abundance of freshwater and saline wetlands (as shown in Fig. 1), that are thought to be at least partially dependent on groundwater. Many of these are recognised as being of international ecological value, in particular the twenty-seven Ramsar listed wetlands which include Lake Corangamite, Australia's largest, inland, permanent, saline lake.

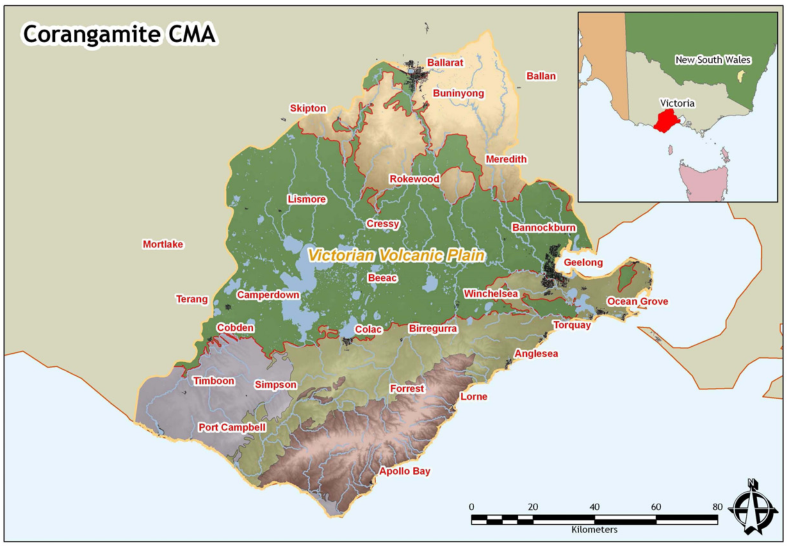


Fig. 1. Location of wetlands in the Victorian Volcanic Plain.

Changes to flow regimes through surface water diversions, increased surface runoff from expanding urban areas and extensive groundwater extraction have impacted on the salinity levels of the lakes and wetlands and may be compromising lake biota. This paper describes an approach using groundwater and surface water chemistry and stable isotopes, to distinguish between the relative importance of surface water and groundwater inputs to the lakes, and whether the lakes are terminal or through-flow systems. Deuterium "excess" (d, where $d = \delta^2H - 8*\delta^{18}O$) reflects the deviation of a given sample from the meteoric water line, with lower values indicating the increasing influence of evaporation, which in turn reflects longer water residence time (terminal lakes) compared with high d lakes that represent through-flow lakes. The HCO_3^-/Cl^- ratio is higher in surface waters than groundwaters, and lakes plot on a continuum between these two end-members. The d versus HCO_3^-/Cl^- plot (as shown in Fig. 2) shows that the lakes plot along two "arms" of three end-members that reflect either surface water or groundwater dominance and through-flow or terminal behaviour.

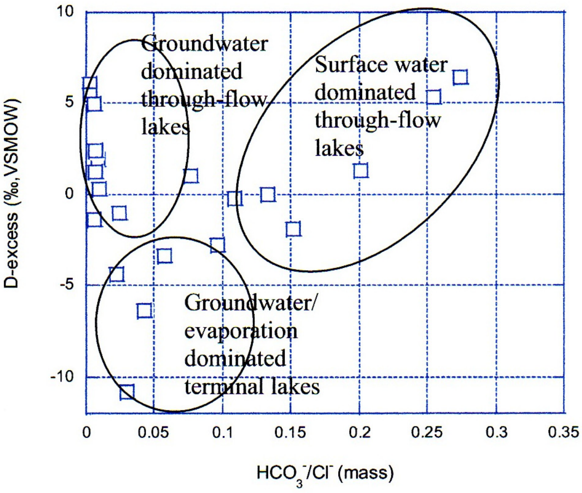


Fig. 2. Deuterium "excess" versus HCO^{-3}/Cl^{-}.

Keywords: Groundwater, ecosystems, lakes, isotopes

Response of surface eco-systems to groundwater table changes in the lower reaches of Tarim river, Xinjiang, China

[1] Yaning CHEN, [2] Zhonghe PANG, [1] Yapen CHEN, [1] Changchun XU

[1]Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, 830011, chenyn@ms.xjb.ac.cn, chenyp@ms.xjb.ac.cn, xcc0110@sina.com
[2]Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, 100029, z.pang@mail.iggcas.ac.cn

ABSTRACT

Tarim river, the longest inland river in China, 1,321km in length, is situated in Xinjiang, an arid area of northwestern China. With dual features of abundant natural resources and fragile eco-environment, Xinjiang is well known to the world for its contrasting regional geographic characteristics and severe water resources and ecological problems. In the last 50 years, under the effect of intensive anthropogenic and social activities centered on water exploitation and utilization, the natural ecological processes have experienced major changes, and the conflicts between economy and ecology over water use have become increasingly stronger than before. In the lower reaches of Tarim river, the surface ecosystems dominated by natural vegetation have been affected severely by the over use of water resources in the upper reaches of the river. The ecology and environment degraded severely, the watercourse has been fragmented, lakes dried out, the groundwater table decreased greatly, the arid vegetation dominated by *Populus euphratica* ruined completely, desertification aggravated, the biodiversity damaged seriously, and the frequency of dust storms increased, a complete ecological disaster.

In order to restore the damaged “green corridor”, i.e. the dying out riverine eco-system composed mainly of Populus euphratica, water has been transferred from upper stream to the 320km dried-up watercourse in the lower reaches between years 2000-2005. In the process, 41 groundwater wells and 18 plant sample plots in 9 sections (Fig. 1) have been monitored to assess the effect of water transfer. In this paper we present an analysis of data, with emphasis on the response of the surface eco-systems to groundwater table variations.

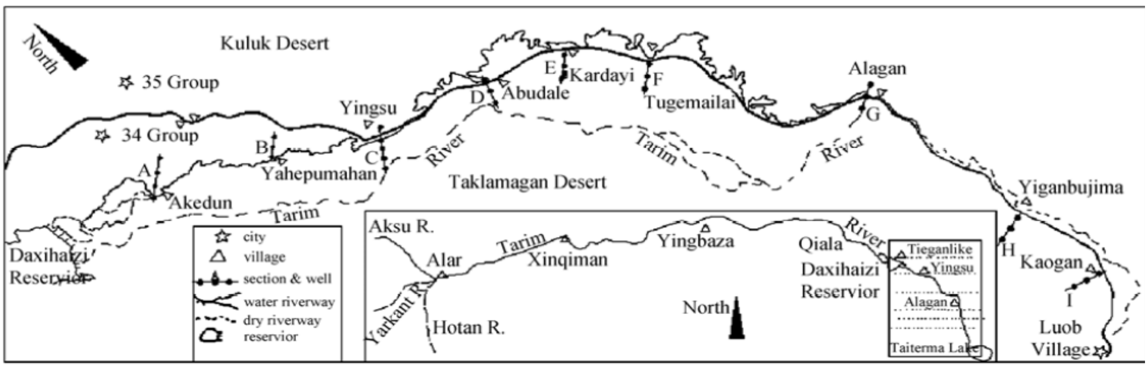


Fig. 1 The distribution of 9 investigation sections in the lower reaches of Tarim river, Xinjiang, China

Several indicators of eco-systems, such as the community composition, plant types show a close relationship with the depth of groundwater table. From the Yingsu section to Kaogan section, with the lowering groundwater table, the degree of damage is aggravated, number of community types is smaller, the number of species reduced, and the coverage, density and richness are all decreased (Fig. 2). In the intermittent water transfer, the groundwater table was lifted from 8~12m to 3~6m below the ground surface. In transverse direction, the groundwater as far as 850m away from the river was affected (Fig.3), and response of *Populus euphratica* and *Tamarix* to groundwater table change reached 700m and 600m away from the river banks, respectively. The coverage of main species and the number of species increased, and the dominance also changed.

Integrated dominance ratio (IDR) increased widely in all sections after water conveyance. In Yingsu section, the difference between IDR of the maximal and the minimal species decreased from 78.2% to 71.27%. The floristics increased from 18 species of 9 families and 15 genus before year 2000 to 20 species of 10 families and 19 genus in year 2005. However, this is true only for herbage but not for arbor, for which there was no new species as a result of water conveyance.

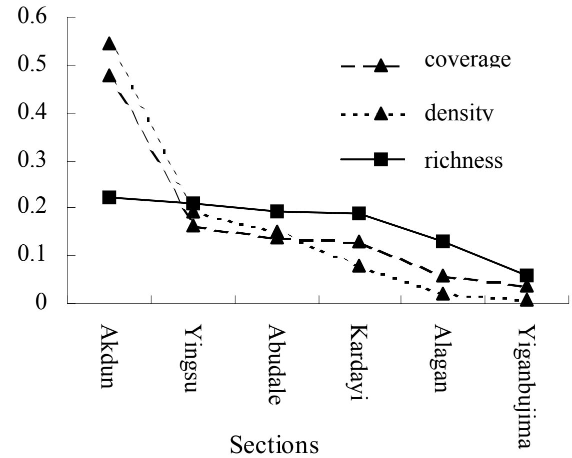


Fig.2 Sketch map of plant regression features at main sections in the lower reaches of Tarim River.

In the study area, the river water replenishes the groundwater when there is water in watercourse. This is the only source of recharge to the groundwater aquifer. The water transfer project has a clear impact on groundwater in the lower reaches of Tarim river by lifting the groundwater table by 2 to 4m, and meeting therefore the survival requirement of the dominating species. In order to maintain a reasonable groundwater table it is necessary to transfer water on a regular basis so that the surface eco-systems in the lower reaches of Tarim river can be restored.

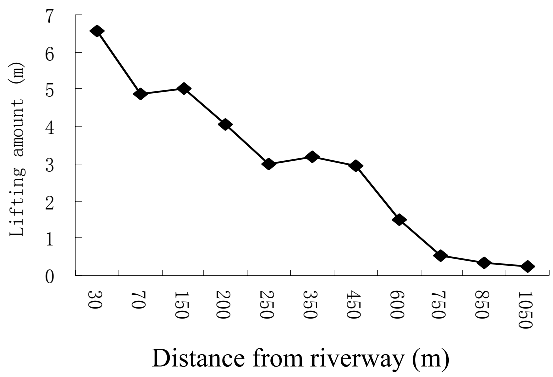


Fig.3 Water delivery and the transverse change of the groundwater table in the lower reaches of Tarim river

Keywords: ecological restoration, water transfer, groundwater table, ecological response, Tarim river

Small-scale water- and nutrient-exchange between lowland River Spree (Germany) and adjacent groundwater

Jörg LEWANDOWSKI, Gunnar NÜTZMANN

Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, D-12587 Berlin, Germany, lewe@igb-berlin.de

ABSTRACT

Water- and nutrient-exchange between surface water and groundwater affect the water quality of both water bodies and, thus, are important for their management. To find out more about the involved exchange processes we use a site surrounded by the current river bed and an old branch of the lowland River Spree, a 6th order river, near Freienbrink, north-eastern Germany. Water levels and temperature in River Spree, in its old branch and in 12 groundwater wells of a 300 m long transect are collected automatically with data loggers in order to model groundwater recharge and water exchange between surface water and groundwater. Bi-weekly pH, conductivity, redox potential, oxygen, phosphate, nitrate, ammonium, sulphate, dissolved iron and chloride are determined in the wells to investigate nutrient exchange. Additionally, in the hyporheic interstitial pore water samplers with a spatial resolution of 1 cm and novel flow microsensors with a resolution of 100 µm are used to study the exchange processes. Performance of the methods and limitations are critically discussed. We observed high spatial variabilities of concentrations of all ions. At some locations there is also a high temporal variability. Exchange pattern between surface water and groundwater is much more complex than previously thought. Infiltration and exfiltration of the surface water into the groundwater alternate depending on precipitation and water level fluctuations of the River Spree. High chloride concentrations in some wells are caused by mineral feeding stuff fed to cattle raised on the study site. Surprisingly high phosphate concentrations in the groundwater (more than 1000 µg PO_4-P/L) are probably due to peat mineralization of reluctant layers in the soil or cattle breeding on the study site. Long-term data also indicate that phosphorus concentrations of the River Spree increase in this section of the river. We assume that this is caused by infiltration of phosphorus rich groundwater.

Keywords: groundwater surface water interactions, water-exchange, nutrient-exchange, small-scale processes, biogeochemistry

Surface and ground water interactions: water quality implications

[1] Bennett C.T. MACDONALD, [1] Ian WHITE, and [1] Peter SOMERVILLE

[1] Centre for Resource and Environmental Studies, Australian National University, Canberra 0200

ABSTRACT

Concerns are growing throughout the world over impacts of land use change on the quantity and quality of surface and groundwaters and on related interactions between ground and surface waters. In Australia, these concerns are heightened due to our generally dry and variable climate, our ancient continent and large-scale land use changes following European settlement. The continued discharge of saline groundwater and wastewaters into surface streams is a major threat to domestic and irrigation water supplies an aquatic ecosystems. The impacts of land use change on groundwater recharge, groundwater movement and the consequent discharge of saline ground and wastewaters into streams are central to concerns.

Several explanations have been advanced for the sources of dryland salinity. In Australia, these include: rainfall-deposited salt advected from the oceans and concentrated in soils and groundwater by evapotranspiration; connate salt stored from past marine transgressions; aeolian salt deposited with dust during dry periods, parent rock weathering and mineralization; and soil weathering products formed *in situ*. These diverse explanations have quite different implications for strategies to mitigate saline discharge. Currently, most assume that rainfall-deposited salt is the prime source and catchment revegetation is the accepted solution. The mechanisms of salinity accumulation and discharge, however appear to be regionally specific. If mineral weathering is a significant source, then catchment revegetation may have little impact on stream salinity.

Most Australian studies on stream salinisation and ground- surface water interactions have concentrated on the Murray-Darling Basin or south-western Australia. Coastal catchments in eastern Australia have been assumed generally free from salinity problems and have been less well studied. The extent of salinity in the Hunter Region in mid-coastal New South Wales (NSW) demonstrates that this assumption is unfounded.

The Hunter is one of Australia's most important mining, industrial and agricultural areas, with major coal extraction for domestic use and export, large coal-fired power stations, and extensive, renowned wine, and livestock production. Most industries use or impact on the region's ground- and surface waters. Significant deposits of salinity in the Hunter Region appear stored in alternating shallow marine and continental Triassic and Permian sediments. Mining of Permian coal measures in the Hunter and use of coal and water in thermal power stations produces significant volumes of saline wastewater. Past, point-source, wastewater discharges into the Hunter caused serious declines in water quality. Stream salinity is of particular concern to the region's communities, dryland farmers and irrigators. Australia's first salinity discharge trading scheme was introduced in 1995 to try to limit salinity in the Hunter from wastewater discharge.

The Hunter River Salinity Trading Scheme operated by the NSW Department of Environment and Conservation, permits discharge of saline water by 21 coalmines and 2 thermal power stations only during high stream flows. In the scheme, the river is divided into the upper, middle and lower sectors, each with a salinity target. Industries issued with pollution permits and are permitted to trade permits in order to optimize operations. The overall target is that the electrical conductivity (EC) of the Hunter River flow at Singleton over a 24 hour period should not exceed 900 uS/cm.

The complexity of the salinity flow relationship for the Hunter River could be due to heterogeneous salt discharge processes such as diffuse groundwater, interflow and point discharges from faults, mines and power stations, as well as to the distribution of rainfall across the catchment, and to possible data errors. Despite the operation of the salinity discharge trading scheme, a recent audit has indicated that salinity levels in the Hunter will increase over the next 100 years.

This paper will address the causes for increasing salinity and the extent of interactions between surface and groundwaters in the Hunter and to develop assessment tools to identify impacts and evaluate remediation strategies.

Keywords: salinity, flow, coal, bicarbonate, quality

Surface and groundwater dynamic interactions in the Upper Great Chao Prhaya Plain of Thailand: semi-coupling of SWAT and MODFLOW

[1]Werapol BEJRANONDA, [1],[2]Sucharit KOONTANAKULVONG, [1]Aksara PUTTHIVIDHYA

[1]Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University, Thailand, sun2child@yahoo.com
[2]Water Resources System Research Unit, Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University, Thailand

ABSTRACT

Surface and groundwater dynamic interactions in the Upper Great Chaophraya Plain of Thailand is being explored. The study area mainly combines 5 river-basins. In the study area, 63% of the basin is dedicated to agricultural activities that rely on conjunctive water use. SWAT and MODFLOW, surface-soil water and groundwater model, are semi-coupled to determine flow behaviour and hydrological components. The surface model is divided into 22 sub-basins on 5 main streams, while the subsurface model is classified into 2 layers with 666 grid-cells. An interface program is specially developed to transmit model information directly to the coupling process. The coupled models are executed by running simulation individually while monthly river-groundwater interaction and groundwater recharge are employed to generate surface and groundwater dynamic interaction. The calibrated results from coupled simulations between 1993 and 2003 show that the coupling method significantly improves the streamflow and groundwater simulation. Moreover, the water balance analysis can describe the local surface and subsurface water interaction. Furthermore, streamflow and groundwater level calculations, especially in the dry season, are improved by 12% and 2.3%, respectively. The dynamic simulation results reveal that interaction is seasonal dependent, i.e., the rivers recharge 0.8 mm. of rainfall into aquifers during wet season while aquifers provide baseflow of 10.4 mm. to the rivers in dry season. The improvement of water balance analysis and modelling accuracy suggest that coupled modelling is a key to clarify the relationship between surface and sub-surface water as well as its interaction.

Keywords: Coupling, Interaction, SWAT, MODFLOW, Water balance

Investigations of surface water groundwater interactions in a groundwater feed perennial creek in the Namoi Valley, NSW, Australia.

Martin S. ANDERSEN and Ian ACWORTH

Water Research Laboratory, University of New South Wales, Australia

Surface water and groundwater has in many cases been managed as a separate resource. In areas where these resources are connected such management practices potentially causes conflict in resource allocation and water stress for groundwater dependent ecosystems. However, the dynamics of surface water and groundwater interactions are poorly understood and in addition notoriously difficult to measure. In order to understand the controlling processes of a connected surface water groundwater system, a survey was carried out along Maules Creek located in the Namoi Valley, NSW, Australia. The surface water in this creek appears to be almost exclusively controlled by surface water groundwater interactions. This makes it an excellent site for developing and testing tools and methodologies for measuring surface water groundwater interactions.

Investigations were carried out along the flowing reach of the creek on two occasions: at the beginning of August 2006 and at the end of October 2006. A conductivity meter was used to measure groundwater and surface water electrical conductivity (EC) and temperature. Resistivity imaging of the subsurface was obtained at selected sites in the creek bed. Positioning information and water level elevations along the creek were obtained by differential GPS.

Maules Creek, is located in an alluvial valley containing interlayered clays, sands and gravels with a total thickness varying from 20 m to more than 100 m. The upper reaches and tributaries drain the basaltic slopes of a 1500 m high tertiary volcano (Mt Kaputar). The upper reaches rarely produce flow reaching into the alluvial valley, except during high rainfall events and associated flooding. It appears that the surface water runoff from the volcano infiltrates the valley alluvium on the foot slopes. However, surface water re-emerges downstream (mid reach) and flows through a series of semi permanent pools. The length of the flowing reach was about 8 km in August and had shrunk to 4 km in October (see Fig. 1). Resistivity imaging at one site shows that water appears to be flowing in a relatively thin (1-3 m) layer of sand and coarse gravel on top of more massive clayey layers. However, the resistivity image suggests that the clay is not laterally continuous with possible hydraulic connections to the underlying aquifer.

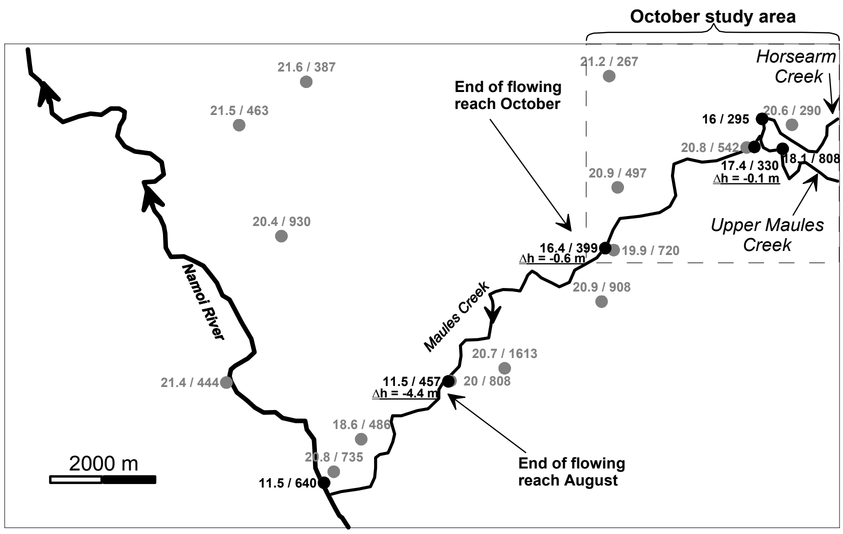


Figure 1. The Maules Creek study site in August: Temperature (°C, first number) and electrical conductivity (µS/cm, second number) measured in Maules Creek (black symbols and numbers) and in shallow groundwater less than 30 m.b.s. (grey symbols and numbers). Vertical head differences (Δh) are also shown for three sites. Insert shows area investigated during end of October.

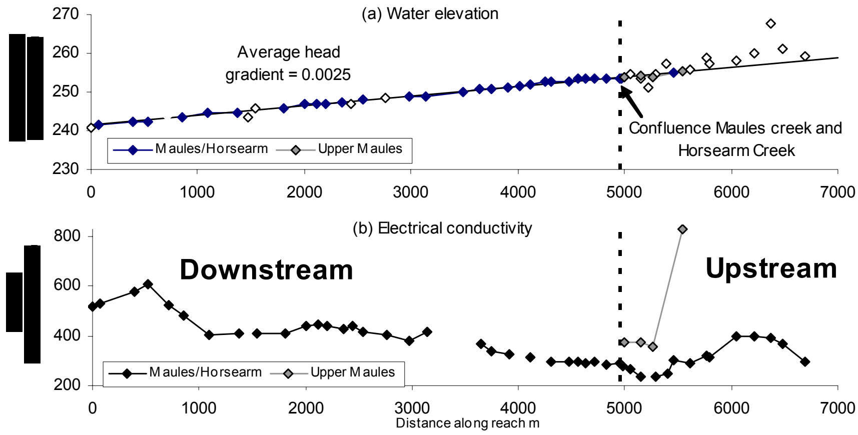
In August (winter) surface water electrical conductivity (EC) and temperatures were measured at 5 sites along the creek (Fig. 1, black numbers) and in piezometers in the aquifer (Fig. 1, grey numbers). Measured water temperatures indicate that groundwater is actively discharging in the upper part of Maules Creek and its tributary Horsearm Creek. In the aquifer, the groundwater temperature was very uniform averaging 21.1 °C reflecting the average annual air temperature of the region (Fig. 1, grey numbers). In contrast, the surface water temperatures measured at around midday were generally lower reflecting the cooler winter air temperatures. In the upper section where the creek starts flowing the surface water temperatures are anomalously high (16-18.1 °C) reflecting the discharge of relatively warm groundwater. Downstream the surface water temperatures drop to around 11.5 °C, due to the cool winter air temperatures and no additional groundwater inflow. In spring (October) temperature measurements did not give any clues about groundwater discharge as the air temperature was warming up. Surface water temperatures were warmer and varied more erratically (20 to 35 °C) due to the much warmer weather.

Electrical conductivity, measured in August 2006, shows low EC groundwater (~300 µS/cm) discharging into the Horsearm Creek and much higher EC groundwater (~800 µS/cm) discharging into the upper Maules Creek reflecting different sources of groundwater from the north and south, respectively (Fig. 1, black numbers). This is supported by the variation in electrical conductivity measured within the aquifer (Fig. 1, grey numbers). From the confluence of the Horsearm and upper Maules creek and downstream to where the flow disappears, the EC increases from 330 to 457 µS/cm. This reflects either an influx of higher conductivity groundwater as suggested by groundwater EC measurements along the reach or evaporative concentration as water flows down along the reach. The first explanation is probably most likely considering the low evapotranspiration during winter.

Vertical head differences between surface water and groundwater levels were obtained at 3 sites during August showing hardly any vertical gradient upstream near the confluence of the Horsearm and upper Maules creek. Downstream, downward head differences were increasing to reach a maximum of −4.4 m at the site where the creek ceases flowing (Fig. 1). This site appears to coincide with sand and gravel deposits in the subsurface of up to 60 m in thickness associated with a paleo-channel of the Namoi River.

In October, the flowing reach had shrunk to a zone close to the confluence with seemingly isolated pools reaching 4 km downstream (insert Fig. 1). The October survey was much more detailed with measurements of surface water level and EC (Fig. 2) every 50-100 m. The surface water levels (Fig. 2a) falls on a very straight line (corresponding to a constant hydraulic gradient of 0.0025) and seem to indicate that there is a hydraulic connection between the pools and that water is flowing in the sand and gravel of the creek bed. The EC measurements during the October campaign (Fig. 2b) revealed an overall increase in the EC from about 300 µS/cm to more than 600 µS/cm from the confluence and 4 km downstream. However, the more detailed sampling revealed that at several sites along the reach, EC was found to decrease (Fig. 2b) implying an influx of fresher groundwater and showing that the system is rather more complex than just an upstream discharge zone and a downstream recharge zone.

Figure 2. (a) Water elevation (m) and (b) electrical conductivity (EC, µS/cm) measured in Maules Creek during October. Solid diamonds in (a) indicate high precision positioning (h = 0.015 m, v = 0.02 m) whereas open diamonds are pore precision due to dense tree cover.



In summary the interactions between Maules Creek and the underlying aquifer was studied using a combination of head data, fluid EC, temperature and resistivity imaging. In the upper part of the flowing reach, groundwater is discharging into the creek as indicated by temperature data. In this region the creek appears to be hydraulically connected to the aquifer as indicated by head data. Further downstream detailed head data suggests that seemingly stagnant pools are hydraulically connected and that water is most likely flowing between them in the shallow coarse alluvium of the creek bed. Down gradient where the creek ceases flowing, high downward head differences were observed and appeared to correlate with the sandy and gravely deposits of the paleo-channel of the Namoi River. Complexity was indicated by the variations in the electrical conductivity downstream pointing towards a varying influx of groundwater with varying EC. However, evaporative concentration down the reach may also have some influence on the EC, which needs to be better understood in order to make quantitative estimates of the surface groundwater interactions.

Keywords: Surface water groundwater interactions, hydrogeology, water quality, temperature.

Surface water surplus storage in aquifers and recovery: applicability to the Algarve (Portugal)

[1]Luis OLIVEIRA, [2]João P. Lobo Ferreira

[1] MSc Candidate at Groundwater Division, Laboratório Nacional de Engenharia Civil, Av. do Brasil, 1700-066 Lisboa, Portugal, e-mail: loliveira@lnec.pt
[2] Dr.-Ing. Habil., Groundwater Division Head, Laboratório Nacional de Engenharia Civil, Av. do Brasil, 1700-066 Lisboa, Portugal, e-mail: lferreira@lnec.pt

ABSTRACT

This paper presents the applicability in Algarve of a method of precaution for a drought in an Integrated Water Resource Management, under the EU Coordination Action ASEMWATERNet under development at the Portuguese Laboratório Nacional de Engenharia Civil (LNEC).

The technique of artificial recharge of groundwater is used in many parts of the world. The objectives are to store water, using the natural ability of the aquifer system, for a future demanding need such as droughts and as protection against pollution and damage or even to provide recovery of the groundwater. Aquifer Storage and Recovery (ASR) plants are structures (cf. Fig.1) created with the purpose of recharging aquifer systems via injection wells with treated water when there is not a high demand for water (or the availability is bigger), and as a way of withdrawing it from the same wells when it is needed, e.g. during droughts. An alternative structure can also be used – Aquifer Storage Transfer and Recovery (ASTR) – where the recharge wells are not the same as the recovery wells.

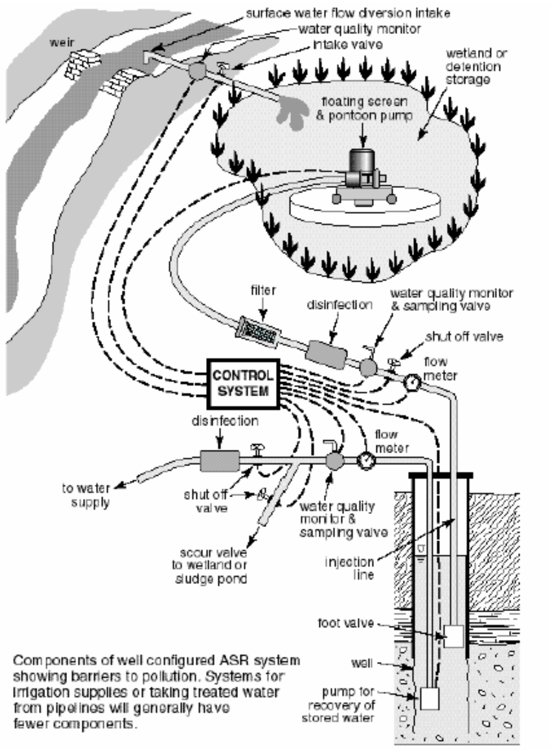


Fig. 1- Components of ASR scheme (From CSIRO Land and Water- Australia)

Artificial recharge of the Querença-Silves aquifer system is introduced in this paper as one alternative to help decrease the vulnerability of the Algarve area to a possible drought.

The Algarve is an area with a special relationship with water. Besides its confused management of water resources over the years, the Algarve is an almost flat area of five thousands square kilometres. It thus has a low potential for the construction of dams and is highly vulnerable to droughts due to it social characteristics. When the surface water is not enough to satisfy the demands there is an over-exploitation of the aquifer systems, with special attention to the important Querença-Silves (cf. Fig.2). The natural recharge of this aquifer is not enough to fulfil the withdrawal of water during crisis periods and saline intrusion is a potential problem.

Fig. 2- Querença-Silves Aquifer System

To achieve a good solution it is necessary to understand the problem well. With that purpose the first part of the paper is dedicated to a brief introduction to the problem of climate changes and a more detailed characterization of regional droughts. The aim of this initial study is to understand what can be considered the definition of drought, how it can be analysed, modelled and monitored, but also to understand the drought as a natural event in relation to anthropogenic activity.

Several analyses are presented in the paper due the fact that studies in Integrated Water Resource Management are multi-disciplinary. The area of study and the aquifer system to which the technique are applied are analysed in diverse aspects. First, a geomorphologic characterization of the Algarve is presented follow by a detailed characterization of the Querença Silves Aquifer System. After the physical characterization, the paper presents the environmental, socio-economic and legal/institutional analyses of factors connected to water resources in Algarve.

The highest point of the paper is the exact analysis of the applicability of the artificial recharge to the Querença-Silves Aquifer System as a solution to the problem. Several factors supporting and opposing the proposed implementation are analyzed. The analyses are made according to the main goals of Integrated Water Resources Management: Environmental Sustainability, Economic Efficiency and Social Equity. This section also has a part dedicated to the analyses of the influence of the future dam of Odelouca and climate changes on the solution.

The EU Coordination Action ASEMWATERNet is considered in the conclusions of the paper by explaining the connection of the issues raised in the paper with the countries of Republic of South Korea and Denmark.

Keywords*:* Drought; Artificial Recharge; ASR; ASEMWATERNet.

Surface water, groundwater and ecological interactions along the River Murray. A pilot study of management initiatives at the Bookpurnong Floodplain, South Australia

[1]Volmer BERENS, [1] Melissa G WHITE, [1] Nicholas J SOUTER, [2] Ian D JOLLY, [2] Kate L HOLLAND, [2] Kerryn L MCEWAN, [3] Michael A HATCH, [4] Andrew D FITZPATRICK [4] Tim J MUNDAY

[1] Department of Water Land & Biodiversity Conservation, South Australia, berens.volmer@saugov.sa.gov.au
[2] CSIRO Land & Water, South Australia
[3] University of Adelaide, South Australia
[4] CSIRO Exploration & Mining, Western Australia

ABSTRACT

Salinisation is a major economic and environmental concern in Australia. It impacts on Australia's most significant river, the River Murray and the sectors of agriculture, industry and recreation that it supports. It is estimated that 40,000ha (40%) of floodplain vegetation on the lower River Murray in South Australia is now dead, dying or stressed. This severe dieback in native floodplain vegetation is largely due to floodplain salinisation, a result of saline regional groundwater discharge, decreased natural flood frequencies, permanently held weir (river) levels and a severe current drought. In an effort to manage current and future decline in tree health, the Bookpurnong Living Murray project was developed to investigate management initiatives such as engineered salt interception schemes and other technologies that artificially manipulate flow regimes. The study integrates the scientific disciplines of hydrogeology, hydrology, ecology and geophysics to examine the interplay between surface water, groundwater and vegetation. The outcomes will aid in the development of governmental policy to guide management decisions for the floodplains and their ecological status.

Keywords: Hydrogeology, ecology, geophysics, manipulated flow

Surface/groundwater interactions: identifying spatial controls on water quality and quantity in a lowland UK Chalk catchment.

[1]Nicholas J K HOWDEN, [2]Howard S WHEATER, [3]Denis W PEACH, [2]Adrian P BUTLER

[1]School of Applied Sciences, Building 53, Cranfield University, Cranfield, Bedfordshire, MK45 0AL, UK, e-mail: n.j.k.howden@cranfield.ac.uk
[2]EWRE, Department of Civil and Environmental Engineering, Imperial College London, South Kensington Campus, London SW7 2AZ, e-mail: h.wheater@imperial.ac.uk
[3]British Geological Survey Hydrogeology Group, Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB, e-mail: dwpe@bgs.ac.uk

ABSTRACT

This paper focuses on the Frome and Piddle catchments in Dorset in southern England, where surface/groundwater interactions play a key role in determining the spatial distributions of water quality and availability in the catchment river systems and, hence, a fundamental control on the supply of water to dependent ecosystems. This is of interest in the Frome and the Piddle as the Frome is the last Chalk stream in the UK to have a naturally breeding population of Atlantic salmon, and the floodplain wetland between the Frome and Piddle rivers around their confluence has the highest density of recorded species in the UK.

Until recently the lithostratigraphic sub-division of the Chalk was crude and traditionally only sub-divided into Upper, Middle and Lower, with one or two other significant marl beds and hard fractured beds (e.g. Melbourn Rock, Plenus Marls etc). The development of a new lithostratigraphic framework for the Chalk (Bristow et al., 1998) allows a much more detailed assessment of the influence of lithological controls on groundwater flow. Also, through a detailed knowledge of the Chalk as mapped (and from supporting data from boreholes, cores etc.), the structural geology may be elucidated with more confidence and in greater detail.

This paper uses a new interpretation of the Frome and Piddle catchment geology (Newell et al., 2002) employing the new Chalk stratigraphy (Bristow et al., 1998) to investigate the hydrogeological controls on surface/groundwater interactions in the river valley corridor, and how these affect the resulting spatial distribution of surface water flows in the Frome and Piddle rivers. Further, an extensive database of chemical determinands is analysed and used to demonstrate some of the impacts of these interactions upon the resulting spatial distribution of surface water chemistry.

Data are presented to illustrate an integrated understanding of the physical controls on the heterogeneous spatial distribution of surface water quantity and quality (e.g. see Fig 1). It is found that, whilst the new Chalk lithology is useful in identifying the dominant controls upon surface/groundwater interactions, there is no apparent hydrochemical link between groundwater flows from individual Chalk lithologies, and thus the observed surface water quality, compared with the contrast between groundwater flows from other lithologies (Greensand, Clay, Sandstone etc.).

Conclusions from this work have a relevance both to this river and other similar lowland Chalk streams. The analyses presented will show the importance of local hydrogeological structure, which must be adequately understood if conceptual models are to be constructed to support process understanding and management decisions.

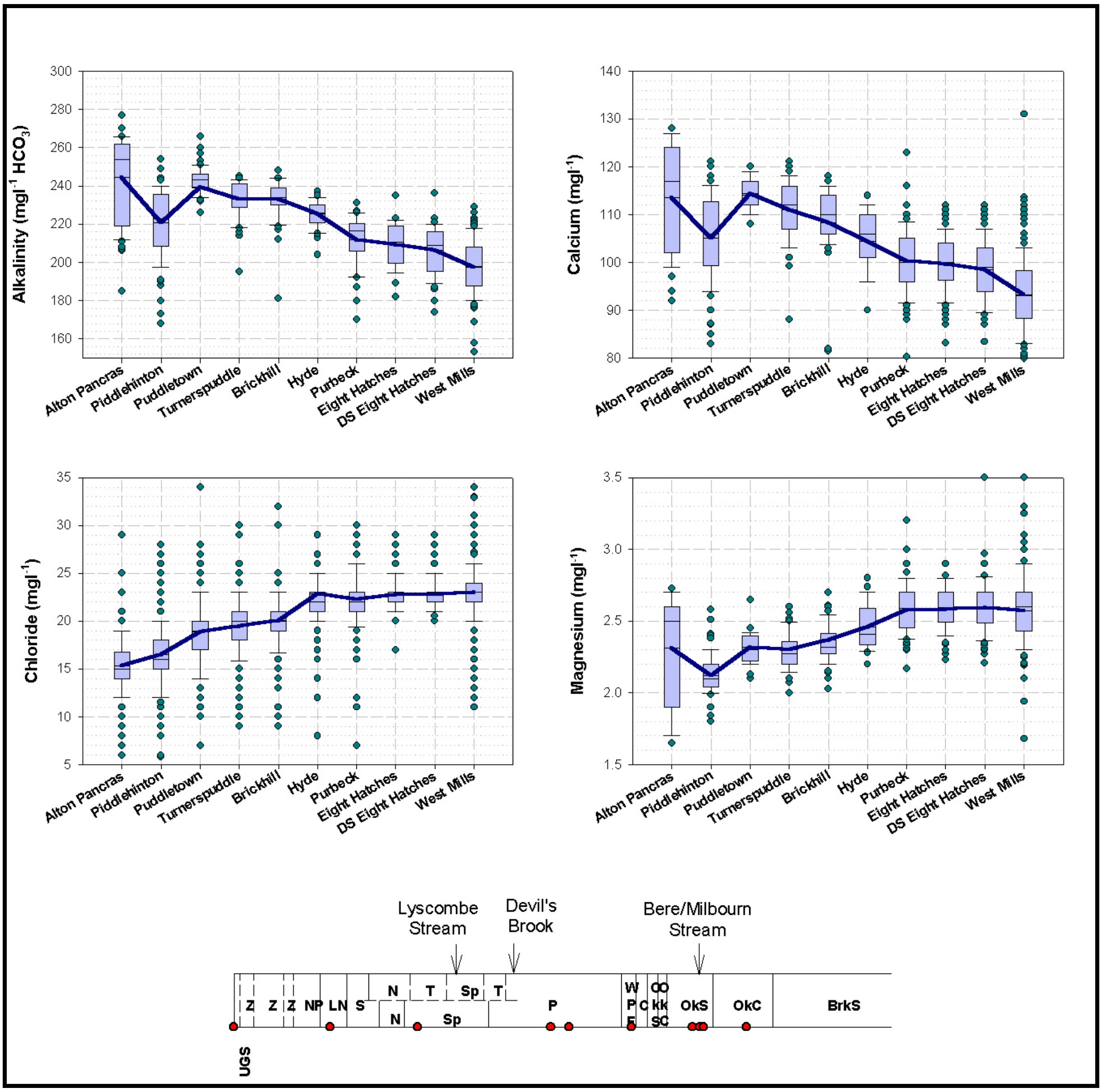


Fig 1 Box and Whisker Plots of selected major ion data at sites along the river Piddle. Concentrations are in mg l^{-1} alkalinity (HCO_3^-), calcium (Ca^{2+}), chloride (Cl^-) and magnesium (Mg^{2+}). Blue boxes indicate the interquartile range and whiskers show the 5th and 95th percentiles. Values above the 95th or below the 5th percentiles are individually plotted. A horizontal line across the blue box indicates the median concentration, and a further horizontal line, joined from site-to-site by the blue line, indicates the mean concentration. *Note: The distance between sampling points is not to scale – sampling sites are represented on the geology plot by a circle.*

Keywords: surface/groundwater interactions, water quality, geological controls, base-flow, Chalk springs

The application of airborne geophysics to mapping river and groundwater interactions

[1]Andrew FITZPATRICK, [1] Tim MUNDAY, [1] Kevin CAHILL, [2] Volmer BERENS, [3] Michael HATCH

[1]CSIRO Exploration and Mining, Australia, Andrew.Fitzpatrick@csiro.au
[2] Department of Water, Land and Biodiversity, Australia
[3] Adelaide University, Australia

ABSTRACT

Salinity in the River Murray and in adjacent floodplains has important environmental economic and social consequences. Methods to monitor the temporal state of river, particularly river-groundwater interactions have been in place for many years now, but few have the capacity to define variability at a resolution appropriate for developing salinity management strategies, such as localised salt interception schemes. One approach, currently employed with some success is the in-stream NanoTEM, a time domain ground electromagnetic system, deployed in a boat with the transmitter and receiver towed behind on a floating boom. Here we report on the potential for employing slightly different electromagnetic technology, namely helicopter electromagnetic systems, for generating similar information to the in-stream NanoTEM, though at a significantly faster rate.

Two different airborne electromagnetic systems have been trialled along different stretches of the River Murray. The SkyTEM time domain electromagnetic system was flown at Bookpurnong, South Australia and the RESOLVE frequency domain electromagnetic system was flown at Kings Billabong in Victoria. Data from both airborne systems have been compared with the In-stream NanoTEM data and available river-bed core data. Conductivity data derived from both airborne systems show very similar trends in conductivity variation mapped in the corresponding NanoTEM data. The RESOLVE system is particularly suited at mapping high resolution near surface data to depths up to 40-50 metres. The SkyTEM system provides depth penetration of over 100 metres, with a slight loss in near surface resolution.

The helicopter data effectively map gaining and losing stream conditions and provide significant insight into the interplay between an irrigation induced groundwater mound, the regional groundwater system and river salinity (Figure 1). The use of a swath acquisition survey design provides additional information in order to evaluate river-groundwater interactions adjacent to the river, compared to in-river measurements alone. We also consider the economic and logistical issues involving the acquisition of helicopter data along the river. The results from this study may help determine the value and relevance of airborne systems in providing a snap-shot of the river's condition in certain time-critical situations – such as in a flood event.

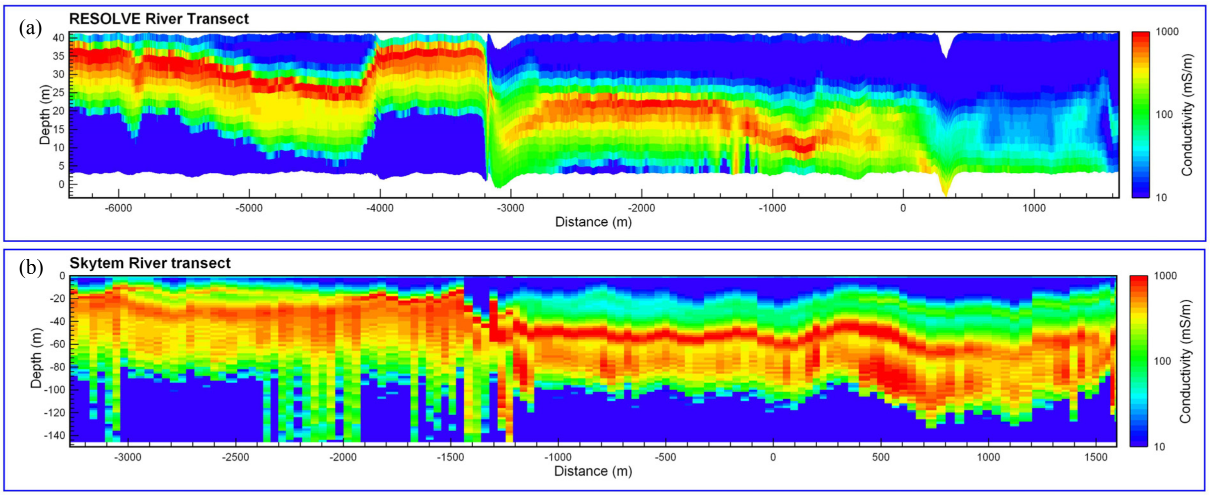


Fig. 1. (a) RESOLVE conductivity depth section along stretch of river- South Australia, (b) SkyTEM conductivity depth section along stretch of river- Victoria; in both cases, the conductive feature (red) defines the highly saline groundwater. High conductivity observed in the near surface infers gaining conditions where the groundwater is discharging into the river, whereas resistive zones infer river losing conditions.

Keywords: Hydrogeology, geophysics, electromagnetics,

The Duna-Tisza Interfluve Hydrogeological Type Section, Hungary

[1]Judit SZŐNYI-MÁDL, [1]József TÓTH

[1]Department of Applied and Environmental Geology, Eötvös Loránd University, 1/c Pázmány Péter sétány 1117 Budapest, Hungary, e-mail: szjudit@ludens.elte.hu

ABSTRACT

A hydrogeological type section is proposed for the Duna-Tisza Interfluve, Hungary. The area has an agricultural economy but is plagued by severe problems of soil and wetland salinization. The genesis and amelioration of salt-affected soils in grain-growing farmlands, or the protection and sustenance of saline lakes and wetlands as favored habitats of migratory birds, have inspired intensive research for more than two centuries. However to date no satisfactory answers have been found to these questions. The objective of the study was to answer the basic questions: what is the source of the salts and what are the controls and mechanism of their distribution pattern.

Fig.1. Index map

To this end, flow-patterns and chemistry of groundwater were evaluated in a 100 km x 65 km area, with emphasis on its Kolon- and Kelemenszék Lakes region (Fig. 1). This area of the Duna-Tisza Interfluve appeared suitable for a local study because the lakes are located 13 km apart and have chemically contrasting water (Kelemenszék: TDS more than 3000 mg/L; Kolon-Lake TDS: 220-450 mg/L), soil types (salt affected and non-saline) and related ecological conditions.

The major data types used in the study comprised water levels and pore pressures from water- and hydrocarbon-wells; chemical analyses of water samples from water wells, lakes, and the ground; lithologic samples and descriptions, petrophysical and geological bore-hole logs; seismic sections; and an ecological landscape map. The information was supplemented by field work.

The analysis of subsurface hydraulics across the full width of the Duna-Tisza Interfluve (≈100 km) has revealed unanticipated regional regularities and seemingly cause-and-effect correlations between the various components of the area's hydrogeology, such as: groundwater flow-distribution, hydrostratigraphy, areal patterns of soil- and wetland-salinization, and lake-water and groundwater chemistry.

Two groundwater flow-domains were identified in the area: a gravity-driven meteoric fresh water one with a TDS of 350-450 mg/L, and an over-pressured deeper domain of saline water (Fig. 2). The total dissolved solid contents of the saline water decreases from 20000 to 30000 mg/L in the basement to maximum 3500-4000 mg/L in near the surface. The gravity-flow pattern conforms to the topography while hydraulic heads are uniformly more than ten meters above land surface from depths below 350-400 m. These systems are hydraulically perched by the ascending over-pressured water. The superjacent fresh-water “lens” forces the ascending waters towards discharge areas in the valleys of the Duna and the Tisza. The pathways of ascending waters are influenced by the eastwardly dip of the basement, and the variable thickness and tectonic structure of the aquitards. Beside tectonically controlled ascent of the deep waters, cross-formational flow through aquitards can not be excluded. Flower structures disect the aquitards in the basin providing direct hydraulic connections between basement and the upper aquifers. The energy of gravitational systems is not enough to push the fresh waters as far as the Duna in the western part of the basin, so their water is discharged in the Duna-valley. In this area deep saline waters and the meteoric waters are conveyed together by a gravel aquifer into the Duna-valley. This highly permeable bed subcrops at the eastern edge of the Duna-valley, causing Kelemenszék to be saline. Kolon Lake receives meteoric groundwater in the trough-flow position, whence its fresh chemical character. The cross-formationally and tectonically controlled ascent of the deep waters, combined with the gravitational systems' geometry and the flow-channeling effect of the near-surface rocks, explain the contrasting chemistry between Kelemenszék and Kolon Lakes, as well as the origin and pattern of soil salinization. The energy of the gravitational systems increases also with the increase of the topographical elevation in the eastern part of the Duna-Tisza Interfluve from South to North. Consequently, the discharge of gravity flow is shifted gradually from west to east going northward. Towards the North, ascending salt water is discharged only beyond the Tisza. However, isolated saline areas can occur in the Interfluve's fresh-water areas also, possibly owing to some conductive structures reaching within 200 m from the land surface. The results of the present study are summarized into a coherent schematic, which we consider to be representative of the entire Duna-Tisza Interfluve. We call this conceptualized flow distribution "The Duna-Tisza Interfluve Hydrogeological Type Section" (Fig. 2).

Acknowledgement: The research was supported by the Hungarian OTKA grant No. T 047159 to J. Szőnyi-Mádl, and the Canadian Natural Sciences and Engineering Research Council's „Discovery grant" No. A-8504 to J. Tóth.

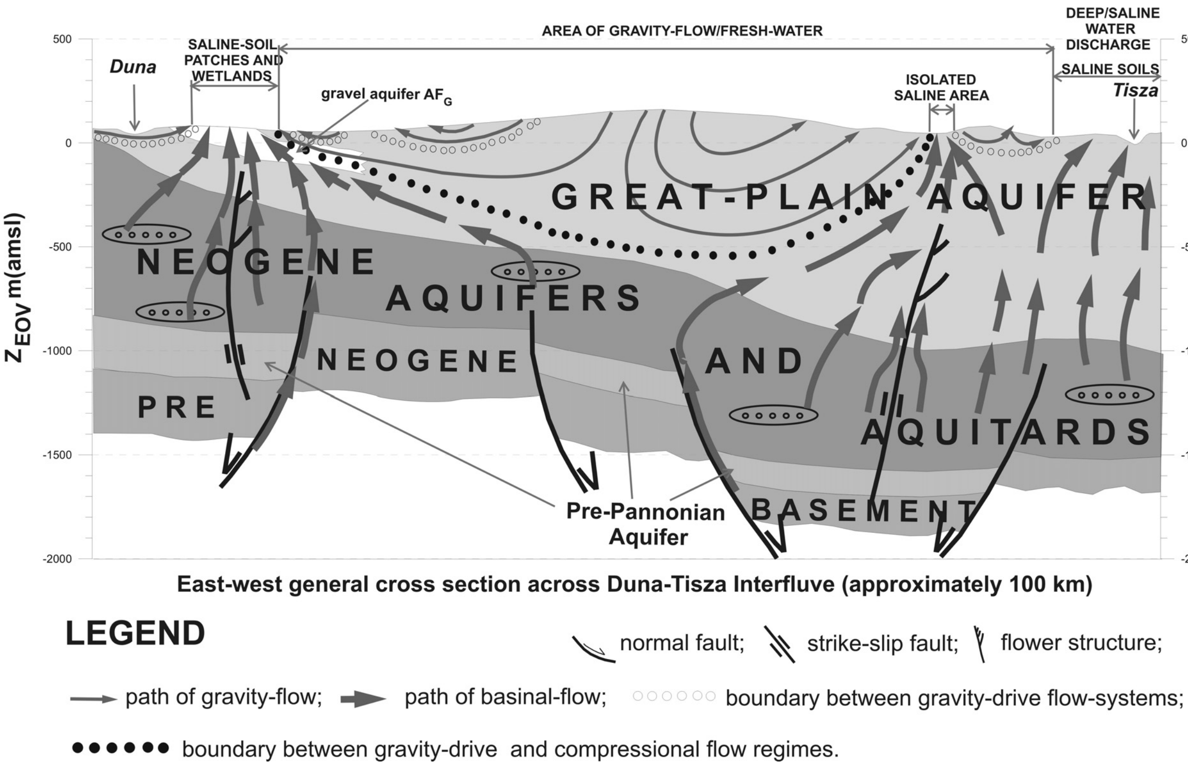


Fig. 2. The Duna-Tisza Interfluve Hydrogeological Type Section, Hungary

Keywords: gravity-flow, over-pressures, wetlands, soil salinization, Type Section.

The role of groundwater in catchment management

[1]David N LERNER, [2]Bob HARRIS, [1]Ben SURRIDGE

[1]Catchment Science Centre, Kroto Research Institute, University of Sheffield, Broad Lane, Sheffield S3 7HQ, UK, email: d.n.lerner@shef.ac.uk, b.surridge@sheffield.ac.uk
[2] Environment Agency, Olton Court, 10 Warwick Road, Solihull, West Midlands B92 7HX, email bob.harris@environment-agency.gov.uk

ABSTRACT

The management of river basins, and the catchments within them, needs to evolve the current compartmentalised and piecemeal approaches to be more holistic. The future catchment manager has to develop solutions to address the many and various land use pressures, often acting in synergistic ways to impact on the aquatic ecosystems which are the measure of the health of our surface water systems. These pressures need to be managed, but their respective importance and how they are promulgated through the catchment, must first be determined. An understanding of the pathways therefore becomes very important, particularly for diffuse pressures such as nutrients and pesticides derived from agriculture land management and urban pollution from the high densities of contaminated land and leaking sewers. In moving towards more sustainable resource management, risk-based approaches (used in addressing existing point source pollution) need to evolve to more proactive approaches based on an assessment of vulnerability.

As point sources of pollution such as effluents are dealt with in catchments, diffuse pollutants become ever more significant. In groundwater dominated river catchments deep and shallow groundwaters can be the major pathway for diffuse pollutants from source to receptor. The large volumes of groundwater which provide the beneficial balancing of flows also provide a large reservoir for pollutants. Changes at source, such as land use practices, take a long time to work through the system to improve conditions at the receptor; a typical turnover or flushing time for aquifers is 300 years, compared to 11 days for rivers. Groundwater is a significant store of and pathway for pollutants even in catchments where there is not a major aquifer. Thus groundwater is a major control on diffuse pollution in most catchments, and catchment management must take account of these loads and the long lag times for changes to take effect.

It is well known that aquifers hold 99% of the fresh water reserves of the planet. They provide typically 50% of the runoff from the continents and, in some river systems fed by major aquifers, groundwater provides 80-90% of the total runoff. Because of the large volumes of stored groundwater, aquifers buffer the variations in flow, providing sustained flow thorough dry seasons and across inter-annual droughts. Even when aquifers are not highly productive in water resource terms, they can make major contributions to flow. However, aquifers are not immune from the law of the water balance and eventually over-abstraction of groundwater will lower water tables with consequent 1:1 reduction in surface flows, and subsequent impacts on groundwater-dependent ecosystems. Nevertheless, the ease with which new wells can be drilled, the time it can take before the effects on surface water become apparent, and the administrative burden of systems of licensing wells, all mean that the role of groundwater in the water balance of catchments is not always fully appreciated.

In addition to supporting river and lake ecosystems, groundwater also plays a key role in sustaining many semi-terrestrial wetland ecosystems. Understanding the links between the ecological functioning of wetlands and changes in groundwater quantitative and chemical status remains a significant challenge to successful catchment management. Major questions continue to face wetland managers, such as whether reduced groundwater discharge to a wetland as a result of abstraction can be compensated for by increased surface water supply, without significant damage to the ecosystem. Better understanding of the interactions between groundwater and wetlands may also enable the services provided by wetlands to be incorporated into catchment management strategies. These services include the potential to increase groundwater recharge and to protect underlying aquifers from surface-derived pollution.

In summary, groundwater provides the majority of the water in most rivers, carries much of the diffuse pollutant load, and supports varied ecosystems when discharging from aquifers. This paper will argue these points and highlight some of the principal research challenges using data from the UK. It will review how groundwater has previously been dealt with in catchment management, and discuss whether more needs to be done to integrate hydrogeology into future management strategies.

Keywords: Groundwater flow, water resources, diffuse pollution, wetlands, ecosystems, Water Framework Directive

Typology of Groundwater - Surface water Interaction – GSI typology

[1]Mette DAHL, [1]Bertel NILSSON, [2]Jesper H LANGHOFF, [1]Jens Christian REFSGAARD

[1]Geological Survey of Denmark and Greenland, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark, e-mail: md@geus.dk, bn@geus.dk, jcr@geus.dk
[2]University of Aarhus, Department of Earth Sciences, Ny Munkegade, Bygning 520, DK-8000 Aarhus C, Denmark, e-mail: jlanghoff@mail.djh.dk

ABSTRACT

The EU Water Framework Directive (WFD) outlines a new approach to water administration in which interactions between groundwater bodies, groundwater dependent terrestrial ecosystems and surface water bodies form a central role. To facilitate monitoring and status assessment the directive allows grouping according to typologies. A typology used for evaluating interdependencies between groundwater bodies, riparian areas and streams must be based on processes controlling flow, contaminant transport and attenuation (Fig. 1). The new typology of Groundwater – Surface water Interaction (GSI typology) has therefore been developed as a process-oriented multi-scale framework classifying interactions between the three hydrological components. The controlling processes are characterized using an eco-hydrological approach based on geomorphology, hydrogeological setting and flow paths on gradually smaller scales. The GSI typology hierarchy encompasses three scales briefly summarized in Fig. 2.

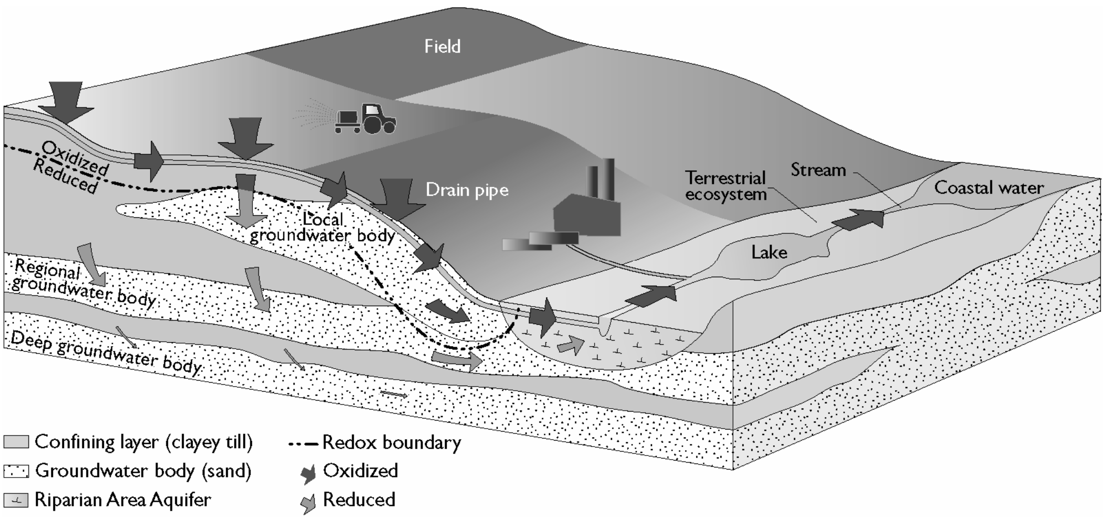


Fig. 1. Example of a moraine landscape with undulating geomorphology creating local, intermediate and regional flow systems, and a groundwater system comprising interbedded aquifers (sand) and confining layers (clayey till) controlling groundwater flow through specific types of groundwater bodies and riparian area aquifers to various surface water bodies.

On *catchment scale* of more than 5 km the Landscape Type classifies the groundwater flow systems and the groundwater system as a regional frame controlling flow processes. The classification criteria are regional geomorphology and regional hydrogeologic setting, respectively. Separation is made between four main hydrogeological settings, namely a single dominant unconfined aquifer, two interconnected aquifers of equal importance, a three-unit system consisting of an unconfined aquifer, a confining layer, and a confined aquifer, or a complexly interbedded sequence of aquifers and confining layers with no dominant aquifer.

On *intermediate or reach scale* of 1-5 km the Riparian Hydrogeological Type classifies the exchange of water between a groundwater body and a riparian area aquifer. The classification criterion is the hydrogeologic setting adjacent to the riparian area aquifer. The hydrogeologic settings are defined by a combition of two features, namely the Contact Type and the Groundwater Body Type. The typology distinguishes between five Contact Types, namely Disconnected, Confined, Lateral, Bottom or Unconfined, characterizing the spatial contact between a groundwater body and a riparian area aquifer, and determining groundwater ability to enter the riparian area aquifer, as well as the entering point. The typology distinguishes between two Groundwater Body Types controlling the temporal contact, flux and stability of groundwater discharge to the riparian area aquifer, namely the Local and the Regional (Fig. 1). A Deep groundwater body is defined as not having contact with the riparian area aquifer. It is therefore not relevant in the GSI typology.

On *local scale* of 10-1000 m the Riparian Flow Path Type finally classifies flow paths through the riparian area to the stream. The classification criterion is the dominant flow path. Four flow paths have been identified as the most important that transfer water through the riparian area to the stream, namely Diffuse, Overland, Direct, and Drainage. They are defined based on type of flow (matrix, preferential, overland, or pipe) and contact time between water and riparian deposits. Very general path-specific reduction capacities are proposed, namely Q_1 and Q_3 close to 100 % if the organic content is more than 3%, and close to 0 % if it is less than 3 %, Q_2 approximately 50 %, and Q_4 close to 0 %. These flow paths, to a large extent, control transport and attenuation processes, and thereby the capability of the riparian area to maintain high water quality of an adjacent stream.

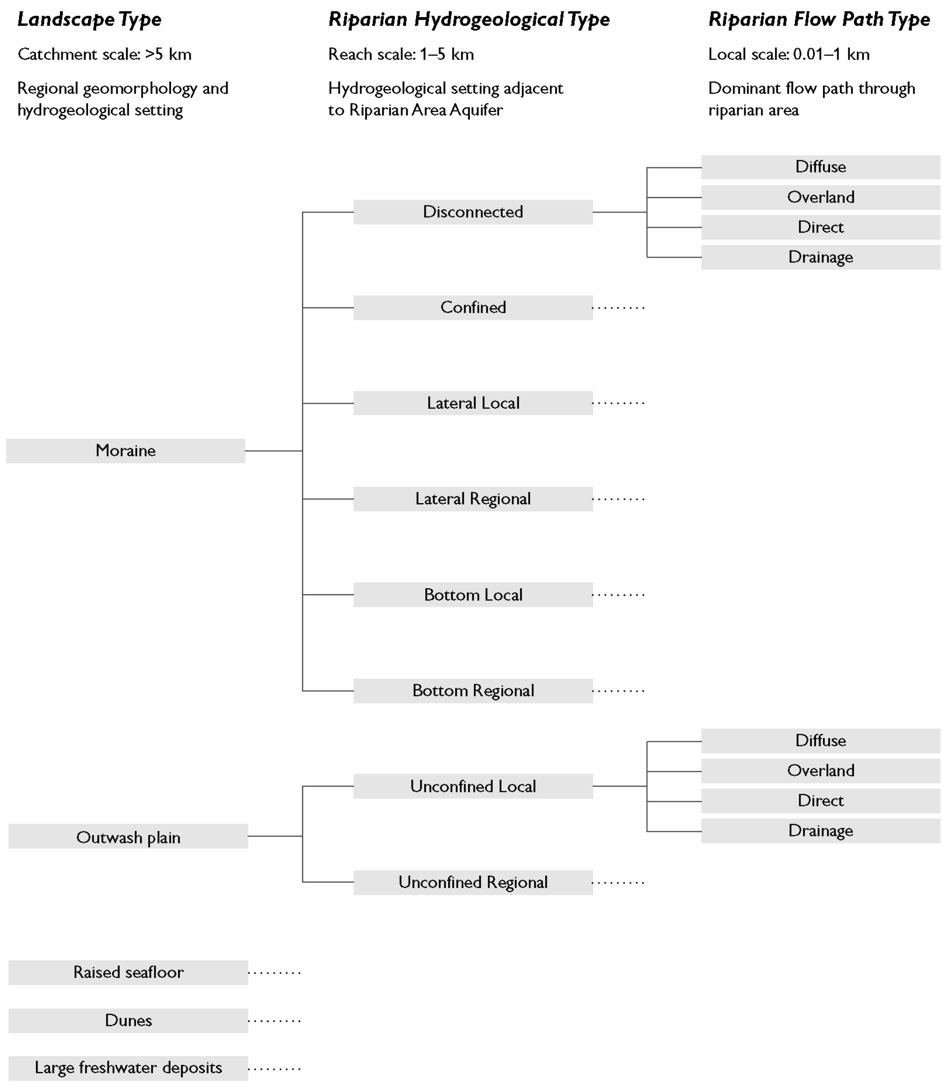


Fig. 2. Terminology, scale hierarchy and classification criteria of the GSI typology.

The GSI typology has been developed for landscapes of moraine, outwash plain and marine deposits. Testing is ongoing in a moraine landscape of Odense River Basin in Denmark. Preliminary results indicate that the typology may be applied to evaluate direction, rate and nitrate content in the exchange between groundwater bodies, riparian areas and streams. The results specifically point to the great importance shallow local groundwater bodies have on groundwater and nitrate discharge to dependent ecosystems.

Keywords: Typology, groundwater, riparian area, stream, interaction

Understanding surface and groundwater interactions and its relationship with salinity dynamics in the Wollombi Brook, Upper Hunter catchment, NSW Australia

[1]Gabrielle YATES & Bennet [2]C.T. MACDONALD

[1]School of Earth and Marine Sciences, Australian National University, Canberra 0200
[2]Centre for Resource and Environmental Studies, Australian National University, Canberra 0200

ABSTRACT

Salinity threatens many surface and groundwater resources in Australian catchments. Salinity in the Upper Hunter catchment is mobilised from connate marine salts associated with Permian strata by percolating groundwaters, as well as weathering of regolith derived from Permian rocks. Agriculture in the district is supported by abstraction of lower salinity waters located in the stream and floodplain sediments that occur along stream corridors within catchments. Coal mining in the Upper Hunter shifts the interactions between groundwater components. The field site, Wollombi Brook is a sand-bed pool-riffle system whose run encompasses diverse geologies. Coal mining and viticulture are dominant industries in the catchment. The integrity of the less saline water resource defined by the stream and floodplain aquifer has been investigated through hydro-geochemical analysis of stream and groundwater components, as well as analysis of stream gauge data.

Gauged data included discharge and EC. Relationships between stream salinity and discharge were investigated. Groundwater-surface water interactions were elucidated using these relationships in addition to investigations of flow duration and baseflow separation techniques. This work also reviews the current conception of groundwater-surface water interactions through critical analysis of tracer methods used to define relationships by an earlier study.

A hydrogeochemical survey of the brook was undertaken, and major ion data collected during this survey was analysed along with data collected by coal mines within the catchment to build a conceptual model for groundwater interactions in the Mid to Lower catchment. This study aimed specifically to gain insight into the interactions between the floodplain aquifer and other surface and groundwater components for the origin and pathways of salinity in the catchment. The floodplain aquifer might currently be seen as a buffer between the deeper saline waters associated with the Permian strata and the surface waters of the Wollombi Brook.

Keywords: salinity, surface-groundwater interactions.

Water balance in the Guarani Aquifer outcrop zone based on hydrogeologic monitoring

[1]Carlos E A G BARRETO, [1]Luis Henrique GOMES, [1]Edson WENDLAND

[1] University of São Paulo, Department of Hydraulics and Sanitary Engineering, PO Box 359, São Carlos-SP, 13560-970, Brazil, e-mail: agbarreto@gmail.com, gomeslh@yahoo.com.br, ew@sc.usp.br

ABSTRACT

Base flow estimate is important for the management and planning of water resources in watershed scale. This work presents the development of an empiric equation that correlates the base flow with the groundwater level in the aquifer. The study was based on hydrogeologic monitoring and water balance in a pilot watershed. The pilot watershed (Ribeirão da Onça) is situated in the outcrop zone of the Guarani Aquifer System between parallels 22°10 ' and 22°15 ' (south latitude) and meridians 47°55' and 48°00' (west longitude). For the execution of the research project, a monitoring network (wells, rain gauge and linigraph) was installed in the watershed. Outflow in the creek has been measured with current meter and monitored continuously with a linigraph. Data have been systematically collected during the period of a hydrological year.
Figure 1 shows schematically the streamlines and variables related to the river-aquifer interaction.

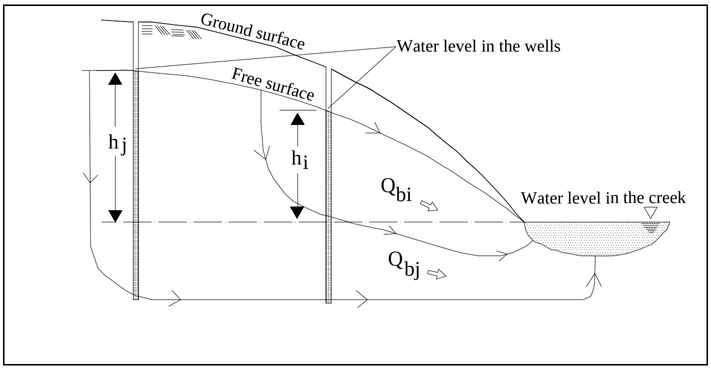


Fig. 1. Schematic profile of river-aquifer interaction with related variables.

The results show that, in this water basin, the relation between the water level in the wells and the base flow can be represented by a mixed function (linear and exponential) of the type

$$Q_b = a_n.\Sigma\Delta h_n + b_n.(1 - e^{-c_1.\Sigma\Delta h_n}) \quad (1)$$

where Q_b is the base discharge, $\Sigma\Delta h_n$ is the summed variation of water level in the monitoring wells in a given period and a_n, b_n and c_n are equation parameters, which are adjusted through optimization.
The base flow quantification, with the use of functions that represent the river-aquifer interaction, is an important tool for use in rivers where it has problems in the accomplishment of continues measures of outflow.

Keywords: Hydrogeology, river-aquifer interaction, monitoring

Water Table Dynamics of a Severely Eroded Wetland System, Prior to Rehabilitation, Sand River Catchment, South Africa.

Edward S RIDDELL[1)], Simon A LORENTZ[1)], William N ELLERY[2)], Donovan KOTZE[3)], Jacobus J PRETORIUS[1)], Silus N NKETAR[2)], Bertram KONING[1)]

[1)] School of Bioresources Engineering and Environmental Hydrology, Pietermaritzburg Campus, University of KwaZulu-Natal, P/Bag X01, Scottsville, 3209, South Africa
[2)] School of Life and Environmental Sciences, Howard College Campus, University of KwaZulu-Natal, Durban, 4041, South Africa
[3)] Centre for Environment and Development, Pietermaritzburg Campus, University of KwaZulu-Natal, P/Bag X01, Scottsville, 3209, South Africa

ABSTRACT

It is generally believed that wetlands in southern Africa are critical to the hydrological function of river systems and thus play a pivotal role in water resource security for this increasingly water-stressed region. There is however, still a paucity of studies that have examined the specific hydrological processes that operate within wetland catchments of the region and consequent up-scaling to river system processes.

This paper describes the findings relating to water table/phreatic surface behaviour in a headwater riparian wetland system undergoing severe erosion and desiccation prior to rehabilitation interventions. This wetland system exists in a region of high anthropogenic pressure in the semi-arid savannah of the South African lowveld, and is subject to a three-year monitoring study examining the impacts of rehabilitation on the wetland catchment's hydrological processes and function.

Observation of the water table during the wet and dry seasons of the first year of monitoring revealed a stratified system of perched, temporary water tables at shallow depths following significant 'wetting-up' of the catchment. In addition, rapid saturation of deep soils at the toe of the interfluves suggests that, when certain antecedent conditions are met within the surrounding catchment, a perched water table will appear within a very short time-frame. Meanwhile, a much deeper water table was also delineated which recharged following the wetting-up of the wetland itself.

Furthermore, hydro-dynamically distinct regions were identified at longitudinal positions along the wetland, whereby water table behaviour was used to identify zones of sub-surface flow buffering in the highly conductive sandy wetland substrate. Sub-surface geophysics surveys revealed a buffering 'plug' of finer sediment thought to be one of many that used to exist and were responsible for retaining the moisture within these sandy wetland systems. These systems are now experiencing severe down-cutting by large erosion gullies, leading to the rapid desiccation of wetlands which are used for subsistence cultivation and play a significant role in livelihood security for the local population.

The findings of this study are used to corroborate the assumption that these large erosion gullies need to be 'plugged' in order to restore the hydrological regime of the wetland environment. These findings will be up-scaled in the future to the entire headwater region of the Sand River whose wetlands are almost all similarly degraded.

Keywords: wetlands; water table; erosion; gullies; South Africa

TOPIC 01

Groundwater/surface-water water interactions and their importance for the sustainability of river and spring base flow, and associated wetlands

An analysis of PAH transport dynamics in a rural watershed: processes on the scale of a flood event

A. MOUHRI, A. MOTELAY-MASSEI, N. Massei & B. LAIGNEL

Laboratoire de Morphodynamique Continentale et Côtière, UMR 6143 CNRS, Université de Rouen, 10 bd de Broglie, 76821 Mont-Saint-Aignan cedex, France

ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs) are produced by the incomplete combustion of fossil fuels and organic matter and are considered as ubiquitous contaminants in the environment. PAHs are semi-volatile compounds emitted in the atmosphere mainly from vehicle exhaust, industrial emissions and domestic heating. Because of their low degradability and their hydrophobicity, these compounds accumulate in soils where they are stocked for many years. Once accumulated in soils, they can be removed from soil by runoff. This resuspension is highly variable according to the land use or meteorological parameters. In rivers, PAHs are mainly in dissolved phase for the low molecular weight PAHs or in particulate phase for the high molecular weight PAHs. However, water catchment points for drinkable waters in Normandy (France) are often contaminated by PAHs during rainy events . This contamination can be explained by the important runoff phenomenon on the silty plateaus of this country. In this karstic area, runoff waters may reach sinkholes and directly affect groundwaters.

PAHs (in particular the high molecular weight ones) are adsorbed on the particulate and colloidal organic matter and preferentially linked to low-size particles. The high molecular weight PAHs are very stable and can thus be used for better understanding the dynamics of particulate and dissolved transfer in rivers and groundwater.

The objective of this work is to use PAHs as a tracer in order to define the transfer of surface water from a rural watershed (Norville, France) to the karstic sinkholes on a scale of flood event. For that, measurements were carried out during the December 2002 flood period. The concentrations of 14 PAHs and 4 hydrological parameters (precipitation, discharge, turbidity, and electric conductivity) were measured.

The methodology used for the data processing was i) first, the decomposition of the PAH curves during the flood event; ii) Secondly, principal component analysis was carried out using 14 active variables (14 PAH concentrations) and 3 hydrological parameters (discharge, turbidity, conductivity).

These two methods enabled us to highlight the dissolved transport of the low molecular weight PAHs and the particulate transport of the high molecular weight PAHs and to distinguish direct transfer and resuspension.

Keywords : PAH transfer, flood event, watershed, sinkholes

Application of hydrological indicators for biodiversity monitoring in the Tordera River (NE Spain)

Josep MAS-PLA and Anna MENCIÓ.

Centre de Geologia i Cartografia Ambientals (GEOCAMB); and Àrea de Geodinàmica, Dept. de Ciències Ambientals, Universitat de Girona, Campus de Montilivi, 17071 Girona, Spain, e-mail: josep.mas@udg.edu.

ABSTRACT

Environmental indicators based on biological data are commonly applied to monitor the biological status of water bodies, and they have become essential for water management purposes and ecological control. Nevertheless, the complexity of the hydrological systems requires the integration of hydromorphological and biological parameters to provide a full analysis of the water body status (Poff *et al*. 1997; Sear; 1999; Richter *et al*., 2003). Presently, the application of the European Water Framework Directive (WFD, 2000/60/CE) has compelled the states members to develop suitable indicators for the monitoring of hydrological and biological status. These indicators must reflect with the idiosyncrasy of their streams, wetlands, and other continental as well as marine waters.

In this sense, the "Tordera Observatory" Project has defined some indicators to characterize hydrological processes in selected reaches of the Tordera River. These results will be added later to a complete database of biological indicators based on diatoms, macroinvertebrate fauna, amphibian, fish and bird populations, vegetation as well as social variables on water use and demand (http://www.observatoririutordera.org). The aim of this project is to be able to record as many data as possible that will help to depict environmental changes on the Tordera basin that affect its biodiversity, and finally, to evaluate the requirements of the WFD and the achievement of its goals.

The Tordera River basin is located in the Internal Basins in Catalonia (NE Spain). It has an area of 894 km^2, and its annual mean discharge is 7.1 m^3/s. Nevertheless, drought periods in the last four years have strongly modified the water regime overriding the seasonal character of the monthly discharge distribution. In this context of variability, the evaluation of hydrological dynamics using indicators on a monthly basis becomes a support for the understanding of biological data and their related indicators.

In this contribution, we present the data-gathering methods and the hydrological indicators that have been defined in the Tordera River. Rainfall and discharge data are obtained from the Administration websites and services, white water-table head and surface water chemistry are sampled on a monthly basis. Dataset consists of 4 meteorological stations, 3 steam gauging stations, 18 wells, and 17 water-sampling points. The latest are selected in agreement with the stream reach division that fits for biological monitoring of the river.
Hydrological indicators are defined according to these data. They are estimated as follows,

1. **Rainfall indicator**, based on the ratio between the monthly rainfall and the average rainfall for that month. Categories are defined according to the coefficient of variation.
2. **Discharge indicator**, based on the flow-duration curve for each month and the established in-stream discharge. Categories are determined according the percentage of days that had a discharge larger than the in-stream flow. Evaluation of the flow alteration and flow environmental components, as postulated by Richter *et al*. (1996), are also used to provide a more detailed examination of flow regime during the biological sampling surveys.
3. **Water-table indicator** defines the magnitude of the stream-aquifer relationship. It is based on the hydraulic gradient between head at wells nearby the stream and the river stage.
4. **Hydrochemical indicators** are based on the nitrogen compound concentrations, according to previously defined ranges of biological alteration, toxicity and eutrophization (Prat *et al*., 2001)

Dataset analysis has provided the following contributions:

- Rainfall variability during the last four years impedes the interpretation of biological indicators using average rainfall data,
- Recession curves on the Tordera river show a small regulation capacity of the related aquifers. Furthermore, a convex decrease of discharge over time reflects the effect of induced infiltration in the stream by ground water exploitation. As a result, many reaches may become dry during the summer season, and even in spring and fall.

- Water treatment plant contributions to stream discharge may reach up to a 60% of the total discharge in summer, being essential for the maintenance of a minimum flow in dry periods, despite a decrease of surface water quality.
- Annual flow-duration curves show that in-stream flow is accomplished only 30% of the days, being down to 10% during the summer months.
- Stream-aquifer relationship based on the water-table head in wells nearby the river shows a lasting “loosing stream” behavior, which turns to a “gaining stream” only during short periods of intense rainfall and aquifer recharge.
- Hydrochemistry indicates industrial and urban pressures on the river water quality, allowing a neat identification of each one of the impacts that occur along the stream. Nitrate and ammonium concentration show a acceptable to mediocre qualities, in most of the points.

Finally, indicators provide a fast and simple description of the hydrological status of the basin that can be easily estimated and described. They synthesize a more complex analysis which is essential to define pressures, impacts and, later on, become a basis to determine management options. Furthermore, the experience in the Tordera River points out the significance of those indicators as guidance for the interpretation of biological data and their subsequent indicators. Joint analysis of hydrological and biological indicators is an ongoing task focused on integrating environmental knowledge and also to depict significant changes in the biological status of streams.

Acknowlegments
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Keywords: Hydrological indicators, in-stream flow, groundwater/surface water interactions, hydrochemistry, Water Framework Directive.

Application of two models for calculating phreatic water evaporation in the lower reaches of Tarim River, western China

zhaoxia YE1)2)3), yaning CHEN1)2), weihong LI1)2), yan YAN4)

1) Key Laboratory of Oasis Ecology and Desert Environment, Xinjiang Institute of Ecology and Geography, Chinese Academy of Science, Urumqi 830011, China;
2) Xinjiang Institute of Ecology and Geography, Chinese Academy of Science, Urumqi 830011, China;
3) Graduate School, Chinese Academy of Science, Beijing 100039, China;
4) College of Resources and Environmental Science, Xinjiang University, Urumqi 830046, China.

ABSTRACT

The Tarim River, in the south of the Uigur Autonomous Region of Xinjiang, western China, is the longest arid and intra-continental river in China and is also one of the most famous in the world. The study area is located between Daxihaizi Reservoir and Taitema Lake in the lower reaches of Tarim River (39°38′-41°45′N, 85°42′-89°17′E). The channel bed stretches from west to east on alluvial fans along the Taklamakan Desert and the Kuluke Desert. In this paper, two typical models (Qunk formula and Аверъянов formula) were chosen to calculate the phreatic water evaporation. In order to apply them to the natural vegetation in the lower reaches of Tarim River, a set of parameters were revised. Thus the field data from 25 monitoring wells across eight study sites and 25 permanent vegetation survey plots in the lower reaches of Tarim River were analyzed and the relationships between phreatic water depth, soil moisture, and plant species diversity were determined. It was proved that the critical phreatic water depth was 5 meter in the lower reaches of Tarim River. Based on previous studies and the analysis of investigating data, the parameters “a” and “b” of Аверъянов formula were determined, and equalled to 0.62 and 3.2, respectively. Averaging the two results of the phreatic evaporation, the mean phreatic evaporation of different groundwater levels every month were determined. In conclusion, the development of vegetation was strongly influenced by the groundwater table, and phreatic water evaporation was close to soil moisture and plant species diversity. A second conclusion is that the evaporation was intense during May to July, and would supply a guide for choosing the best time of artificial water delivery. This research will be an effective approach to study the ecological water demand of natural vegetation in the lower reaches of Tarim River.

Keywords: application; phreatic water evaporation; Tarim River

Assesment of the hydrogeological environment in the eastern Nile Delta, Egypt, for the applicability of the bank filtration technique

[1]Kamal GHODEIF & [2]Birgit FRITZ

[1] Geology Department, Suez Canal University, Ismailia, Egypt
[2] Kompetenz Zentrum Wasser Berlin, Berlin, Germany

ABSTRACT

The present drinking water supply system in the eastern Nile Delta region, Egypt, uses Nile water directly as source water for further purification processes. Conventional filtration treatment with chlorine as main disinfectant is commonly used. Nevertheless, due to pollution of the source water, high amounts of coagulants and chlorine are used. Chlorine is added in two stages: pre-chlorination and post-chlorination. This has caused an increase in both the ratio of disinfectant by-products, mainly trihalomethanes (THMs), and the cost of water treatment. This research aims to evaluate the safety of drinking water quality under the present treatment system and to assess the suitability of the hydrogeological environment in the region for the establishment of bank filtration as an alternative technique. Water quality of both source water and tap water is assessed in seven water treatment plants in the region and the suitability of the hydrogeological environment for the use of the bank filtration technique is investigated. The source water has a relatively high organic load, total organic carbon (TOC) ranges from 4.9 to 3.6 mg/l, which enhances the formation of THMs. The THMs species are found in both source and tap water. In source water the total trihalomethanes (TTHMs) range from 1.3 to 3.3 µg/l. In tap water, TTHMs ranges from 39.1 to 175.2 µg/l with median value 87.7 µg/l. The dominant species in tap water is chloroform, where values range from 140 to 22 µg/l with median value 54 µg/l. TTHMs exceed the EPA drinking water standard (80µg/l) in 71% of the cases and exceed the Egyptian drinking water standard (100 µg/l) in 28% of the cases. These results have urged us to propose bank filtration as an alternative technique to improve the source water quality and decrease the amount of chlorine added to the minimum level. This may reduce the total cost for production of drinking water. The hydrogeological environment around the surface water source in the study area is favourable for the application of the bank filtration technique. The Pleistocene sand and gravel layer has a great extent and average thickness is about 250 meters. It forms the main aquifer in the region. It changes from unconfined in the west to leaky confined in the east and in some parts with variable conditions. It has very good hydraulic properties that vary laterally and vertically. The Pleistocene aquifer is in direct hydraulic contact with the River Nile surface water systems and receives recent recharge from them. It has fresh groundwater quality in the south and west but salinity increases to the north and to the east with the general direction of groundwater flow. The average natural background chloride concentration in the southern parts is about 178 mg/l. Anticipating mixing with surface water (average chloride concentration 21 mg/l,) provides an opportunity to improve the quality of the produced water from bank filtration wells. Five sites are investigated along one of the main watercourses in the eastern Nile Delta (Ismailia Canal) to test the efficiency of the bank filtration technique. The share of bank filtration water to the productive wells is high. It reaches about 90% using Bank Filtration Simulator software. Chloride concentration has been used as a tracer to calculate the percentage of bank filtrate in wells that have a surface water signature. It ranges from 93.3 to 48.1 mg/l in the tested sites. The location for one field site has been selected and designed to measure the effectiveness of bank filtration in such arid environments. A pumping well will be drilled about 30 meters from the surface water bank and an array of three observation wells will be installed for further detailed investigation of the hydraulic, biological and geochemical processes. Accordingly, the bank filtration technique can be widely used to improve the drinking water quality in Egypt.

Keywords: Bank filtration; Drinking water treatment; Trihalomethanes; Egypt; Pleistocene aquifer

Chemical transfers from atmospheric waters towards groundwaters. Application to volcanic aquifers (Argnat basin, France).

[1] Guillaume BERTRAND, [1] Hélène CELLE-JEANTON, [2] Paolo LAJ, [1] Gilles CHAZOT, [3] Céline FAJON, [4] Jérôme RANGOGNIO, [5] Marius PARAZOLS, [1] Sébastien LOOCK, [6] Frédéric HUNEAU

[1]Laboratoire Magmas et Volcans, Université Blaise Pascal, 5 rue Kessler 63000 Clermont-Ferrand, France, e-mail : G.Bertrand@opgc.univ-bpclermont.fr, H.Celle-Jeanton@opgc.univ-bpclermont.fr, G.Chazot@opgc.univ-bpclermont.fr, S.Loock@opgc.univ-bpclermont.fr
[2]Laboratoire de Météorologie Physique, Université Blaise Pascal, 24 avenue des Landais 63170 Aubière, France, e-mail : P.laj@opgc.univ-bpclermont.fr
[3]Laboratoire de biologie des protistes, Université Blaise Pascal, 24 avenue des Landais 63170 Aubière, France, e-mail : C.Fajon@univ-bpclermont.fr
[4]Centre National de Recherche Météorologique, 42 avenue Gaspard Coriolis 31057 Toulouse cedex 01, France, e-mail : J.Rangognio@cnrm.meteo.fr
[5]Laboratoire de Photochimie Moléculaire et Macromoléculaire, Université Blaise Pascal, 24 avenue des Landais 63170 Aubière, France, e-mail : M.Parazols@univ-bpclermont.fr
[6]Centre de Développement des Géosciences Appliquées, Université Bordeaux 1, B18 avenue des Facultés, 33405, Talence, F.Huneau@cdga.u-bordeaux1.fr

ABSTRACT

We present preliminary chemical and isotopic results obtained from rainwater and groundwater in a volcanic basin in order to assess the different processes affecting horizontal and vertical chemical transfers in this kind of environment.

In this purpose, we used a combination of two different approaches:

- A chemical characterization of the rainwater to study the chemistry of regional precipitation and its variations as a function of air origin and meteorological parameters. These results are used as the composition of the input water arriving into the system.
- A monthly sampling of groundwater from the Argnat basin, near Clermont-Ferrand, characterized by the superposition of several quaternary lava flows. The sampling included several water catchments for analysis of major ions and stables isotopes. To study vertical transfers, rain falling on the basin was sampled, both unsaturated zone and saturated zone on a weekly time-scale.

Each precipitation event is sampled at Opme meteo-station (45°43'00" N; 3°5'30"E), in order to establish whether there is a relationship between chemical and meteorological parameters. Major ions (Na^+, Mg^{2+}, K^+, Ca^{2+}, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-), some minor ions such as PO_4^{3-}, NH_4^+, organic acids and Total Organic Carbon (TOC) were analysed. The results allowed the definition of five different chemical rainfall signatures (anthropogenic-acid, marine, ammonia- neutralisation, Ca-neutralisation, non-specific neutralisation with NH_4^+ and Ca^{2+}). Their nature clearly depends on air-mass origin and cloud trajectories. A local imprint can occur, influenced by atmospheric column feature when it's raining.

In the Argnat basin, groundwater from nine sampling points are analysed for major ions, TOC and isotopes (^{18}O, ^2H, ^{13}C) with a monthly time-scale. An altitudinal gradient is put in evidence with an enrichment in NO_3^-, Cl^- and Ca^{2+} from the highest water catchment 1 to the lowest one 9 (Fig. 1).

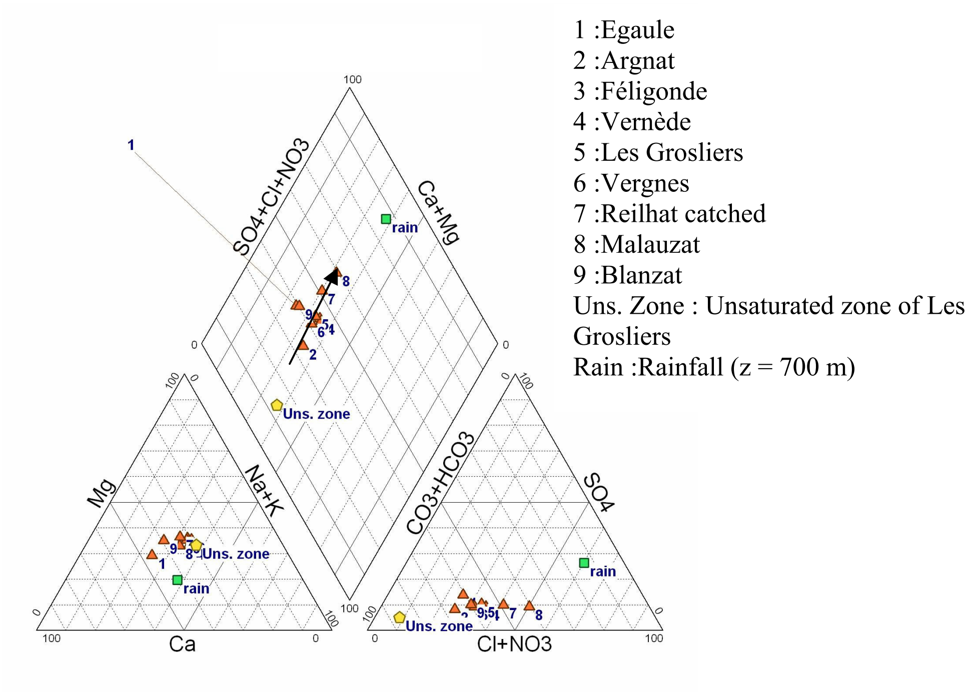


Fig. 1: Piper diagram for 9 water catchments (the altitude decreases from 1 to 9), precipitation and unsaturated zone of the Argnat basin

Changes in Ca^{2+} content imply circulations over basements of various natures, mainly granite in the upper part of the basin, and sedimentary deposits in the lower basin. Increase of NO_3^- and SO_4^{2-} values in the lower part of the basin is due to anthropogenic influence (increase of population density and cultivated areas).

The detailed study of vertical transfer at Les Grosliers water catchment (Rainfall - unsaturated zone - saturated zone) highlights the modalities of infiltration in volcanic environment. Low TOC and high $NO3^-$ values of the saturated zone (respectively around 0.5 and 13 mg/l) compared to the data obtained in the unsaturated zone seem to be due to surface run-off that infiltrates the volcanic media through the geological lava flow-basement contact. This specific zone is composed of volcanic scoria and altered basalt characterised by a high porosity. High TOC and low NO_3^- values of the unsaturated zone (about 2 and 4 mg/l) are confirmed by $\delta^{13}C$ (near -13‰ V-PDB) that suggest the participation of horizontal circulations and the presence of perched reservoirs within the unsaturated zone.

The variability of the environmental elements such as nitrate and TOC led to an interest in microbiological activity. Many studies (Pauwels *et al*, 2000; Abdelouas *et al*, 1998, …) have shown that nitrate can be consumed by bacteria within the aquifer; NO_3^- is then the terminal electron acceptor in anaerobic conditions and in presence of organic carbon. On the contrary, in aerobic conditions, oxidation of organic matter like ammonia creates NO_3^-. As volcanic media and more peculiarly unsaturated zone of this kind of environment are poorly investigated, a monthly monitoring has been settled since July 2006 in order to count viable and active micro organisms in both saturated zone and unsaturated zone waters. From these data, biological processes that can influence water quality will be assessed.

Keywords: Rainfall, unsaturated zone, major ions, isotopes, bacteria

Control of the storage capacity of the dams at the time of the drought in the Tone River Basin

[1] Miyo SHIMIZU, [2] Mitsukuni TSUCHIYA

[1] 460-1 Kamisadori, Maebashi, Gumma 371-0816, JAPAN, e-mail: ilcalcio512@yahoo.co.jp
[2] 460-1 Kamisadori, Maebashi, Gumma 371-0816, JAPAN, e-mail: tsuchiya@maebashi-it.ac.jp

ABSTRACT

The existing dams in the Tone River Basin serve the purpose of providing hydroelectric power generation, drinking water supply, and flood control. However, dam projects are increasingly criticised due to the influence of dams on the surrounding ecosystem and environment. As a result construction of a new dam is a difficult undertaking. It has therefore become even more important that the existing dam reservoir is used effectively.

In this study, the roles and change in water storage of six existing dams in the Tone River Basin at the time of a drought were considered. The Tone River's water resource is used for drinking water supply, industrial water, agricultural water use, and power generation for metropolitan areas.

About 29 million people depend on this water supply for their drinking water. The dams provide about 90 percent of the water supply, which is thus greatly dependent on the water infrastructure, such as a dam.

The main purpose of the Yagisawa, Shimokubo, Naramata and Kusaki dams is for irrigation. The storage capacity of the six dams, the four previously mentioned and the Aimata and Sonohara dams, has been investigated. The Yagisawa dam has the largest storage capacity (service water capacity of about 115 million m^3) and forms 25 – 34% of the service water capacity in the Tone River basin. Fig.1 shows the map of Tone River Basin, which is an object basin.

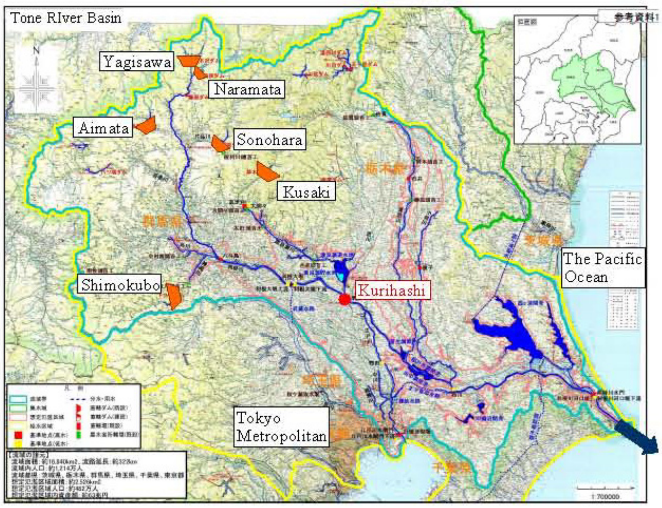


Fig.1 The map of Tone River Basin

In the Tone River basin, since integrated management of the dam was started, the drought caused a 30% reduction in water supply in 1994 and 1996. This caused a water shortage throughout Japan in 1994.

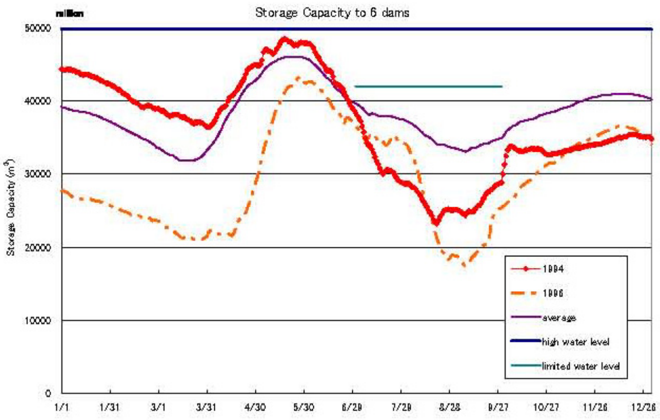


Fig.2. Changes of the storage of the six dams

Fig.2 shows the changes in storage of the six dams of the Tone River in 1994 and 1996 (the drought years), and a normal year. The storage from the winter to spring was normal (average for the year) or more than an average in 1994. However, since there was little rain in June and afterwards and outflow discharge was the same, storage decreased, resulting in a reduction in water supply.

The storage became the lowest ever from the winter to spring, and some recovery occurred through snowmelt in 1996. However, the storage did not recover completely, and reduced water supply commenced from the middle of August. Thus, although there was a similar reduction in water supply, there was a difference in storage in the summers in 1994 and 1996.

In spite of having more storage in the dams in 1994 than it had in 1996, the drought in 1994 had serious impacts. In addition to having had little rain, it is considered that dam control through integrated management could did not occur.

It became clear that the impacts of drought can be reduced by utilising the complete storage of the dam and performing integrated management more efficiently.

Keywords: dam, drought, storage capacity

Effects of surface water-groundwater interaction on ecotones in Ogun River Basin

Gbolagade A. BOLAJI

Department of Civil Engineering
University of Agriculture, Abeokuta. Nigeria gbolaji@yahoo.com

ABSTRACT

River and groundwater are usually interconnected and hydrodynamic studies have confirmed that, surface water impact on groundwater systems. When surface and groundwater interacts, unique gradients develop and the two realms can be considered essentially as one resource. Groundwater loses water to the river through the hydraulic connection that is created and this is recognized as base flow or "ecological base flow" during the dry periods. Surface water has the ability to enhance or detract from groundwater quality and vice versa. The interdependency of Ogun River and its adjoining surface aquifers have been studied so. The support that this vital link provides in ecosystem sustenance through environmental flow is being presented in this paper.

A study which include the climate, hydrology, geology, hydrogeology and morphology, was carried out on Ogun river basin. A section of the floodplain of Ogun River that is usually inundated for about seven months has been classified as a wetland. Human activities like farming and fishing are very common on the floodplain. Hydraulic interconnection between the aquifer and the river channel was established by using flow nets and mathematical models. Areas where surface and groundwater interacts were designated on the floodplain and the ecotones existing there were identified. The quantity of base flow discharged from the aquifer into the river channel was estimated. Water samples obtained from groundwater (tubewells and wash bores) and the river were analysed to determine the physico-chemical and bacteriological parameters present. Hyporheic portions of the river were identified in the study area and sampled to determine the flora, fauna, micro-flora and micro-fauna populations present. The spatial and temporal impacts were assessed in line with the human activities on the floodplain. Results of the study revealed that there are temporal variations in surface/groundwater interactions as well as contribution of groundwater as base flow during dry periods. The effects of the hydrological changes on the ecotones could not be ascertained due to limited data.

Keywords: hydrogeology, ecosystems, wetlands, base flow

Estimation of total recharge of unconfined Rio Claro Aquifer, Brazil, obtained from automated water level monitoring

[1] Hung K. CHANG & [2] Dagmar N. CARNIER

[1] LEBAC - IGCE – UNESP
Av. 24A, 1515 – Rio Claro - SP - Brasil
chang@rc.unesp.br
55 19 35325119

[2] LEBAC - IGCE – UNESP
Av. 24A, 1515 – Rio Claro - SP - Brasil
dagmarcn@rc.unesp.br
55 19 35325119

ABSTRACT

The understanding of mechanisms that cause water level variations and the capacity to monitoring it is a critical factor for recharge quantification studies, whether on aquifer-scale for water-resource assessment and management or local-scale for assessment of groundwater contamination.

The purpose of this paper is to present values for the total recharge of an unconfined aquifer portion situated in an urban area during a four year period, using sampled data obtained via water level automated monitoring.

The shallow unconfined aquifer is constituted by Cenozoic sedimentary rocks of Rio Claro Formation of fluvial origin. The sediments are composed of fine to median sand with abundant clay matrix. Thickness of the aquifer varies from few meters up to 50m. The water table in the studied area is within 6m and 10m of land surface. However there is a large variation in water levels throughout the aquifer domain, the majority shallower than 18m. Recharge occurs along the majority of the aquifer, with discharge areas located near the formation contact and along narrow valleys.

The water level monitoring was automated using a water column probe connected to a computer recording the water level every five seconds. The two monitored wells were drilled on the university campus. The results of four years water level data acquisition is shown in Figure 1. The graph was obtained after data pre-processing including gaps correction, offset adjustments and resampling that reduced a large number of data to one measurement a day. The seasonal fluctuation is associated with the rainfall period starting in November and December and ending between February and March.

Determination of total recharge was performed by applying the WTF (water-table fluctuation) method. To calculate Δh, each recession curve was extrapolated and the difference between the peak of the rise of the water level and the extrapolated value of previous recession at the time of the peak was calculated. The average specific yield of the sediments is 0.17 as obtained from undeformed samples collected along a 7m deep dug well. Table 1 shows the recharge for three consecutive years (2003 to 2005). It is clearly seen that there is a significant drop in recharge values as rainwater precipitation is reduced, such as occurred in 2005..

It is worth noting that not only is the absolute total recharge controlled by the rainwater precipitation but also its proportion to the total annual precipitation changes. A reasonable explanation is that the rainfall events in 2005 were concentrated in a very short time interval. This is in contrast to 2003 and 2004 with a much wider rainfall distribution. Poor distribution probably resulted in increased runoff and decrease humidity in unsaturated zone, thus diminishing the infiltration leading to a low total recharge value.

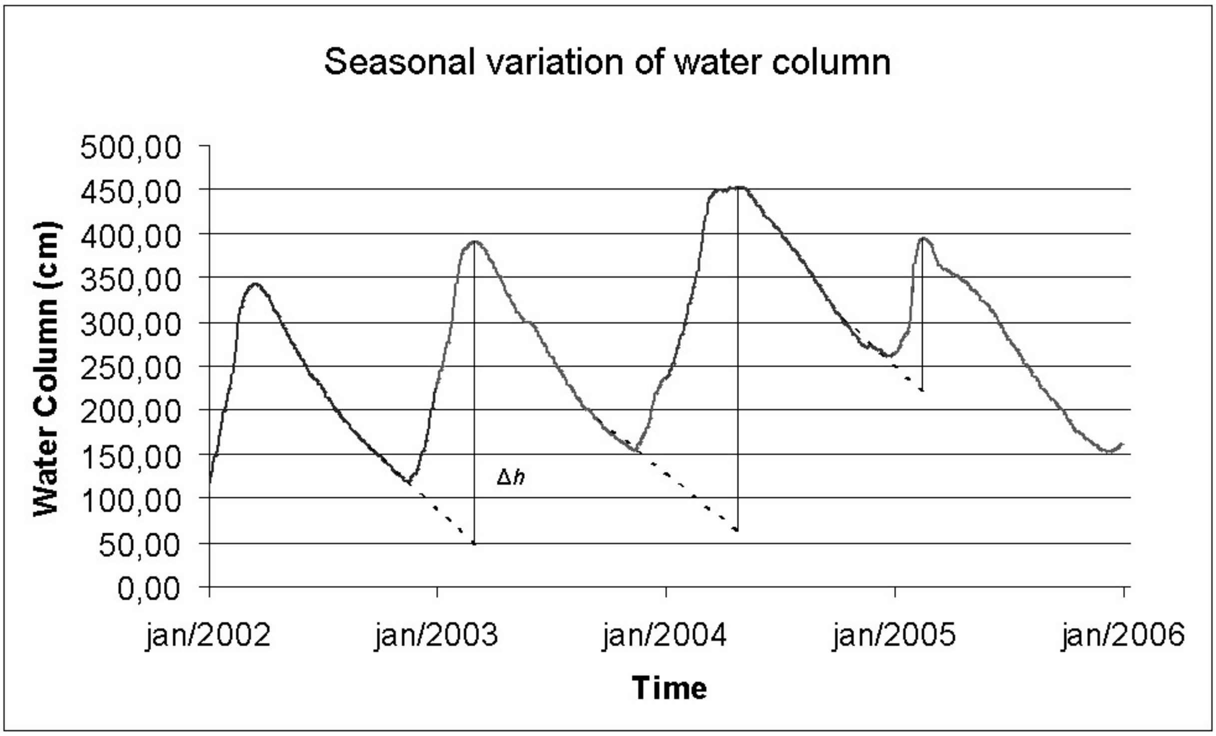


Fig. 1. Seasonal variation of water column recorded from monitoring well installed in the unconfined Rio Claro Formation Aquifer.

Table 1. Comparison of net recharge for three consecutive years.

Year	Δh (cm)	Δh x Specific Yield (cm)	Total Rainwater Precipitation - between maximum peaks - (cm)	% of precipitation
2003	313,19	53,24	146,26	36
2004	394,51	67,07	182,04	37
2005	176,03	29,93	123,11	24

Keywords: recharge; water level monitoring; unconfined aquifer; Cenozoic

Evaluating the Effects of Groundwater Extraction on a Brook Charr Population in Southern Ontario, Canada

[1]Richard S PALMER, [2] Rob G FRIZZELL, [3] Robert EJ LEECH

[1] 6400 Roberts St., Suite 490, Canada, e-mail: rpalmer@gartnerlee.com
[2] 300 Town Centre Boulevard, Suite 300, Canada, e-mail: rfrizzell@gartnerlee.com
[3] 300 Town Centre Boulevard, Suite 300, Canada, e-mail: bleech@gartnerlee.com

ABSTRACT

Water extraction has been a foremost environmental topic of discussion in Ontario for the past few years, involving government agencies, industries, universities and public interest groups. The primary issues being discussed are the potential effects of groundwater extraction on stream-resident fish and fish habitat. Depending on area geology, groundwater withdrawals may interact with surface water to change the quality and quantity of stream habitats, with the most obvious effects being on stream flow and temperature. Potential interactions between groundwater and surface water have become increasingly controversial, and government regulation now requires careful investigation by a multidisciplinary team of biologists, hydrogeologists and geologists. There is a constant tension between over zealous regulations and the scientific knowledge needed to meet the demands of proponents and the public.

New innovative approaches are required to assess the ecological impacts of groundwater extraction projects. This paper focuses on the combined use of traditional groundwater and fisheries field and analytical methods. Linkages between methodologies for drawing inferences about the effects of water-taking projects, with emphasis on the conduct of pumping tests in headwater streams regions to determine potential impacts on key salmonid fish species and their habitat are explored.

Findings to date demonstrate that careful watershed instrumentation and detailed documentation of baseline groundwater and stream flow conditions is critical. Also other physical parameters are important for monitoring the effects of groundwater extraction e.g., gradients, temperature. It is interesting to note that changes at the fish population level are more likely based on multiple habitat variables such as hydraulic gradient, temperature and channel width and not on a single variable (i.e., flow).

Keywords: water taking, ecosystems, hydrogeology, fish habitat, stream flow

Groundwater and surface water interactions at catchment scale in Radmilovac (Serbia)

[1]Sava PETKOVIC, [1]Enika GREGORIC, [1]Vera RAICEVIC, [1]Igor KLJUJEV, [2]Steve QUARRIE

[1]Faculty of Agriculture, University of Belgrade, Institute of Land Management, 11080 Belgrade-Zemun, Nemanjina 6, Serbia, e-mail: savap@agrifaculty.bg.ac.yu, enikag@agrifaculty.bg.ac.yu, verar@agrifaculty.bg.ac.yu, ikljujev@agrifaculty.bg.ac.yu
[2]Visiting Professor, Newcastle University, NE1 7RU-UK, e-mail: quarrie@agrifaculty.bg.ac.yu

ABSTRACT

The Western Balkan region in general is suffering from drought, especially during the main growing season. Consequently drought is a major limitation to agricultural production. To contribute to development in the Western Balkans by introducing strategic water management for drought alleviation and sustainable agricultural practices, four EU and three WB partners are taking part in the EU FP6 project WATERWEB (**Water** resource strategies and drought alleviation in **We**stern **B**alkan agriculture). A small river basin in an area with undulating hills near Belgrade, representative of typical Serbian small peri-urban catchments, was selected to characterise the dynamics of water quantity and quality.

The area of the catchment being studied is about 280 ha (2.8 km^2), including the Faculty of Agriculture experimental farm 'Radmilovac' (86 ha). Water levels were measured from August 2005 using automatic divers in two flumes installed in the stream about 850 m apart in the experimental farm, and flow discharges calculated using calibrated rating curves. Ground water levels were determined automatically using divers, and manually with a dipper in a series of five piezometers radiating from the lower flume on a ca. 2.5˚ slope. Measurements of meteorological parameters were recorded hourly using an automatic weather station. The numbers of total coliform and fecal coliform bacteria in monthly water samples collected during the growing season from the stream at the upstream and downstream flumes, and from selected piezometers were determined on MacConkey broth using the Most Probable Number method (MPN).

As there are waste water outfalls and several fresh water springs between the two flumes, significant differences of about 9-fold in flow discharges were found between the two flumes, despite the relatively short distance between them (equivalent to an additional 0.79 km^2 catchment area). However, even in the downstream part of the stream, the flow discharges were relatively small with a mean of 0.046 m^3/s over 16 months. Both flumes responded quickly to rainfall events (within 3-4 h), and the maximum discharge recorded at the lower flume during the period was 0.44 m^3/s, following 24 mm rainfall during the previous 5 h. The variations of the flow discharges in downstream flume are shown in Fig.1.

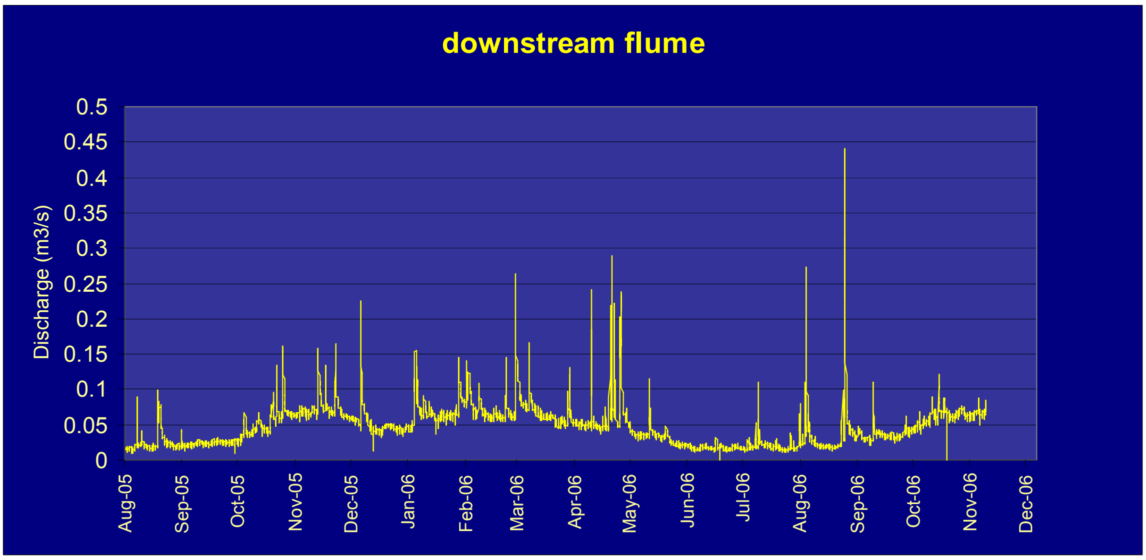


Fig.1. Flow discharges in downstream flume

Very small variations of groundwater level, of about 60 to 100 cm, are the consequence of soil characteristics. Due to very low permeability, the influence of precipitation on groundwater levels was small. On one side of the stream, the water table remained 2-5 m below the surface throughout the year. On the other, flatter side of the stream, the groundwater level was higher during the whole year, with a tendency to flood during the winter, indicating that an old field drainage system was probably no longer functioning. The fluctuations of groundwater level in one characteristic piezometer of the flatter side of the stream are shown in Fig.2.

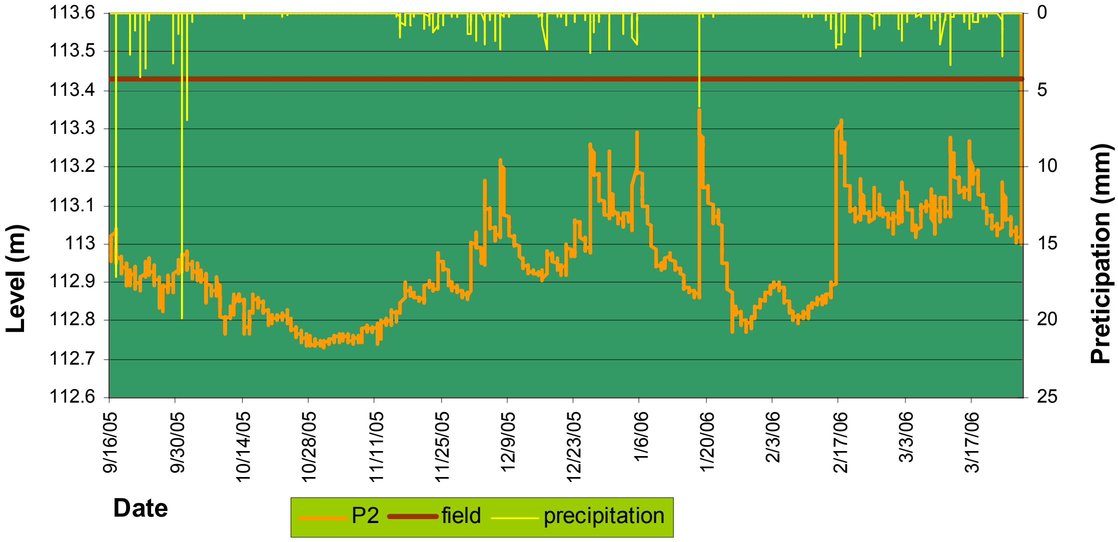


Fig 2. Groundwater variation

Measurements of the quality of water from the stream and groundwater clearly demonstrated that both the stream and groundwater were polluted during the year. Thus, total and fecal coliform bacteria in water from the downstream flume typically ranged around 4000 and 700/ml, respectively. Water sampled from the highest elevation piezometer, located in the downstream part of the stream, showed 1500 total coliform bacteria/ml on 28th August, 2006, and 450 fecal coliform bacteria/ml on 23rd July, 2006. However, groundwater on some occasions from some piezometers showed no contamination with coliform or fecal bacteria.

The very small quantities in the stream and poor quality of both surface water and groundwater would be limiting factors in their use for irrigation on the experimental farm.

Keywords: Groundwater, surface water, quantity, quality

Groundwater Recharge Sequence in Badain Jaran Desert as Related to Oasis Ecology: Reassessment of Environmental Tracers

[1, 2]Tianming HUANG, [1]Zhonghe PANG, [2]Jinzhu MA

[1] Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, 100029
[2] Key Laboratory of Western China's Environmental System, Lanzhou University, Lanzhou, 730000
Tel: +86-10-62008062; E-mail: z.pang@mail.iggcas.ac.cn

ABSTRACT

Groundwater recharge is the most important parameter for the assessment of ecological sustainability in arid and semi-arid regions. Environmental isotopes and other tracers are used widely to estimate fluxes and ages of groundwater in these regions. In recent years, Badain Jaran Desert, Northwest of China, has been a focus of international studies. Water chemistry and isotopes of groundwater and surface water samples, and soil moisture profiles in particular, have been applied in the studies. Based on these results, we have attempted to formulate an integrated 2D hydrogeological conceptual model for the groundwater system linking Badain Jaran Desert and Gurinai oasis. The dominant recharge to groundwater underneath the sand dunes is from neighbouring Yabulai mountains and the groundwater flow is towards northwest, to Gurinai. Groundwater emerges into lakes on its flowpath, where it evaporates, but also collects local precipitation in the mean time. The final discharge destination of the groundwater is the Gurinai oasis where it feeds a wetland ecosystem. Vertical recharge from local precipitation through the desert sand is measured to be minor (1.2mm/a). Groundwater in the desert was probably recharged from palaeo rivers sourced from Qilian Mt. and local palaeo-rainfall in the period between Pleistocene and early Holocene. During the mid to late Holocene, the groundwater has undergone evaporation and recharge. In the last two thousand years aridity has increased, the groundwater table in the desert has declined gradually.

Keywords: Groundwater Recharge; Badain Jaran Desert; Environmental Tracers; Ecosystem; Arid-semiarid regions

Groundwater – surface water interactions near a Chemical Complex (Estarreja, Portugal) – implications for groundwater quality

Carlos Miraldo ORDENS[(1)], M.T. CONDESSO DE MELO[(1, 2)], C. GRANGEIA[(1)] & M.A. Marques da Silva[(1)]

[(1)] Departamento de Geociências da Universidade de Aveiro, Aveiro, Portugal;
[(2)] Instituto Superior Técnico, Lisboa, Portugal.

ABSTRACT

A detailed study of groundwater quality was carried out around the Estarreja Chemical Complex (NW Portugal), which has a long history of soil, surface water and groundwater contamination. For decades, solid waste and liquid effluents were released and deposited from operating factories without any treatment to remove pollutants (heavy metals, metalloids, organic compounds, etc). Agriculture and livestock (cattle) activities around the Chemical Complex also contribute to further soil and groundwater contamination.

The Estarreja Chemical Complex is located in an area adjacent to a shallow coastal lagoon with both marine and estuarine waters ("Ria de Aveiro") and is regarded as one of the most important humid areas in Portugal. It also overlies a shallow unconfined or semi-confined, highly permeable groundwater body (Aveiro Quaternary Groundwater Body), which presents significant vulnerability to contamination episodes. Small streams and/or canals cross the region and are in hydraulic connection with both the groundwater body and the coastal lagoon (Fig. 1). Some of the southern streams discharge to a small lagoon or wetland area that almost dries during the summer months.

Recharge to the groundwater body is by direct infiltration of rainfall, seepage through the beds of streams and canals constructed in the stream valleys or downward percolation of applied irrigation water. The groundwater body discharges by leakage to streams and canals, pumpage from wells and boreholes, and evapotranspiration (evaporation plus transpiration by plants, especially crops during the growing season).

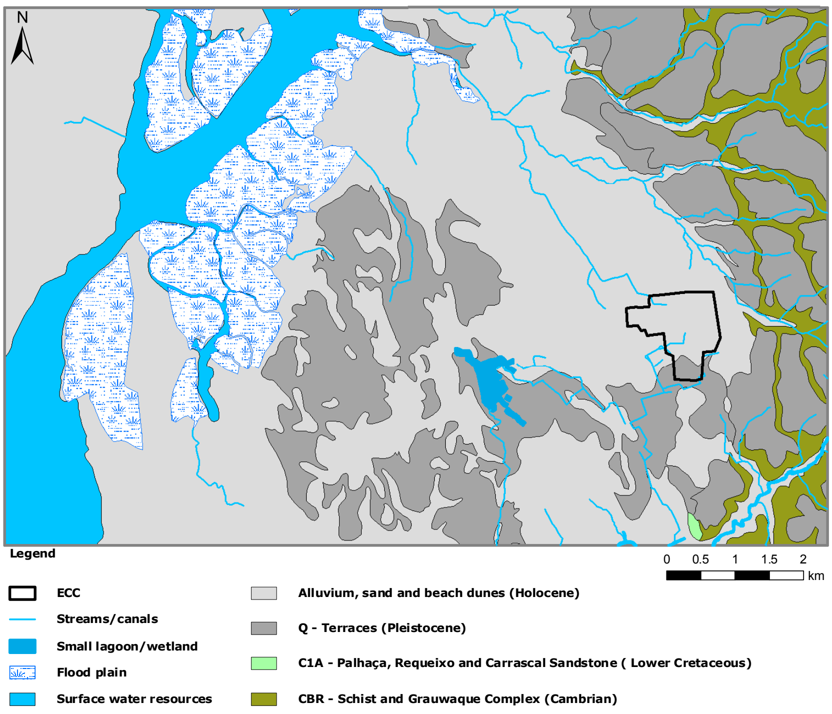


Fig. 1. Location map of the Estarreja Chemical Complex within the study area.

A three-dimensional lithostratigraphic model of the study region was prepared based on the information provided by 56 boreholes drilled for water supply or geological characterization. The analysis of the available geological information allowed for the definition of a sequence of seven layers of sand and mud, and to integrate them into two different hydrogeological units, characterizing their spatial and vertical distribution. The shallower hydrogeologic unit has an average thickness of 10 to 14 m and lies directly on the schist bedrock in the northeast part of the study area where the Estarreja Chemical Complex is located. The deeper hydrogeologic unit (8 to 20 m) and the semi-confining covering layer (10 to 20 m) are present in the rest of the study area, thickening towards the southwest part of the study area.

An electromagnetic survey using Geonics equipment EM34-3 was carried out to map the extension and the depth of the contaminant plume. Apparent electrical conductivity (ECa) proved to be a good indicator of groundwater contamination contributing to the definition of two contaminant plumes, one originated from a non-confined (unsealed) landfill near the Chemical Complex, and the other, shallower plume, originated from a pipeline that discharged liquid effluents into a stream that runs into the small lagoon/wetland in the study area, for several years. The background ECa level of the region was estimated to be less than 50 $\mu S\ cm^{-1}$, but in some of the contaminated areas the ECa reached 2 600 $\mu S\ m^{-1}$. The shape of the two contaminant plumes follows the groundwater flow pattern and is influenced by the seepage from the streams and/or canals. The small lagoon/wetland seems to have an attenuation effect on groundwater contamination, possibly due to degradation processes induced by organic matter.

The electromagnetic survey results were used to prepare a groundwater sampling campaign to characterize the groundwater contamination in the shallow aquifer. Thirty five groundwater samples were collected for major, minor and trace element analysis. Field parameter determination included the measurement of pH, redox potential, temperature, dissolved oxygen and electrical conductivity (EC). Some pre-selected samples were analysed for several organic compounds. The results show groundwater contamination levels that compare well with the electromagnetic survey data. In the contaminated sites, groundwater EC is over 20 000 $\mu S\ cm^{-1}$; pH presents either very low values (<5.0) or very high (>8.5); Cl reaches values of 10 300 $mg\ l^{-1}$; NO_3 and SO_4 are well above 100 and 2000 $mg\ l^{-1}$, respectively; and, a clear enrichment in most heavy metals is observed as induced by low pH values. Traces of organic compounds were detected in several boreholes (benzene, aniline, vinyl chloride, nitrobenzene, chlorobenzene and nitrophenols).

Both the geochemical and geophysical results confirm the vulnerability of the aquifer to contamination by the different human activities developed in the studied region. Surface water-groundwater interaction plays a double role in the study area, contributing to groundwater contamination through the seepage of contaminant effluents through the beds of streams and canals constructed in the stream valleys. On the other hand, groundwater contamination is attenuated when it discharges into wetlands.

Keywords: Estarreja Chemical Complex; Aveiro Quaternary groundwater body; vulnerability; electromagnetic survey; hydrogeochemistry; attenuation.

Groundwater-surface water interactions and their importance for ecosystem sustainability in wetlands (Ecowet Project)

[1,2]Maria Teresa CONDESSO DE MELO, [1]Clara SENA, [3]Ana Maria CASTILHO, [4]Tibor STIGTER, [3]João PRATAS, [3]Pedro DINIS, [3]Fernando FIGUEIREDO, Luís CHÍCHARO[4], Amélia CARVALHO DILL[4], Jacob KEIZER[5].

[1] ELMAS, Departamento de Geociências da Universidade de Aveiro, Aveiro, Portugal, e-mail: tmelo@ua.pt
[2] CVRM-Centro de Geosistemas, Instituto Superior Técnico, Lisboa, Portugal.
[3] Centro de Geociências, Departamento de Ciências da Terra, Universidade de Coimbra, Coimbra, Portugal
[4] IMAR–FCMA, Universidade do Algarve, Campus de Gambelas, Faro, Portugal.
[5] Centre for Environmental and Marine Studies, University of Aveiro, Portugal

ABSTRACT

Wetlands are among the most biologically productive natural ecosystems in the world because of the diversity of species they support. Along the coastline of Portugal there are several wetland areas that are valuable not only for their beauty, but also for critically important functions they perform in our environment.

Wetlands provide water quality improvement, protection of groundwater supplies, flood protection, shoreline erosion control, food and habitat for fish and wildlife, and still opportunities for recreation, education, and research. Because of the capacity of their water retention associated with their abundant vegetation, wetlands serve as natural water storage areas.

Groundwater and the surface water of wetlands interact in various ways and can influence the characteristics of a wetland. Sometimes groundwater can be the major source of water to a wetland. Likewise, wetlands can be a major source of recharge water to the groundwater system. The influence of these interactions on wetlands varies according to natural factors such as topography, water table levels and climate as well as human influence such as groundwater pumping, artificial drainage to and from wetlands, and rising water tables.

Wetland values are affected by the quality of the groundwater discharging into them and groundwater is likewise affected by the water quality that enters it from wetlands. Management of wetlands, therefore, involves consideration of both the surface and groundwater systems.

The EcOwEt project focus on the importance of surface-groundwater interactions for ecosystem sustainability in three wetland areas of major ecological and economical significance - the ‘Ria de Aveiro’ lagoon and the S. Jacinto dunes natural reserve (Aveiro), the ‘Pateira de Fermentelos’ lagoon (Águeda), the Quiaios lagoons (Figueira da Foz) and the Guadiana estuarine (Castro Marim).

The overall research is planned with the principal purpose of bringing together expert knowledge on the geology, hydrology, geophysics, ecology, hydrochemistry and groundwater flow at the interface that separates surface and groundwater in order to derive a coherent and broad understanding of the hydrologic fluxes and to assess the cumulative influence of hydrologic and chemical interactions between the surface and groundwater on the wetland geochemical mass balance, transport of contaminants, water quality and ecology.

The fundamental processes are usually difficult to study because hydraulic driving forces and resistances change sharply across the surface and groundwater interface, and because hydrologic fluxes are spatially variable and difficult to observe directly. The EcOwEt project will integrate field and modelling methods to develop predictable capabilities about water flow and water quality in wetlands.

The results of the project will be available to contribute for a sustainable management of wetlands in Portugal.

Keywords: wetlands, groundwater-surface water interaction, Portugal

Hydraulic interactions between stream and aquifer at a Mangyeong river floodplain, Korea

[1]Kyoochul HA, [2]Dong-Chan KOH

[1]Groundwater and Geothermal Division, Korea Institute of Geoscience and Mineral Resources, 30 Gajeong-dong Yuseong-gu Daejeon, Korea, e-mail: hasife@kigam.re.kr
[2] Groundwater and Geothermal Division, Institute of Geoscience and Mineral Resources, 30 Gajeong-dong Yuseong-gu Daejeon, Korea, e-mail: kao@kigam.re.kr

ABSTRACT

The hydraulic interaction between streams and adjacent aquifers is an important issue for water resource management where streamflow depletion or water quality is concerned. This study presents the analysis of the hydraulic interaction between aquifer and river. The site is a floodplain of the Mangyeong river located in the western part of Korean peninsula, where various agricultural activities related with rice farming and greenhouse cultivation for pumpkins are practiced. Sand and silt layer (SS), gravel and sand layer (GS), and residual weathered soil layer (WZ) are distributed in ascending order from land surface. Most of the developed wells yielded groundwater from the gravel and sand layer that can be the main aquifer in the site. The three hydrogeologic layers have different hydraulic conductivities and storage coefficients and their ranges are very wide.

The groundwater levels and river stages were monitored using automatic water level devices. Since periodic components by the floodgate operations and tidal effects are dominant in the study site, they are shown in the river stage records, and the river stages have just a weak correlation with rainfall. From the results of cross-correlation analysis, the groundwater level fluctuations near the river are closely related to river stages, but those in distant wells did not mimic the river stage fluctuations. The response time becomes longer with the increasing distance from the river. The transfer time between each layer could not be deduced from the correlation analysis.

River discharge measurements were performed to assess groundwater discharge to river, or river water seepage into the surrounding aquifer. The groundwater does not always discharge into the river. The groundwater discharge on one side aquifer ranged from -1.01 to 2.03 m^3/s during the discharge measurement period.

The river water is characterized by high concentration of Cl^-, compared with the groundwater. HCO_3^- is dominant in the groundwater. The Iksancheon is highly contaminated with sewage or waste water. Less permeable silt layer plays an important role in discriminating the groundwater quality in the site. The groundwater in the site is highly contaminated by Fe^{2+} and Mn^{2+}. In particular, Fe^{2+} contamination is very serious. The high concentrations of Fe^{2+} and Mn^{2+} in the site reflect that the groundwater environment is ideal for Fe^{2+} and Mn^{2+} elution which is a redox condition.

Aquifer response, discharge and bank storage induced by river stage fluctuation were analyzed. A convolution equation was developed to analyze the aquifer response, discharge, and bank storage based on the river stage fluctuation. River stages were generated to describe flood peak, asymmetry, and duration. The simulation results suggest that the geometry of flood hydrograph can play an important role in affecting the discharge and bank storage. The presented model was applied to the field data, where the site is a floodplain aquifer of the Mangyeong river. Aquifer responses for the various flood duration and flood peak were observed in the site, which matched well with the simulated results. A model parameter, the riverbank leakance was determined from calibration with the simulated and observed groundwater levels. After determination of relevant parameters, the discharge and bank storage can be calculated.

A conceptual model can be established to explain the hydraulic interaction between the river and the alluvial aquifer. Though groundwater generally flows towards the river, known as a gaining characteristic, abrupt increase or decrease of river stages by rainfall or flood gate operation related to the tide can change the groundwater flow pattern. In the vicinity of the river, the groundwater is frequently mixed with the river water. In particular, there is a well showing a high connectivity to the river, indicating a high homogeneous feature in the site.

Keywords: aquifer diffusivity, river-aquifer interaction, flood wave response, Mangyeong river, riverbank leakance.

Hydrogeochemical Characterisation of the wetlands of Punta Entinas and Salinas de Cerrillos and implementation of the Water Framework Directive

F. SÁNCHEZ MARTOS, L. MOLINA SÁNCHEZ and J. GISBERT

Dpto. de Hidrogeología y Química Analítica, Universidad de Almería. Campus Universitario, 04120 Almería. España.
fmartos@ual.es, lmolina@ual.es y jgisbert@ual.es

ABSTRACT

Introduction

The Water Framework Directive (WFD) considers it necessary to define terrestrial aquatic ecosystems that are directly related to groundwaters and even to link the quality objectives of the groundwater bodies to the need to maintain the environmental demands of the terrestrial ecosystems. This requires an understanding of wetlands that are directly associated with groundwater flows.
Coastal wetlands in the Mediterranean area are an example of this situation, since their extent and development are not exclusively dependent on marine influence. In these cases, there is a need to understand the interdependence between the terrestrial ecosystems and the groundwater. This is especially true for coastal areas with a semiarid climate, where surface inflows are very limited and where a marked marine influence considerably complicates the analysis of the influence of the groundwater. The objective of this study is to determine the degree of dependence between the surface water bodies and the groundwater flows and to analyse how difficult it is to define the reference conditions demanded by the WFD. The study area comprises two coastal wetlands (Humedales de Punta Entinas and the Salinas de Cerrillos), located on the coast of the Campo de Dalias in southeastern Spain (Fig. 1). Surrounding the wetland are outcrops of calcarenites, which are locally covered by marine terraces and some marly outcrops.

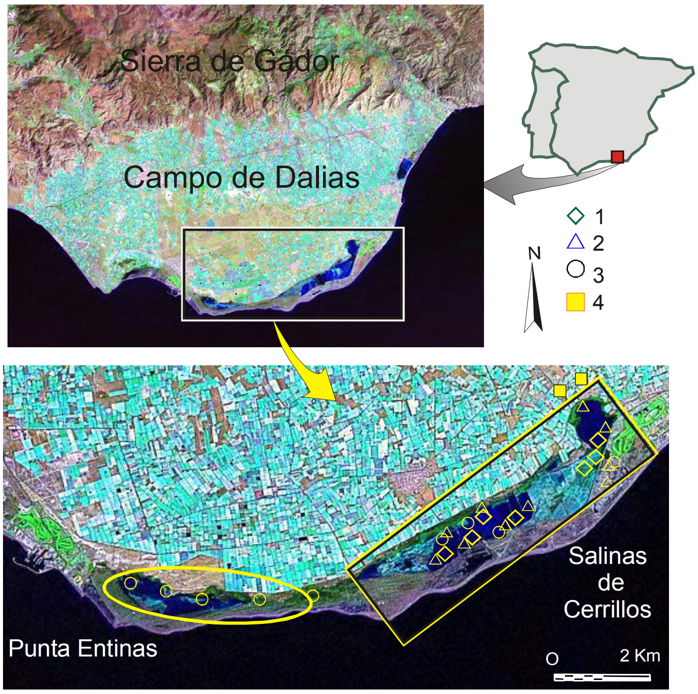


Fig. 1. Location of the study area and of the sampling points for the three data series used. Surface waters. (1: 1985; 2: 1996; 3: 2005). Groundwater (4).

Results and discussion

The data used in this study were collected over three periods in 1985, 1994 and 2005. Figure 2 uses box plots to show the variability in ion content of the surface water in the wetlands. These have a sodium chloride facies as a consequence of the environment in which they formed.

The relative distribution of SO_4^{2-} and Cl^- (Fig. 3) indicates a general saline enrichment of the surface waters. The most saline waters are found in the Salinas de Cerrillos, where ion content exceeds that of seawater. The points are scattered, since mineralisation of the water is influenced by saline concentration caused by direct evaporation of seawater, and by the presence of salts in the substrate of the pools. In water samples taken in 1994 in the eastern part of the Salinas de Cerrillos, the SO_4^{2-}/Cl^- ratio is greater than for the other points, indicating that there must be an input of SO_4. The most saline points are scattered and this may be explained by dissolution of chlorides in the substrate of other pools since, in the summer months, a complete evaporation is achieved and $MgSO_4$ or $MgCl_2$ salts are precipitated, which are rich in Cl^- and Mg^{2+} and highly soluble. These salts, being more soluble, dissolve during the wet season, without a renewed dissolution of the sulphates, so that the majority of the salts in the final brine are Mg^{2+} and Cl^-, at elevated concentrations (160 mS/cm).

The chemical variability of these waters is also due to certain sampling points whose salinity is less than that of seawater. These are found in an intermediate position between the sea and the aquifer that surrounds the southern part of the wetlands. This influence of groundwater can also be detected through a consideration of the Cl^- and Br^- ion content (see Fig. 3). The sampling points showing a groundwater influence are found in an intermediate position between the groundwater data and seawater.

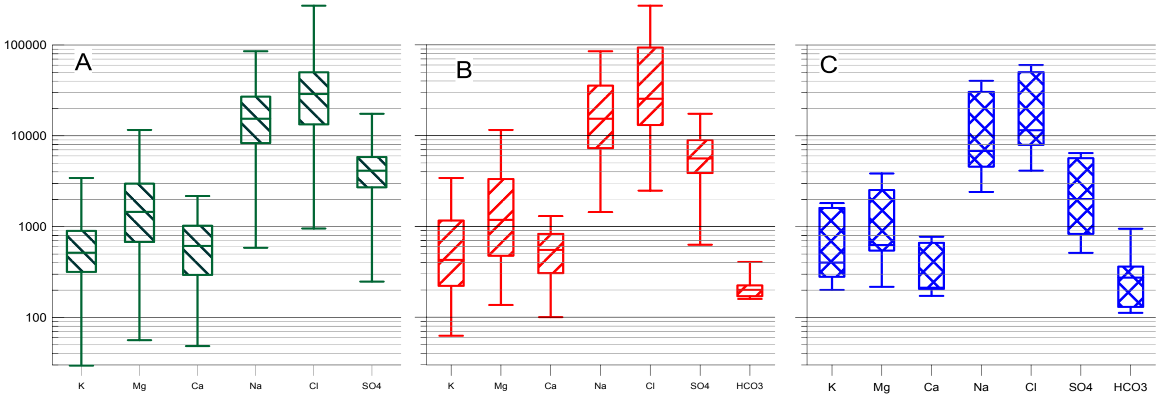


Fig. 2. Box plot of the data used in this study, grouped by date: A: 1985; B:1994 and C: 2005. Range is indicated by a line, whilst the 25 % and 75 % percentiles and mean lie in the box.

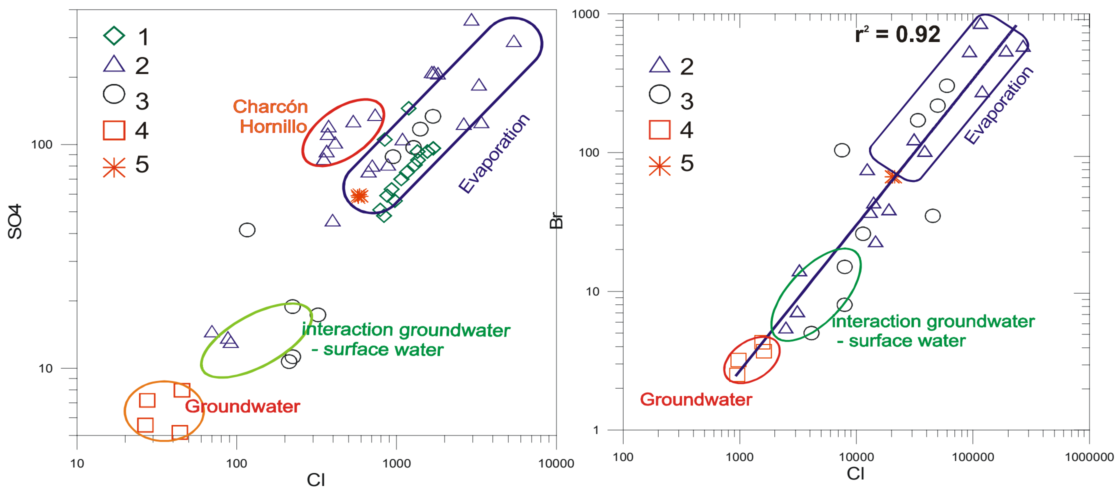


Fig. 3. Relationship between SO_4^{2-} and Cl^-, (meq/l) and between Cl^- and Br^- ($mg \cdot L^{-1}$). Surface water (1: Dronkert, 1985; 2: Sánchez Martos and Molina, 1994; 3: September 2005); 4: groundwater; 5: seawater.

Final Considerations

By means of hydrogeochemical methodology, the principal processes that determine the diversity of waters occurring in the Punta Entinas wetlands and the Cerrillos saltpans have been identified. The salinity of the waters is related to the different salts occurring in the substrate of each of the pools as well as by the influence of groundwater in the case of the eastern part of the Punta Entinas. In short, the use of hydrogeochemical tools provides a useful and rapid method for establishing an initial reference condition, as required by the WFD. In turn, it is also a precursor to more precise studies, especially for areas where there is no piezometric monitoring to supply historic data on water levels in the wetlands and the associated aquifers.

Keywords: Brines, groundwater, evaporites, wetlands, WFD.

Hydrograph Separation Using a Mixing Model during Two Consecutive Rainfall Events

[1] Sung-Hyeon Cho, [2] Moo-Young Song

[1] Korea Institute of Geoscience & Mineral Resources, Daejeon 305-350, South Korea,
e-mail: sh-cho @daum.net
[2] Dept. of Geology & Earth Environmental Sciences, Chungnam national university, Daejeon 305-764, South Korea, e-mail: mysong@cnu.ac.kr

ABSTRACT

This study aims to separate baseflow from a hydrograph and seeks to calculate the contribution of the baseflow to a stream of two consecutive rainfall events. During no excess rainfall period, the channel discharge is composed entirely of groundwater. The chemical concentration in the stream water can be regarded as being in equilibrium with that in the groundwater. After two successive rainfall events, the stream discharge was mixed with the baseflow and two rainfall components. A new mixing model was developed for the separation and was compared with two-component model (Fig.1). The separations were performed using environmental tracers ($\delta^{18}O$, Cl^-) at a small catchment in Daejeon, South Korea (Fig. 2). The new model indicated the effect of the overlay and lag of new components on hydrograph of consecutive rainfall events. The separation results are more or less different from the tracers and application models, which is caused by property of each tracer and limitation of the binary model (Fig. 3).

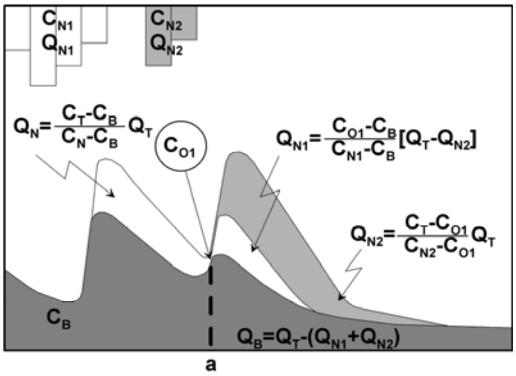


Fig. 1 The conceptual mixing model to separate the baseflow from hydrograph during two consecutive rainfall events.

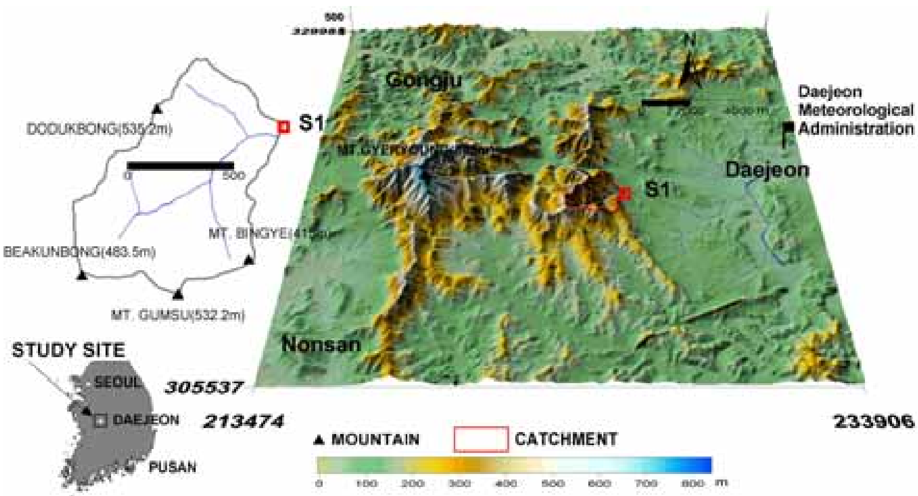
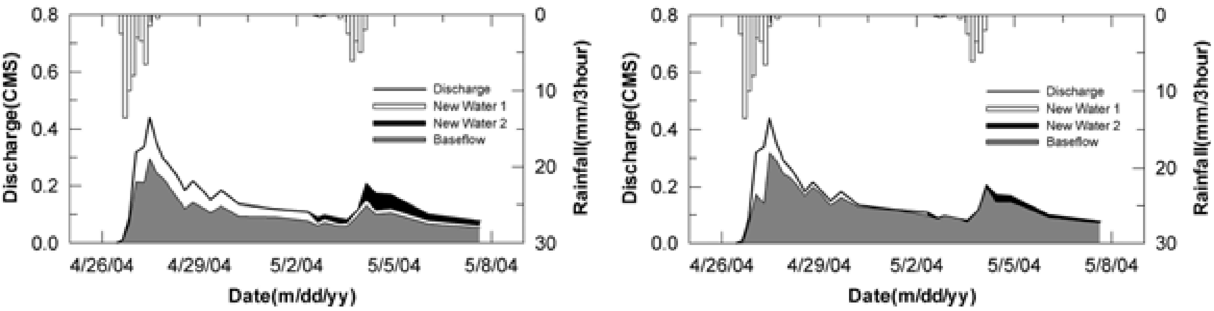


Fig. 2 Location show the study site of the map.



(a) (b)

Fig. 3. Results are applied the new mixing model of SCTCE, when tracers are used $C1^-$ (a) and $\delta^{18}O$ (b).

Keywords: baseflow, consecutive rainfall, tracer

Hydrograph separations based on the catchment areas.

[1] MinJoe Cho, [2] Sung-Hyeon Cho, [3] Moo Young Song

[1] Korea Institute of Geoscience & Mineral Resources, Daejeon 305-350, South Korea,
e-mail: minjoe@kigam.re.kr
[2] Korea Institute of Geoscience & Mineral Resources, Daejeon 305-350, South Korea,
e-mail: sh-cho@daum.net
[3] Dept. of Geology & Earth Environmental Sciences, Chungnam national university, Daejeon 305-764, South Korea, e-mail: mysong@cnu.ac.kr

ABSTRACT

This study is a comparison of the baseflow rates in three small catchments in Daejeon, South Korea. The catchments adjoin and the area of one is approximately three and six times as large as the two others, respectively. Using Cl^- as a conservative tracer, two-component hydrograph separations were performed during a period of two rainfall events. The required data were obtained by monitoring of the surface water table along with the discharge rate of the stream. The Cl^- concentrations in the rainfall and surface water were measured and recorded. Hydrograph separation, a mixing model using chemical tracers, was applied to the chemical hydrograph separation technique. These results found that the baseflow rates are 74.7%, 53.4% and 68.0% in order of smaller catchments. The reasons for the differences in the baseflow rates appear to be the area and slope of the catchments. The greater the area and slope of the catchments, the greater the amount of rainfall that collects in the channel. In addition, a greater relative amount of collected rainfall corresponded to a lower baseflow rate.

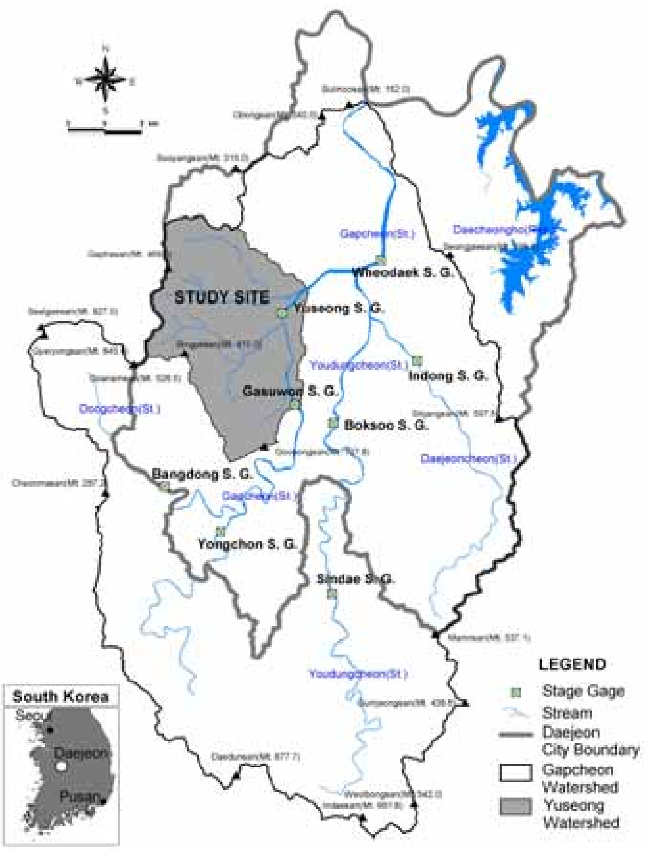


Fig. 1 Location map of the study site

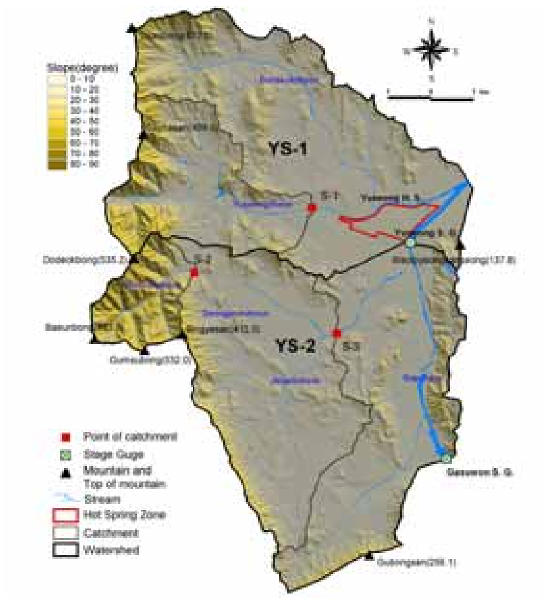


Fig. 2 Map of the study site showing catchments, s tream stages, outlet points and slope.

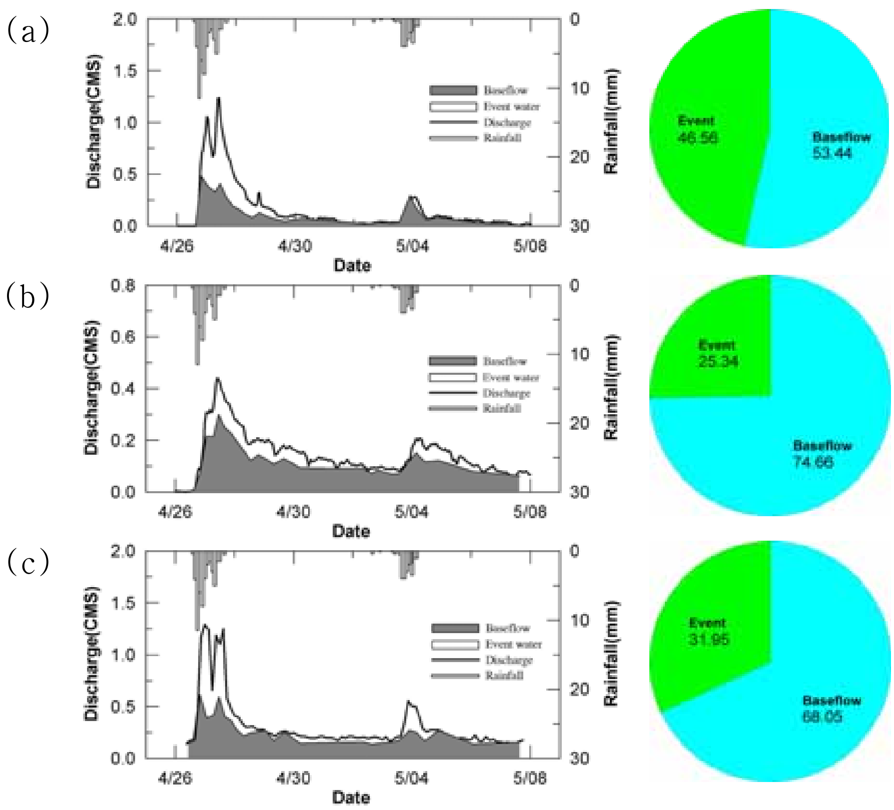


Fig. 3 Comparison of the results of hydrograph separation by two-component mixing models when Cl^- tracer is used. The numbers of the pie-diagrams are percentages to total discharge at the S1 (a), S2 (b) and S3 (c) catchment.

Keywords: baseflow, mixing model, chemical hydrograph separation technique

Hydrological characteristics of a semi-arid playa-lake complex and related detritic aquifer

Authors:
Miguel Rodríguez-Rodríguez*
University Pablo de Olavide (Seville)
Francisco Moral-Martos
University Pablo de Olavide (Seville)
José Benavente Herrera
University of Granada

**Corresponding autor:*
Miguel Rodríguez-Rodríguez (mrodrod@upo.es)*
University Pablo de Olavide. Carretera de Utrera, Km 1. Seville 41013, Spain.

ABSTRACT

The hydrogeological unit Osuna – La Lantejuela (Seville, Spain) comprises detritic materials of Pliocene and Quaternary age. The northern sector contains the endorheic complex of La Lantejuela, which consists of eight playa-lakes and other smaller wetlands. The main water inputs to this complex are surface run-off from the Salado de Osuna River and groundwater contributions from the aquifer. At present, the only well conserved playa-lakes are those of Calderón and La Ballestera, which have been declared Natural Reserves. The others are only flooded sporadically, due to the channelling of the streams, drainage works and groundwater pumping. The whole area lies within the Olistostromic Unit of the Betic Cordillera, and presents a clayey, evaporitic nature. The aims of this work are to describe the hydrological alterations made in the detritic aquifer Osuna-La Lantejuela and to establish the hydrological relations between this aquifer and La Lantejuela playa-lakes, influenced and modified by the above mentioned anthropogenic alterations.

Key words: wetland hydrology, detritic aquifer, water balance, hydrochemistry.

Impact of gravel extraction activities on hyporheic processes in a pre-alpine turbulent river (W Slovenia)

Nataša MORI, Anton BRANCELJ, Tatjana SIMČIČ

Večna pot 111, Ljubljana, Slovenia, e-mail: natasa.mori@nib.si

ABSTRACT

The structural and functional characteristics of the hyporheic invetebrate community from the Bača River (W Slovenia) were studied together with its response to natural variation in environmental factors and to gravel extraction activities carried out in this river channel. Sampling was carried out from June 2004 to May 2005. Two sampling sites were selected: the reference site, where hyporheic invertebrate community was observed in relation to natural variation of environmental factors, and the impacted site where gravel extraction was carried out. Two different habitat types were distinguished at both sites, river bed sediments and gravel bars. Physical and chemical parameters, together with the amount of loosely associated organic matter (LOM) were measured through the time at both sites and both habitat types. Respiratory electron transport system (ETS) activity and oxygen consumption in the interstitial water, and in the fine (i.e. silt) and coarse (sand) sediment fraction from the hyporheic zone were measured in order to estimate the intensity of potential and actual mineralization through microbial communities. Discharge of the Bača River varied greatly over a one year period. Mean daily discharge ranged from 108 m^3s^{-1} in October 2004 to 1.6 m^3s^{-1} in March 2005. Streambed sediments at both sites were composed of heterogeneous mixture of boulders, cobbles, pebbles, gravel, sand and silt. The mean values (seven dates) of physical and chemical parameters measured at each site are given in Table 1. The temperature of hyporheic water was on average higher than that of surface water at both sampling sites. Dissolved oxygen was close to 100 % saturation in surface water, while saturation in hyporheic water from the river bed was around 90 % and from gravel bars around 80 %.

Table 1: Average values (± SD, n = 7 dates) of physical and chemical parameters measured in the hyporheic zone and surface water of the Bača River (W Slovenia).

	Reference site - site 1			Impacted site - site 2		
	surface water	river bed	gravel bars	surface water	river bed	gravel bars
T (ºC)	9.2 ± 4.1	9.7 ± 4.3	10.4 ± 4.6	10.5 ± 5.0	10.8 ± 4.9	11.0 ± 5.8
dissolved oxygen (%)	106 ± 6	90 ± 13	82 ± 12	100 ± 4	94 ± 7	82 ± 15
pH	8.3 ± 0.1	8.1 ± 0.1	8.1 ± 0.1	8.3 ± 0.1	8.2 ± 0.1	8.1 ± 0.1
specific conductance (µS cm-1)	273 ± 7	275 ± 12	281 ± 13	273 ± 8	271 ± 9	280 ± 16
Ca^{2+} (mg L^{-1})	45.9 ± 2.6	45.4 ± 2.9	46.7 ± 4.8	44.7 ± 2.5	45.7 ± 3.4	43.3 ± 13.7
Mg^{2+} (mg L^{-1})	7.1 ± 0.7	6.8 ± 0.7	7.1 ± 0.7	6.9 ± 0.6	7.1 ± 0.7	7.4 ± 0.9
Na^{+} (mg L^{-1})	2.0 ± 0.4	1.9 ± 0.4	1.9 ± 0.3	1.5 ± 0.3	2.3 ± 0.4	2.1 ± 0.3
NO_3^- (mg L^{-1})	4.3 ± 0.6	4.1 ± 0.2	4.1 ± 0.5	3.9 ± 0.2	4.0 ± 0.6	4.2 ± 0.4
LOM (g 10 L^{-1})		0. 3 ± 0.3	0.5 ± 0.4		0.4 ± 0.6	0.4 ± 0.3

ETS activity and respiration rates of all fractions did not differ significantly between river bed and gravel bars. ETS activity and oxygen consumption of biofilm attached to 1 g of the silt were higher compare to that attached to the same mass of the sand. Significant correlation between ETS activity and oxygen consumption indicated that ETS activity could be a good indicator of intensity of bioactivity of hyporheic sediments. A total of 75 invetebrate taxa were identified, 40 of which belonged to the occasional hyporheos, 26 to the permanent hyporheos and 9 were stygobites. At both sites, fauna was dominated numerically by juveniles of Cyclopoida and early stages of Leuctra larvae (Plecoptera). Chironomidae (Diptera) contributed significantly to the overall density in the river bed of reference site and Baetoidea (Baetidae and Siphlonuridae; Ephemeroptera) to the total density of impacted site.

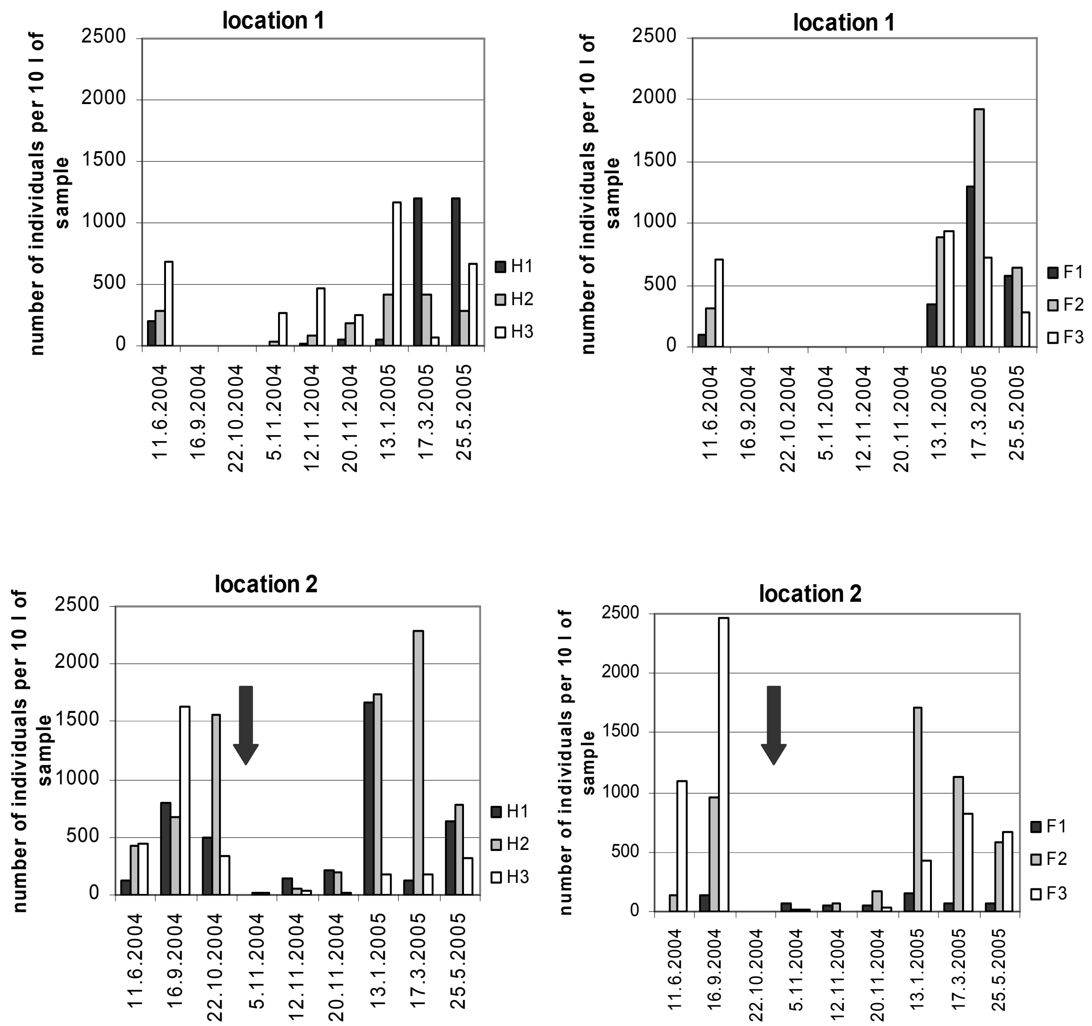


Fig. 1. Fluctuations of hyporheic invertebrate densities during one year period at two sampling sites (reference and impacted). Left figures – river bed sediments; right figures - gravel bars. Arrows indicate a period of gravel extraction.

Fluctuations of invertebrate densities were great at spatial and temporal scale (Fig.1). At impacted site a great decrease in density is present immediately after the gravel extraction. However, the recovery is relatively fast (two and a half months). At reference site, the decline in density appeared as well. This can be explained by high flow events which caused washing out the hyporheic fauna. The results obtained indicate that discharge has the major role in shaping hyporheic invertebrate community in the Bača River, followed by temperature, which influences the life cycles, reproduction time and rates of species and productivity of the community. Removal of sediments due to gravel extraction leads to the impoverishment of the structural and functional characteristics of the hyporheic community. Despite the fact that recovery is relatively fast, the cautious approach to the use of river sediments is recommended. Especially the frequency of extractions must be well planned and based on preliminary studies of hyporheic community characteristics.

Keywords: hyporheic zone, invertebrates, respiration, anthropogenic impacts

Influence of Land Use Change and Regional Hydrogeology on Groundwater Flows in Indochina.

[1]Edward B WRONSKI,

[1] Wronski @ Associates, Vientiane, Lao PDR, e-mail: edwronski@yahoo.com

ABSTRACT

Despite the rainfall occurring mainly in the summer in Indochina, groundwater provides significant and economically valuable dry season river flows. For example the summer base flow of the Mekong River from areas south of Chiang Saen in Southern China, constitute about 15-20% of the annual water flow. In other rivers it can amount to up to 25% of the annual flow.

The dry season flow is important for agricultural development in that it provides an irrigation water supply early in the dry season for a second crop of rice. It also can reduce the capacity and sometimes the area of reservoirs required for hydroelectric generation. Relative to the benefits from such projects, there can be significant savings in both construction and social costs from smaller reservoirs.

Without soils and aquifers with appropriate hydraulic properties, most of the wet season rainfall excluding evaporation, would run off. Thus these assets of the region provide an element of self regulation in the hydraulic system that drains Indochina. Land management practices can also influence recharge and subsequent dry season flows, but determining what these influences are by monitoring river flows can be confounded by the effects of climatic change and groundwater inflows into the river system..

An analysis has been made of the surface and ground water flow regimes of selected rivers in Indochina over the last half century, relative to the rainfall. It is concluded that the transmissivity of aquifers involved in generating the observed flow regime have been significantly enhanced through the dissolution of limestone and fracturing. Moreover there have been some land use changes so large as to effectively eliminate late season dry season flows. These observations point he way to beneficial management practices relating to the land and water resources of the region and the design of new infrastructure.

Keywords: Hydrogeology, land-use, groundwater, reservoirs

Influence of water residence time on zooplankton depth distribution in a pseudokarstic alpine lake

[1] Ulrike OBERTEGGER, [1] Giovanna FLAIM, [2] Andrea BORSATO

[1] IASMA Research Center – Natural Resources Department, Via E. Mach, I-38010 San Michele all'Adige, Italy; obertegger@gmx.net; flaim@ismaa.it
[2] Museo Tridentino di Scienze Naturali, Via Calepina 14, I-38100 Trento, Italy; borsato@mtsn.tn.it

ABSTRACT

Hydrology has seldom been recognised as an important structuring force for plankton in lakes. However, our study site, Lake Tovel located at 1177 m a.s.l. in the Brenta Dolomites (northern Italy), provides an ideal natural laboratory for the study of interactions between hydrology and plankton.

The hydrogeological situation of this lake ($A = 38$ ha, $V = 7.4 \cdot 10^6$ m^3, $z_{max} = 39$ m) is very complex. A deep karstic drainage is determined by the presence of an aquifer in porous carbonate debris blocks into which the main tributary of the lake disappears about 1 km upstream of the lake. The total lake inflow was calculated from direct gauging of the tributaries, coupled with piezometric measurements inside the porous aquifer, and tracing test techniques that permitted estimating the permeability coefficient of the aquifer. The aquifer directly fed the lake (81% of the total inflow) through several perilacustrine springs, and the lake level followed the springs' level fluctuations. The particular hydrogeological setting also controlled the temperature of the inflow water, and was found to be constant at about 5.4 ± 0.1 °C throughout the year. Even after strong rainfalls, turbidity and nutrient loads were negligible, because both were buffered and modulated by passage through the carbonate aquifer. In spring, the lake is subject to large water level fluctuations of up to 6 m due to downing in porous debris blocks.

All of these peculiarities influence lake biology. In contrast to most temperate lakes, in Lake Tovel rotifers numerically dominated the zooplankton throughout the year, while crustaceans (*Bosmina*, *Daphnia*, and *Cyclops*) were less abundant. In order to understand this relationship better, a 5-year data set (2002-2006) of zooplankton depth distribution was related to water residence time (Fig. 1).

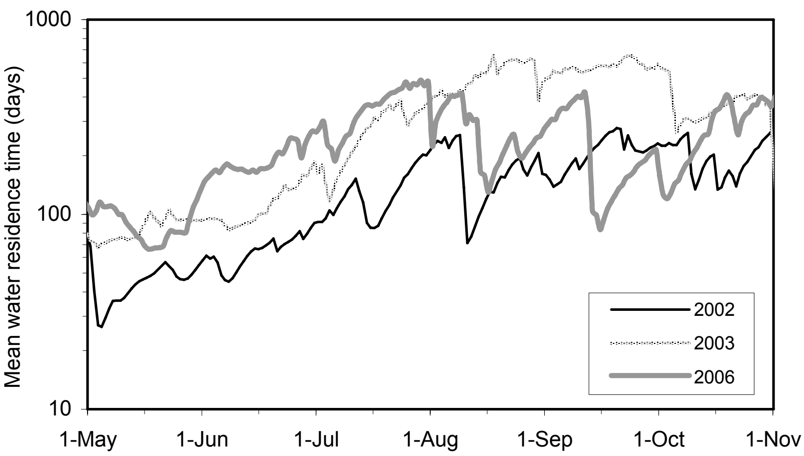


Fig. 1. Mean residence time (May-November) for three distinctive seasons 2002, 2003, 2006

Water inflow was transformed to mean water residence time (WRT) as a proxy for the mechanical force of water on zooplankton. Zooplankton positions itself in the water column to maximise growth, but is constrained by its ability to adapt to changing environmental conditions, such as temperature, anoxia, predation pressure, food availability, and hydrology. A multivariate analysis was performed in order to relate zooplankton depth distribution to WRT, temperature, oxygen, and algal biomass. Zooplankton depth distribution showed a spatial separation, with crustaceans preferring the upper water layers. A principal component analysis (Fig. 2) followed by a redundancy analysis supported our hypothesis that rotifers and crustaceans reacted differently to WRT because crustaceans are positively correlated to WRT while rotifers are negatively correlated. According to us, this contrasting behaviour depended on life cycle length, being about 1 week for rotifers and over 3 weeks for crustaceans. Crustaceans' longer life cycle might be hindered by washing out effects during low WRT, while rotifers' shorter generation time could favour their colonisation within a rapidly changing environment.

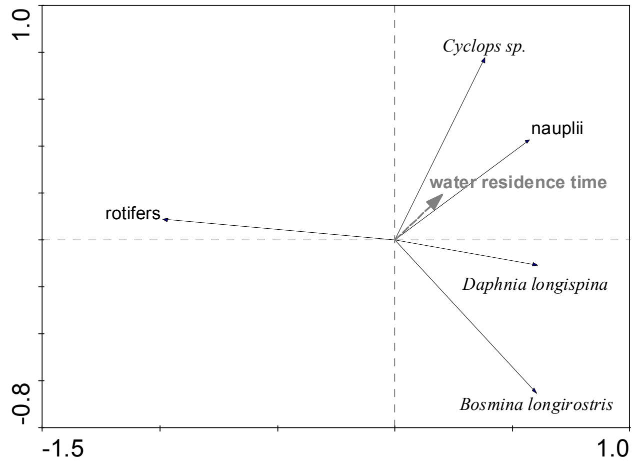


Fig. 2 Principal Component Analysis of zooplankton abundance with WRT inserted as the environmental variable.

The study revealed that water residence time values can have a substantial influence on zooplankton depth distribution. It is concluded that the importance of hydrology may have been underestimated in lakes when explaining zooplankton depth distribution, because studies usually focus on other factors such as temperature, anoxia, predation, or food limitation.

Keywords: hydrology, rotifers, crustaceans, competition, habitat preference.

Interaction between groundwater and surface water with rock in arid environments, case study Cuatro Cienegas Valley, Coahuila, México

[1]Eloisa DOMÍNGUEZ-MARIANI, [2]Oscar ESCOLERO-FUENTES, [3]Pedro MORALES [4]Pedro SANTILLÁN

[1] Instituto Potosino de Investigación Científica y Tecnológica A.C, Camino a la Presa San José 2055, Col. Lomas 4ª Sección, C.P. 78216, San Luis Potosí, SLP, México, edominguez@ipicyt.edu.mx
[2] Departamento de Geología Regional, Instituto de Geología, Universidad Nacional Autónoma de México. Ciudad Universitaria. 04510 México, D.F., escolero@geologia.unam.mx
[3] Departamento de Geoquímica, Instituto de Geología, Universidad Nacional Autónoma de México, Ciudad Universitaria. 04510 México, D.F., mopuente@servidor.unam.mx
[4] Posgrado de Ciencias de la Tierra, Instituto de Geología, Universidad Nacional Autónoma de México, Ciudad Universitaria, C.P. 04510, México, D.F., pesantillan@yahoo.com.mx

ABSTRACT

Cuatro Ciénegas Valley is located in the northern part of Mexico (Fig. 1). It is characterised by the existence of a large number of ponds of salty water with endemic fauna and flora contrasting with the arid landscape. This zone has been studied with diverse methodologies through different disciplines for example: microbiology, ecology, ictiology, hydrogeology, structural geology, speleology. The results show that a particular balance exists, in the valley, between water (surface water and groundwater) and the rocks, which are very soluble, such as limestone and gypsum.

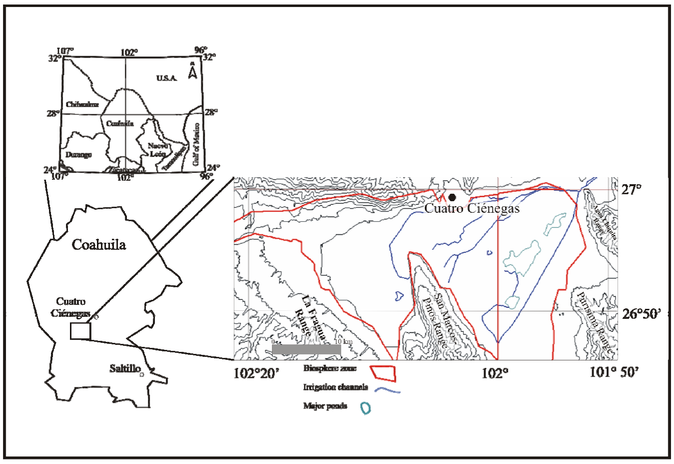


Fig. 1. Locality map of cuatro Ciénegas Valley, Coahuila, Mexico

Groundwater levels varies between around one hundred meters in deep wells and a few meters in shallow wells (*norias*). Both types of wells present water from diverse origins. Water extracted from deeper wells is related to a cretaceous limestone aquifer while the shallow aquifer consist of tertiary granular materials. There are also several springs in the valley.

A geochemistry approach is presented for the simulation of the origin and evolution of the salty ponds through the variations in the hydrologic regimen and dissolution–precipitation of minerals such as calcite and gypsum.

The modelling was done using the PHREEQC software and including the water chemical composition from ponds and wells in the area and the mineralogical composition of soils and geologic material. The modelling procedure was used to reproduce the groundwater hydrochemical composition of the water resulting from the interaction of different hydrogeochemical processes, such as evaporation, dissolution and carbonates precipitation. Another parameter that was evaluated was the evaporation produced by climatic conditions. Results show a differential contribution of these processes and their relationships with different groundwater flowpaths. Thus, modelling demonstrates that the water chemical composition is related to the geologic material composition together with variations in the hydrologic regime of the Cuatro Ciénegas Valley. Those conditions are unique in this zone and are distinguishable from the conditions in other surrounding valleys.

In order to confirm the impact of evaporation, a stable isotope data analysis (^{18}O-^{2}H) was used. The intensity of evaporation is different for each site of the valley because of the geologic structure of surrounding mountains, Fig. 2.

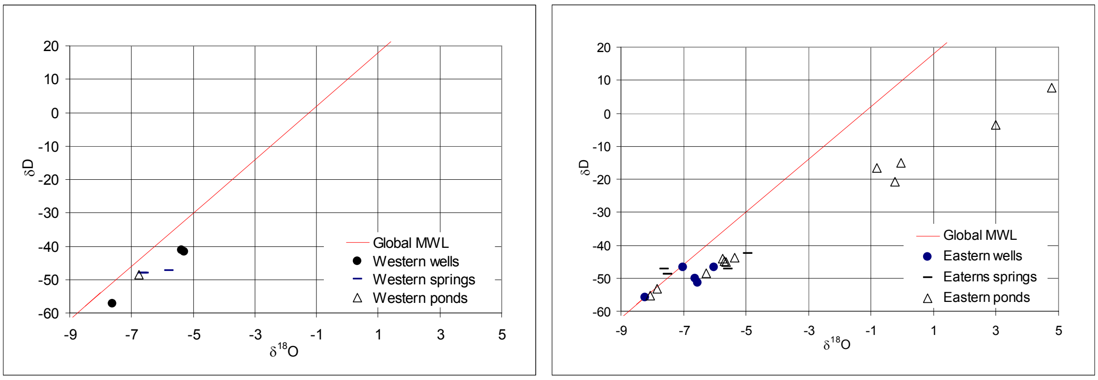


Fig. 2 $\delta^{18}O$(‰) vs. δD(‰) for sampled points in both sides of the Cuatro Ciénegas Valley.

Results suggest that salty ponds results from the regional flowpath which discharges into valley, where some minerals are precipitated. Sols mineral composition is determined through dissolution of salts, which can be originated from tertiary carbonates and gypsum, that precipitated into valley.

Keywords: evaporation, limestone, salty water, ponds, Mexico, gypsum

Pilbara Iron's Catchment Approach To Regional Environmental Management

[1]Jed YOUNGS, [2]Damien LYNES, [3]Sally MADDEN, [4]Doug BROWN, [5]Peter LANDMAN

[1] and [4] MWH Australia, 178 St. George's Tce., Perth, WA, Australia
[2] Pilbara Iron, 1 William St., Perth, WA, Australia
[3] Rio Tinto Iron Ore, 152-158 St. George's Tce., Perth, WA, Australia
[5] Rio Tinto, 6 St. James Square, London, UK

ABSTRACT

The catchment (the area of land drained by a waterway) forms a logical unit for the study of regional hydrology. It defines boundaries with physical significance, describes an area where surface and subsurface waters flow in broadly the same direction, and sets a focal point at the base of the catchment which is influenced by all the hydrological processes in the study area. The catchment is also the logical area for the investigation of groundwater dependent ecosystems (GDEs) and riverine fauna, which are closely linked to hydrology. This is particularly valid in the semi-arid Pilbara region of Western Australia, where water availability is often the critical factor for ecosystem sustainability.

Pilbara Iron is a major producer of iron ore with ten operational mines and three ports in the Pilbara. Parent company Rio Tinto has incorporated a catchment approach to water resources within it's environmental standards by stating that operations are required to: *"Develop and maintain a detailed understanding of the cumulative demands and impacts being placed on water resources in the catchments in which the operations work."*.

Pilbara Iron has developed the catchment approach for it's operations over several years through a process of catchment delineation, assessment of monitoring coverage and groundwater impacts, and action plans for improvement of the monitoring network. A major program of works completed during 2006 and 2007 will expand the network of regional monitoring stations through installation of monitor bores across all the Pilbara watersheds in which the company operates.

Selected catchment (regional) groundwater monitoring bores across the region are being developed as general environmental monitoring stations. The stations will monitor ecosystem status parameters such as the health, productivity, and water and carbon balance of groundwater dependent vegetation; and the distribution, abundance and habitat requirements of subterranean fauna. They will provide effective control points for ongoing assessment of the impacts of mine operations and for the effectiveness of mine closure management.

The benefits of the catchment approach as a framework for regional environmental management include:

1) enhanced understanding of natural conditions with subsequent improvement in the detection of operational impacts (eg characterisation of the natural range in groundwater level fluctuations and GDE health parameters);
2) protection of significant water features (eg pools and springs);
3) early indication of regional impacts and trends;
4) consideration of the effects and concerns of all stakeholders (eg. borefield operators, communities, land management groups); and
5) characterisation of current or potential water resources.

Keywords: catchment, groundwater, GDE, regional, stakeholders

Preliminary interpretation of geological and hydrogeological data obtained in Quiaios Lagoons

[1]Ana Maria CASTILHO, [2]Manuel MARQUES DA SILVA, [3]António FERREIRA SOARES, [4] Fernando Pedro O. FIGUEIREDO, [5]Manuel SENOS MATIAS, [6]Pedro DINIS

[1] Centro de Geociências, Earth Sciences Department, University of Coimbra, P-3000-272 Coimbra, Portugal; e-mail: amcastil@dct.uc.pt
[2] Departamento de Geociências da Universidade de Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal, e-mail: msilva@geo.ua.pt
[3] Earth Sciences Department, University of Coimbra, P-3000-272 Coimbra, Portugal
[4] Centro de Geociências, Earth Sciences Department, University of Coimbra, P-3000-272 Coimbra, Portugal; e-mail: fpedrol@dct.uc.pt
[5] Departamento de Geociências da Universidade de Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal, e-mail: mmatias@geo.ua.pt
[6] [1] Centro de Geociências, Earth Sciences Department, University of Coimbra, P-3000-272 Coimbra, Portugal; e-mail: pdinis@dct.uc.pt

ABSTRACT

In the Quiaios coastal area (central Portugal) there are four lagoons – Braças, Vela, Salgueira and Teixoeiros - that constitute a valuable natural resource. The Quiaios Lagoons, as they are known, are important breeding winter areas for birds, classified as Biotope Corine. In addiction, they guarantee part of the water supply for the town of Figueira da Foz.

Related to the Aveiro Quaternary multilayer aquifer system, the Quiaios Lagoons are small, shallow, freshwater lakes, formed on a coastal dune area. A number of hydrogeological studies have been carried out on this aquifer, especially at its North side. However there was not a clear understanding of the interactions between groundwater and these wetlands, from the hydrodynamic and hydrogeochemical point of view. Also the geometry and characterization of the geological and hydrogeological units was not well known, because of the uniform coverage of the area and the lack of outcrops or boreholes information data.

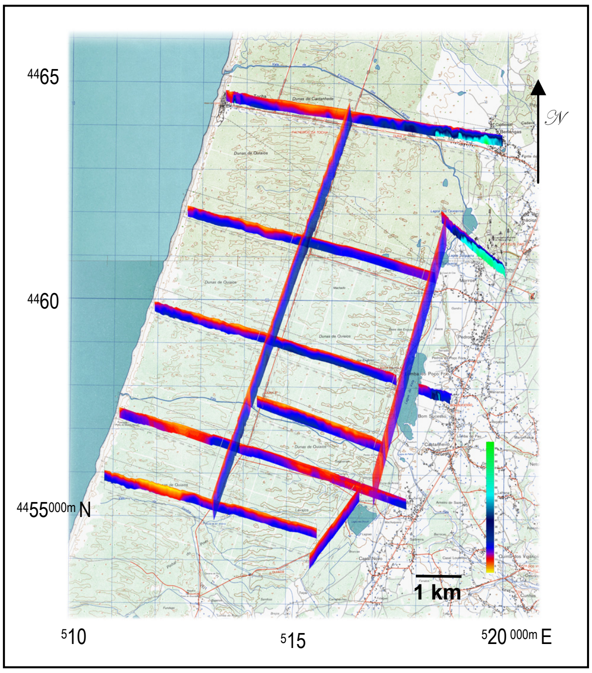


Fig. 1. Geophysical survey and geographic location of Quiaios Lagoons (adapted from 1:25000 scale Portugal Map, ed. by S.G.E - UTM - 29- European Datum 1950 coordinate system).

This research was planned to overcome these uncertainties. It started with a geophysical survey, from which a total of 54km electromagnetic data profiling was obtained using both the Geonics EM31 and EM34. The apparent electrical conductivity sections are shown and interpreted graphically (Fig.1).

The hydrogeological inventory was carried out, at first, on the existing wells, located only East from the lagoons and used for domestic and agriculture purposes. Since at least 2/3 of the total area was not covered by boreholes, wells or any other access points to the aquifer units, it became necessary to create a new network of observation wells. The geophysical preliminary data helped to make the decision on the drilling sites, where the network was installed to monitor groundwater levels and quality. During the construction of the boreholes all the relevant information was listed and samples were collected for laboratory analyses.

From the analysis of the well and borehole data it is possible to consider two distinct geological successions at western and eastern locations. At the eastern fringe over the Upper Cretaceous basement the sediment fill comprises, from the base to the top, fluvial muddy coarse sands, palustrine organic rich mud, podzolised aeolian sand and non-podzolized aeolian sand. At the western fringe the succession consists of, from the base to the top, beach sands, lenses of brackish mud, and sometimes wash-over fan sands, covered by aeolian sands. Between these two fringes the Quaternary record comprises exclusively aeolian sands over beach sediments.

A database was made to link the geological, hydrodynamic and hydrogeochemical, geophysical and other sources of information that is going to be collected during the monitoring period. All data will be assembled in a conceptual model of the local geology and hydrogeology.

***Keywords**:* Electromagnetic methods, aquifer units, wells, hydrogeology, lagoons.

Relevance of hydrogeological processes on the ecological status evaluation in a Mediterranean stream (Onyar River, NE Spain).

Anna MENCIÓ and Josep MAS-PLA.

Centre de Geologia i Cartografia Ambientals (GEOCAMB), and Àrea de Geodinàmica, Dept. de Ciències Ambientals, Universitat de Girona, Campus de Montilivi, 17071, Girona, Spain, e-mail: anna.mecio@udg.edu.

ABSTRACT

Streams and rivers in Mediterranean areas are characterized by a variable discharge regime with annual floods and droughts. Natural flow perturbations imply the occurrence of permanent and temporary rivers (including the intermittent and ephemeral ones), allowing singular ecological community structures as revealed by biological indexes. Furthermore, human pressures upon these watercourses (e.g., treated and non-treated waste water pouring and hydromorphological alterations of the stream channel) are responsible for even more severe disturbances. In this context, we perform a joint analysis of biological and hydrogeological data to provide an integrated interpretation of the spatial and temporal variability of the stream ecological status.

This research was conducted at the Onyar River watershed (NE Spain), with an extension of approximately 330 km^2. According to the System A river classification proposed by the Water Framework Directive (WFD; 2000/60/EC), this watershed can be considered as a lowland, siliceous, and medium watershed, in the Iberic-Macaronesian ecoregion. If we take into account System B, Onyar River is classified as a dry Mediterranean climate area-river placed lowlands (<400 m). Mediterranean climate shows a high annual air temperature (about 14-16 ºC), dry summers with an average rainfall of 650 mm/year, high flow variability, variable drainage area (<1000 Km^2), low slope, and flow velocity and discharge smaller than 1 m^3/s.

In this area, human pressures are also as important as natural perturbations on surface water hydrology. Recent developments of industrial and urban activities, jointly with intense agricultural and livestock production, result in a high water demand, which is mainly based on groundwater exploitation. Pressures turn into hydrochemical water changes, variations on the channel and riparian vegetation, and intense flow regime modifications. Therefore, human activities constitute a constraining factor for a good hydrological as well as ecological status of streams. In this way, the assessment of the origin of these restraints is then crucial to understand hydrochemical data, biological indexes and to develop adequate management strategies.

Our results prove that a lack of an appropriate stream discharge is related to natural summer low-flows and, more importantly, to intensive groundwater withdrawal from the alluvial aquifers. Hydrogeological cross-sections, transversal to the Onyar middle reach, show that the water-table gradient towards the stream diminishes during dry periods, and in some locations it may even reverse, creating a "loosing stream" scenario. In any case, summer seasons are characterized by a very low or even null groundwater contribution as base-flow.

Such hydrodynamic relationship between river and aquifer is also recognized in the hydrochemical dataset. Surface water hydrochemistry shows noteworthy spatial and temporal variations in the Onyar River, in contrast to ground water hydrochemistry. On the one hand, the Onyar River alluvial aquifer mainly presents a calcium-bicarbonate facies. On the other hand, downstream evolution of surface water changed from calcium-bicarbonate to sodium-chloride facies during the dry seasons, which can be attributed to the contribution of water treatment plants, and the lack of dilution due to an inexistent base-flow component. A dilution effect in wet periods is indeed observed and related to a "gaining stream" condition showing how surface water chemistry drifts towards that of groundwater.

The biological status of this river was determined using the IBMWP indicator (Alba-Tercedor & Pujante, 2000), based on macroinvertebrate occurrence. It shows that good biological qualities are observed in the higher and middle reaches of the Onyar River in winter and/or spring. Water quality, however, worsens during the rest of the year, especially in the middle and low reaches. Discharge diminutions at these reaches reflect the severe influence of summer groundwater withdrawal on the natural flow regime, which may last well into autumn if rainfall events do not improve this hydrological scenario.

Biological status of the water is then correlated to water-table oscillations that control both stream base-flow and surface water chemical content by diluting used-water contributions to discharge. This observation points out that restoration of stream biological quality must integrate groundwater management as a way to re-establish an appropriate hydrological dynamic in the basin that will partially minimize the effect of human pressures.

Figure 1 shows the spatial and temporal distribution of the ECOSTRIMED indicator of the stream ecological status (Prat et al; 2000). ECOSTRIMED considers biological data from the IBMWP indicator, altogether with riparian vegetation and floodplain characteristics included in the QBR indicator (Munné et al., 1998). The use of additional information results in an even worse evaluation of the stream status, that is not related to hydrological or hydrochemical pressures but to the substitution of autochthonous species by foreign plants, as those used for timber and paper industries, and to hydromorphological alterations.

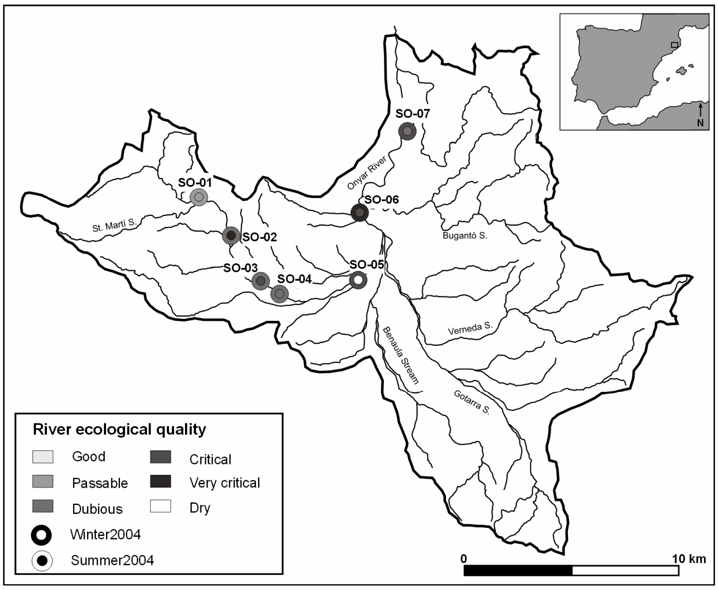


Figure 1: ECOSTRIMED classification during winter and summer, 2004.

This contribution points out how the use of biological data on the characterization of water bodies' status may be tampered by multiple factors, some of them not related to hydrological processes. Nevertheless, we point out how alterations of river-aquifer dynamics by groundwater exploitation constitute a relevant pressure upon stream hydrology and its quality.

In conclusion, this analysis brings out an additional perspective for diagnose and management of human-modified streams. The joint use of biological indexes, hydrochemical data, as well as groundwater and surface water interactions provides an integrated analysis of the stream ecohydrology and, therefore, an enhanced interpretation of its ecological status.

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Keywords (5): surface water/ground water interactions; hydrochemistry; biological indicators; ecohydrology; environmental pressures.

Risk assessment for groundwater dependent tree systems and relationships with groundwater surface water interaction

[1]R.W. VERVOORT

[1] Hydrology Research Laboratory, Faculty of Agriculture, Food and Natural Resources, The University of Sydney, NSW 2006 and Cotton Catchment Community CRC.e-mail:w.vervoort@usyd.edu.au

ABSTRACT

Provision of environmental water for groundwater dependent ecosystems is embedded in the water management legislation in Australia. This provision is to be determined objectively, but many field methods are either short term or expensive. Many rivers in Australia are losing and this means the local aquifer is highly responsive to the stream flow level. Simulation modeling can be used to predict requirements and the uncertainty related to the groundwater requirement determination. Recently two different stochastic analytical models have been suggested to model the interaction between groundwater and trees (Brolsma and Bierkens, 2007; Camporeale and Ridolfi, 2006) In this poster, a case study involving a terrestrial groundwater dependent ecosystem containing River red gum trees (*Eucalyptus Camaldulensis*) is discussed. Using a combination of these approaches probability density functions of leaf area, oxygen and water stress as a function of water table depth can be developed (Fig. 1).

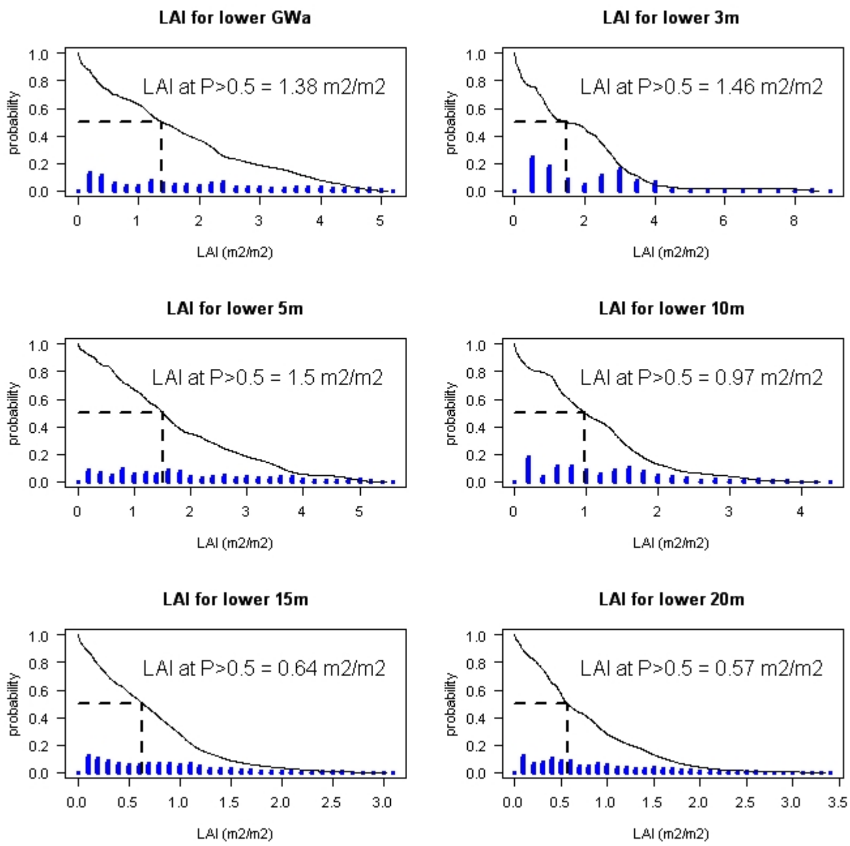

Fig. 1 Examples of probability density curves of leaf area index (LAI) for a groundwater dependent ecosystem in NSW (Australia).

A relationship between water table depth and stream flow can also be predicted based on the streamflow groundwater relationship. Using this information, the risk of a tree system dropping below a critical health level can be predicted under different climate and streamflow scenarios. This approach is suggested as a risk assessment tool for riparian ecosystems dependent on groundwater surface water interaction.

Keywords: Risk assessment, groundwater dependency, groundwater surface water interaction, modelling approach

Seasonal variations of biogeochemical characteristics in predominantly anaerobic groundwater from a riverine alluvial aquifer

[1]Dong-Chan KOH, [2]Hyeon-Joong KIM, [1]Kyoochul HA, [2]Kangjoo KIM,
[1]Beom-Kyu CHOI, [1]Su-hyun CHEON

[1]Korea Institute of Geoscience & Mineral Resources, 30 Gajeong-dong, Yuseong-gu, Daejeon 305-350, Republic of Korea, e-mail: chankoh@kigam.re.kr, hasife@kigam.re.kr, fossils95@hotmail.com, suhyunblue@hotmail.com
[2]School of Civil and Environment Engineering, Kunsan National University, san 68, Miryong-dong, Kunsan, Jeollabuk-do, 573-701, Republic of Korea, e-mail: guswnd8@kunsan.ac.kr, kangjoo@kunsan.ac.kr

ABSTRACT

Hydrogeochemical parameters were investigated for groundwater from six multi-level wells (up to 30 m deep) in a riverine alluvial aquifer with intense agricultural activities of rice, barley and vegetable cultivation during two sampling campaigns in rainy summer (July) and dry spring (March) season to identify seasonal variation in biogeochemical processes in the aquifer. The alluvial aquifer is located in flooldplains of the Mangyeong River, in the western part of South Korea near the city of Jeonju. The aquifer overlies granitic basement and comprised of gravel and sand, and partially silt and mud. The land use of the area is mainly agriculture with cultivation of rice in paddy fields, barley and vegetables in non-paddy fields. The river is mainly in a gaining condition throughout the year though flooding is frequent in monsoon season from late June to July and in typhoon season from August to September. pH, concentrations of Na, Cl, Ca, F show little difference between the two sampling periods. Electrical conductivity (EC) and concentrations of HCO_3, Mg, SO_4 are slightly increased on the whole from rainy season to dry season. Dissolved concentrations of major ions in river water increased by more than three fold during the seasons. These features indicate that the groundwater system is relatively stable and less affected by the river in hydrogeochemical aspects. Dissolved oxygen (DO) concentrations were less than 1 mg/L for most of the wells, whereas two wells turned to aerobic conditions in dry season which can be attributed to removal of stagnant water in the paddy fields. NO_3 concentrations decreased significantly in the dry season at most well points near the paddy fields. This indicates that denitrification is dominant over nitrate supply by infiltrating water from the land surface, which is likely to be significantly decreased after harvesting of rice during the dry season. However, NO_3 increased in upper zones (<10 m) in two wells near the barley and vegetable fields, which suggest continued nitrate supply from the crop fields to the upper part of the aquifer during the season. Fe concentrations have relatively small variations in most of wells for two sampling periods. However, from rainy season to dry season, Fe concentrations increased significantly more than two fold in two wells whereas NO_3 concentration decreased below detection limit from 2 to 8 mg/L. The increase of Fe resulted in the increase of HCO_3 concentrations by two fold and significant increase of EC, which even transformed hydrogeochemical pattern of major ions in those intervals, which can be attributed to the much higher proton consumption in iron reduction than in denitrification (Fig. 1).

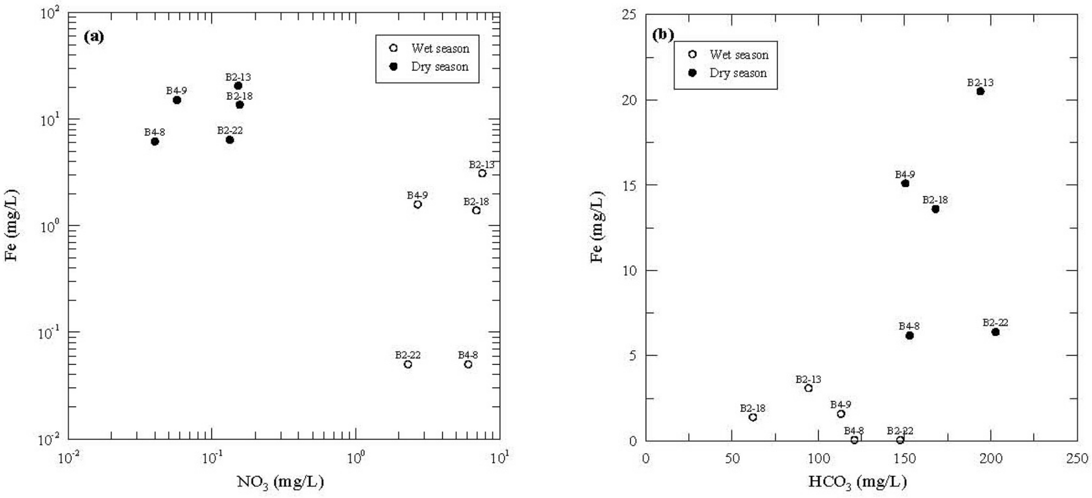

Fig. 1. Concentrations of Fe(total) versus NO_3 (a) and Fe(total) versus HCO_3 (b) in well points where a seasonal change in concentrations of the ions was observed. Open circles are for wet season and solid circles are for dry season

This is indicative of the seasonal change in electron-accepting processes from nitrate reduction to iron reduction along with decrease in nitrate supply from the land surface. Seasonal variations in concentrations of DO, NO_3, and Fe show that the temporal change in agricultural activities on land surface significantly affects biogeochemical processes in an alluvial aquifer. Denitrification of agriculturally derived NO_3 and iron reduction in the alluvial aquifer can significantly affect water chemistry of the river.

Keywords: Biogeochemistry, alluvial aquifer, redox processes, iron reduction, riverine environment

Some aspects of groundwater behavior under tidal conditions in estuarine systems: Itanhaém River Estuary, south coast of Sao Paulo State, Brazil.

Job J. BATISTA FILHO [1]; Sueli Y. PEREIRA [1]; Fresia R. BRANCO [1];
Paulo R.B. PEREIRA [2]; Fabio C. BRANCO[3]

[1] Institute of Geosciences UNICAMP. Pandiá Calógeras Street, 51, Postal Code 6152, 13083-970, Campinas-SP, Brazil, emails: jobjbf@ige.unicamp.br; sueliyos@ige.unicamp.br; fresia@ige.unicamp.br
[2] Forest Institute. State Secretariat of Environment of Sao Paulo. Postal Code 35, Horto Florestal, 13801-350, Mogi Mirim-SP, Brazil, email: paulobrum@cena.usp.br
[3] EnvironMentality, rua Michigan, 177, 04566-000, São Paulo, SP. Brasil, email: fabio.tcl@uol.com.br

ABSTRACT

This paper presents some aspects groundwater behavior under tidal conditions in the estuarine system, located on the south coast of Sao Paulo State, Brazil. The region has a tropical to humid subtropical climate with a relatively stable temperature. The annual average temperature is above 20°C. The annual precipitation varies from 2 350 to 4 554 mm with the highest rainfall occurring during the summer months from January to March, and little rain falling during the winter months from June to August. There is no well defined dry season, however, with the average relative air humidity being about 80%. The coastal plain of Itanhaém basin extends some 50 km with an average width between 15 and 16 km. Its evolution during the Quaternary is related, basically, to two events of transgression. The first, known as the Cananeia transgression, occurred during the Pleistocene (120 000 years BP) and was characterized by the buildup of sandy sediments of marine coastal depositional systems or strandplains. The second transgressive event, nowadays known as the Santos transgression, occurred during the Holocene (5 100 years BP) and it is characterized by an estuary-lagoon depositional system. At present, the estuary-lagoon paleosystem is overlain by river sediments from the flood plain of Itanhaem River and its tributaries. Moreover, the mouth of Itanhaem River acts as a channel for the tide, so that the river is subject to daily inversions along its course. The study was carried out at a small site (10 000 m^2), where seven monitoring wells were installed on the right bank of the Itanhaem river, 2 km from the Atlantic Ocean. Groundwater and surface water levels and physical and chemical parameters were monitored in two seasonal periods: summer – April 2005 (rainy season) and winter – August 2005 (dry season). The water and physical-chemical monitoring program consisted of measuring continuously (45 to 45 minutes) for a period of 15 days the water level, pH, Eh (mV), Electric Conductivity (EC in microSiemens/cm) and Total Dissolved Solids (TDS in mg/L) in monitoring wells. Tidal oscillations and climatic parameters were measured by tidal gauge and weather station located at CePeRio (Research Center of Itanhaem River), two kilometers from the site. The study has identified two aquifers in the area: the first one, which is phreatic, is formed by fine sand with phyto rests and has a thickness of about ten meters; the second and deeper aquifer is composed of fine sand to clayey silts with shells, from 10 to 22 meters depth.

The phreatic aquifer has 10^{-4} m/s of hydraulic conductivity (K), a linear average velocity in the order to 10^{-6} m/s, pH varying from 4.0 to 5.0 and TDS averaging 40 to 70 mg/L. TDS and pH measured in waters from Itanhaem River varied from 90 to 5,000 mg/L and from 6.0 to 7.0, respectively. The deeper aquifer has K equal to 10^{-6} m/s, linear average velocity in the order to 10^{-8} m/s, TDS averages varying from 310 to 2,000 mg/l and pH from 6.0 to 7.5. The Itanhaém River showed effluent behavior; the groundwater has discharged into this river. This effluent condition was dominant in the upper and lower tide oscillations monitored, but groundwater flow directions in the phreatic aquifer had changed according to tidal fluctuations. The phreatic aquifer presented NW direction to groundwater flows in low tide, and North direction in the upper tide. The deeper aquifer showed east to west direction to groundwater flows in low and upper tide levels, so no significant changes were observed in groundwater flow directions. The phreatic aquifer had direct influence from tidal oscillations with a variation of groundwater level amplitude five times lower than the tide. The deeper aquifer oscillation was 11 times lower than the tide, showing no external influence. Furthermore, in summer, the groundwater flow of the phreatic aquifer was modified during strong flows of the tide northward, moving into the river channel. Groundwater TDS varied slightly with saline intrusion and the river water TDS that reached 5,000 mg/L. Near the study area the river had no influence of saline intrusion in the daily upper tide level. A preliminary and hypothetic regional model of groundwater circulation suggests high rate of recharge in the Serra do Mar, a mountain range formed by Precambrian terrain, and which has 4 554 mm of annual precipitation. The estuary would be a regional discharge region when high volumes of ground water pass slowly through the estuary, moving toward the ocean. The higher tide fluctuations would reach no long distances onshore. The characteristic tropical lack of a pattern

of well-defined seasons suggests that the main variations in water characteristics, related to tide influence over time, would be a consequence of patterns of variation due to the action of the tides and the intensity of rain and winds.

Thus, in this case study and under the conditions described above, the saline intrusion moving into the river channel generally had no influence on groundwater at that distance (2 km) from the sea.

Keywords: groundwater, tide, Itanhaem Estuary, Brazil,

Surface water influencing methane emission from Nawagaike wetland in Toyama, Japan

Yasuhiro KIYOSU, Ayumi MURAOKA

Department of Environmental Biology and Chemistry, University of Toyama, Gofuku 3190, Toyama 930-8555, Japan, e-mail: kiyosu@sci.u-toyama.ac.jp

ABSTRACT

The role of surface water influencing methane emission was seasonally (late spring to early fall) investigated at a temperate fen in Toyama, Japan. A negative correlation between soil temperature and water table depth describes the fundamental seasonal signal (Fig. 1). All seasonal emissions for several sites ranged from 0.3 to 1426 CH4-C mg/m2/day Methane fluxes among some soil ecosystems were slightly different from one another, although emission from all sites was lowest in late spring and increased quickly after late spring to peak rates in summer. Cool season (spring) fluxes appeared to be suppressed by surface water covered peat soil. The high variability of the emission is probably due to variations in hydrological system at different sites and times within the fen. Consistent spatial and temporal different in flux could be ascribed to difference in water table depth and temperature. The poor correlation of depth to water table (r2 = 0.319) and peat soil temperature (r2 = 0.271) with CH4 flux in late spring to early fall for sites may be attributed to other more restricting variables created by the surface water flow through the fen. Methane emission was indirectly correlated with the water table levels at all measurements. We conclude that variability in water table level versus CH4 emission is significantly influenced by variability of sunshine duration, independent of precipitation. That is, weather appears to control methane flux in this temperate wetland.

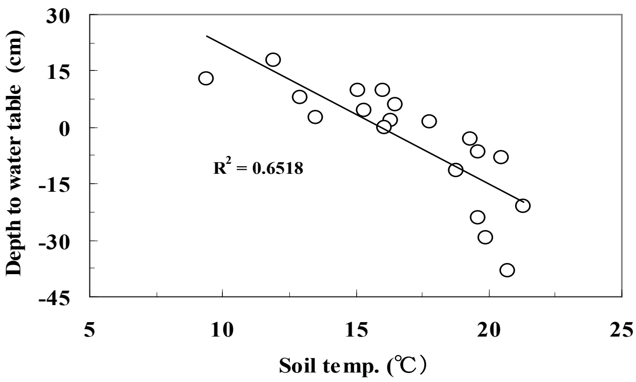

Fig. 1. Depth to water table versus soil temperature.

Keywords: methane emission, surface water, depth of water table, sunshine duration, wetland ecosystem

Surface water-groundwater interaction in the Nattai River catchment, New South Wales, Australia

[1]Wendy MCLEAN, [1]Katarina DAVID, [2]Jerzy JANKOWSKI

[1]Hydrogeology Unit, Parsons Brinckerhoff, Ernst & Young Centre, Level 27, 680 George St, Sydney NSW 2000 AUSTRALIA, e-mail: wmclean@pb.com.au
[1]Hydrogeology Unit, Parsons Brinckerhoff, Ernst & Young Centre, Level 27, 680 George St, Sydney NSW 2000 AUSTRALIA, e-mail: kdavid@pb.com.au
[2]Sydney Catchment Authority, Level 2, 311 High Street, Penrith NSW 2750, AUSTRALIA, e-mail: jerzy.jankowski@sca.nsw.gov.au

ABSTRACT

The groundwater resource of the Nattai River catchment, located in the Southern Highlands of New South Wales, Australia, is a valuable groundwater resource that is used for stock and domestic water supply, viticulture, dairy farming and irrigation. Groundwater also provides base flow to the Nattai River and its tributaries, and is likely to support groundwater dependent ecosystems such as ecosystems in creeks and rivers. The Nattai River catchment is renowned for its majestic River Oaks (*Casuarina cunninghamiana*), a gallery forest which follows the river for most of its length.

Heavy groundwater development in this catchment and other parts of the Southern Highlands has occurred over the last decade, yet until this recent baseline study there has been little investigation into the groundwater chemistry and water quality, and the relationship between groundwater and surface water interaction in the Nattai River catchment. The aim of this baseline hydrochemical and environmental isotope study was to understand the hydrochemistry and water quality in the Nattai River catchment, and the relationship between groundwater and surface water systems to develop a conceptual groundwater model.

The geology of the Nattai River catchment comprises a gently deformed sequence of Triassic sandstones and shales that form the upper sequence of the Sydney Basin sediments. These are overlain by the Tertiary Robertson Basalt in topographically high areas in the south of the catchment. The Triassic Wianamatta Group Shales also outcrop on elevated areas in the south of the catchment and the Hawkesbury Sandstone outcrops across the majority of the catchment. A Permian sequence of siltstones, sandstones and conglomerates (Shoalhaven Group) and coal measures (Illawarra Coal Measures) outcrop in the north of the catchment, where the Nattai River becomes deeply incised. Structural deformation since deposition has produced a series of gentle folds and warps in the dip of formation surfaces and west-northwest to east-southeast trending horst and graben structures occur in the south of the catchment, comprising the Mittagong Horst and Graben Complex. Local faulting is significant and Late Jurassic intrusives, including syenite, diorite plugs and sills, form prominent topographic and geological features in the catchment such as the Mount Flora Dome, Mount Jellore Dome and Nattai Dome.

The Hawkesbury Sandstone provides the main groundwater resource in the Nattai River catchment. The Hawkesbury Sandstone behaves as a leaky confined aquifer and comprises a multilayered aquifer system with groundwater occurring in discrete horizons that occasionally have vertical hydraulic connection. Geological uplift and fracturing has enhanced the secondary (fracture) permeability of the Hawkesbury Sandstone. Major fractures provide preferential pathways for enhanced groundwater recharge and, due to their proximity to surface, are likely to be rapidly recharged when large rainfall events occur.

Important recharge zones are located in topographically higher areas and, where there is exposed Hawkesbury Sandstone, are enhanced by local structural features in the investigation area. One area in particular is the structural zone to the south of the Mount Jellore Dome. It appears that the faulting has caused the uplifting block to the west of the structural lineament as continuation of the intrusion complex at Mount Jellore Dome. This is an area of increased recharge as indicated by the springs and artesian bores identified during this study.

The primary recharge zone identified to the west of the catchment is associated with the topographically higher zones capped by basalt. The fracturing of the basalt may provide groundwater flow paths to the underlaying sandstone aquifer. In addition, the uplifted (horst) blocks of exposed sandstone in the vicinity of structural lineaments and faults are potential recharge zones.

Chemical data indicates that in areas where the Hawkesbury Sandstone outcrops, groundwater is generally fresh (EC <500 µS/cm), acidic (pH 4 to 6) and is Na-Cl or Na-Mg-Cl type of water. The dominance of chloride is due to the principal source of recharge for these aquifers being coastal rainfall. Groundwater from the Hawkesbury Sandstone typically has elevated concentrations of iron and also manganese, although some variability was observed in the iron concentrations in groundwater from the Nattai River catchment. Sources of iron in the

Hawkesbury Sandstone include siderite and iron oxyhydroxides and oxides. Other commonly occurring trace elements include barium, copper, manganese, nickel, strontium and zinc.

Variations in the chemistry of groundwater in the Nattai River catchment occur where the Wianamatta Group shales and Robertson Basalt outcrop, and also where igneous bodies have intruded the country rock. Groundwaters associated with these units typically have a higher pH than groundwater from the Hawkesbury Sandstone, and are either mixed cation-HCO_3-Cl type waters or mixed cation-Cl-HCO_3 type waters. Higher TDS values occur in waters associated with the Wianamatta Group shales, which have a naturally high salinity due to entrapment of connate salts. Higher TDS waters are also found in the vicinity of igneous intrusions. The dissolution of silicate minerals is an important contributor to TDS in these waters. Weathering of silicate minerals in the Robertson Basalts contributes dissolved silica, cations and bicarbonate to groundwater, and weathering products (kaolinite) are often observed on outcrops of the Robertson Basalt in the Southern Highlands.

Surface water from the Nattai River is fresh (EC <350 µS/cm). The pH becomes more acidic downstream, with pH values decreasing from 7.45 at upstream locations to 5.63 downstream. The chemical composition of surface water varies from upstream chemical type Na-Mg-Cl-HCO_3 to downstream chemical type of Na-Mg-Cl-HCO_3-SO_4 to the final chemical type Na-Cl-HCO_3. Trace elements detected in surface water include barium, copper, iron, manganese, nickel, strontium and zinc.

Oxygen-18 values for all groundwater samples range from -7.30 to -4.53‰ and deuterium values range from -42.7 to -27.1‰. Groundwater in the Nattai River catchment is interpreted to be of meteoric origin and the relative depletion in isotopic signature to the local meteoric water line (LMWL Botany Basin $\delta^2H=8.22\delta^{18}O + 15.41$) is due to the altitude effect (elevation of site varies from 600 to 870 m AHD). Surface water samples generally show more enriched oxygen-18 and deuterium signatures than groundwater in the Nattai River catchment. The isotopic signature of surface water samples from the Nattai River showed a gradual isotopic enrichment downstream due to increasing dominance of rainfall and runoff contribution to stream flow over base flow contribution, and also due to the effects of evaporative enrichment. The most isotopically depleted surface water samples were taken from the upstream locations after a period of prolonged drought, indicating the importance of groundwater base flow under current climatic conditions.

Stable isotope data supports the hydrogeological and chemical data, which indicates that groundwater base flow is an important component of surface water flow in the Nattai River and its tributaries. The groundwater level gradients are mainly interpreted to be steep (0.04 to 0.02) across the catchment and groundwater flow is interpreted to generally follow surface contours and flows to the east-northeast and towards the Nattai River, nearby creeks and lower lying areas in the landscape. The Nattai River is a deeply incised watercourse, and it becomes more incised to the north of the investigation site. In the southern part of the catchment the groundwater elevations appear to be above the Nattai River elevation. The groundwater in the sandstone is expected to discharge as base flow at the southern and northern ends of the catchment. High strontium concentrations and the presence of barium are excellent tracers for indicating base flow discharge, and the presence of both ions in surface water indicates a component of base flow contribution to surface water.

Keywords: Nattai River, Hawkesbury Sandstone, base flow, hydrochemistry

The definition of potential areas of infiltration in the Paraíba do Sul River Basin – an integrated approach using physical and land use elements

Paulo Valladares SOARES [1]; Sueli Yoshinaga PEREIRA[1]; Silvio Coelho SIMÕES[2]; George de Paula BERNARDES[3]; Sérgio Augusto BARBOSA [4]

[1] Institute of Geosciences UNICAMP. Pandiá Calógeras Street, 51, Postal Code 6152, 13083-970, Campinas-SP, Brazil, emails: pvsoares1@yahoo.com.br ; sueliyos@ige.unicamp.br
[2] Faculty of Civil Engineering UNESP. Dr. Ariberto Pereira da Cunha Avenue, 333, 12.516-410 – Guaratinguetá-SP, Brazil, emails: simões@feg.unesp.br; gpb@feg.unesp.br
[3] Agência Nacional de Águas. ANA. Setor Policial, Área 5, Quadra 3, Bloco "B". 70610-200, Brasília, DF, Brazil, email: gsatconsultoria@terra.com.br

ABSTRACT

This work intends to present procedures to classify Homologous Areas related to the infiltration process in the Paraíba do Sul river watershed. The method used to define these areas consisted of creating “patches”, grouping several properties of the terrain in order to identify infiltration areas, which are capable of supplying the storage water into the ground and to maintain the underground water system of the basin. The landscape elements used to classify these areas were: rocks and structures, land surface, soil characteristics, precipitation and land use. For each element a value from 1 to 5 were applied, which corresponded to the range of potential infiltration capacity varying from low (1) to high (5). GIS (Arcview) was used to overlay the maps of the attributes, already scaled according to its infiltration capacity, in order to create the map with the Homologous Areas. This procedure was carried out to evaluate the Homologous Areas on two scales: (1) regional map, 1:250,000 scale, with a medium portion of the Paraiba do Sul river (7,600 square kilometers) and (2) Guaratinguetá river basin, 1:50,000 scale, with 160 square kilometers, located at left edge of Paraiba do Sul river. Homologous Areas on the regional scale showed that the high infiltration capacity areas are situated on hills, between scarps and alluvial plains in the North West portions of the region and in the east portion, limited to the São Paulo State (Fig. 1).

For the Guaratinguetá river basin, the areas of high infiltration capacity are located in the central and northwest of the basin (Fig. 2). For both analyses, scarp areas and alluvial plains presented low infiltration capacity. However, scarp areas are important as the transfer mechanism from production areas to storage areas. The alluvial plains are capable of water storage and continuous supply to the drainage system. This paper indicates the following as environmental indicators to the infiltration potential evaluation: land use, dynamic of springs and minimum stream volumes (base flow).

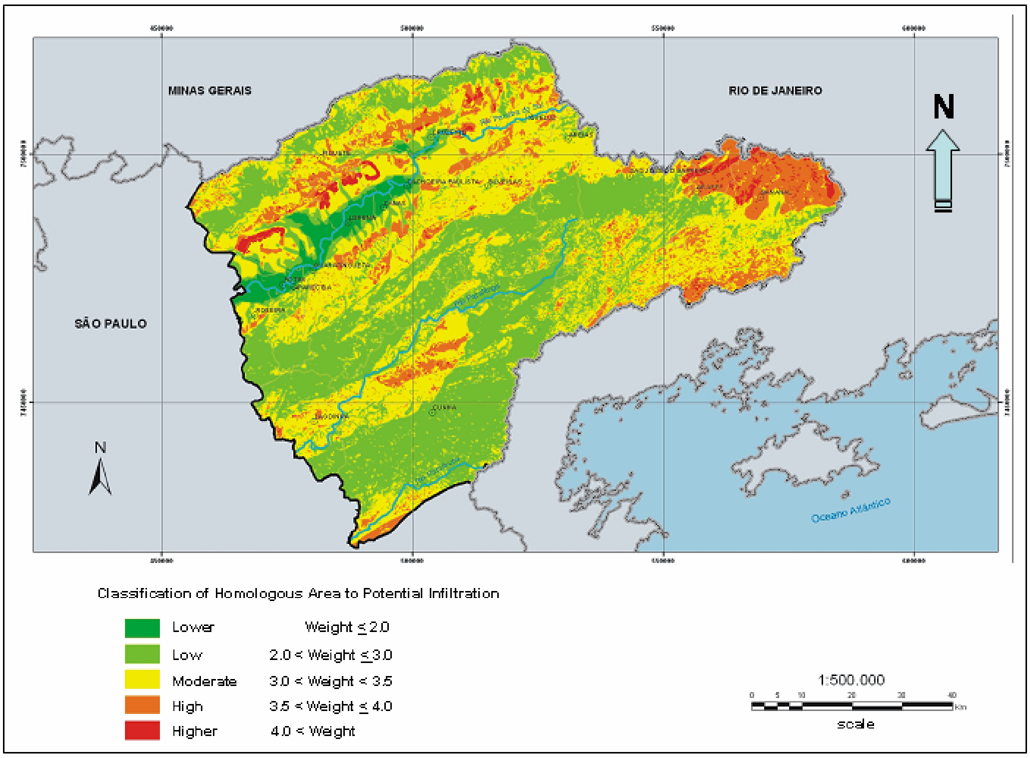

Fig. 1 – Homologous Areas for potential areas of infiltration in medium portion of Paraíba do Sul River Basin (1:250,000 scale)

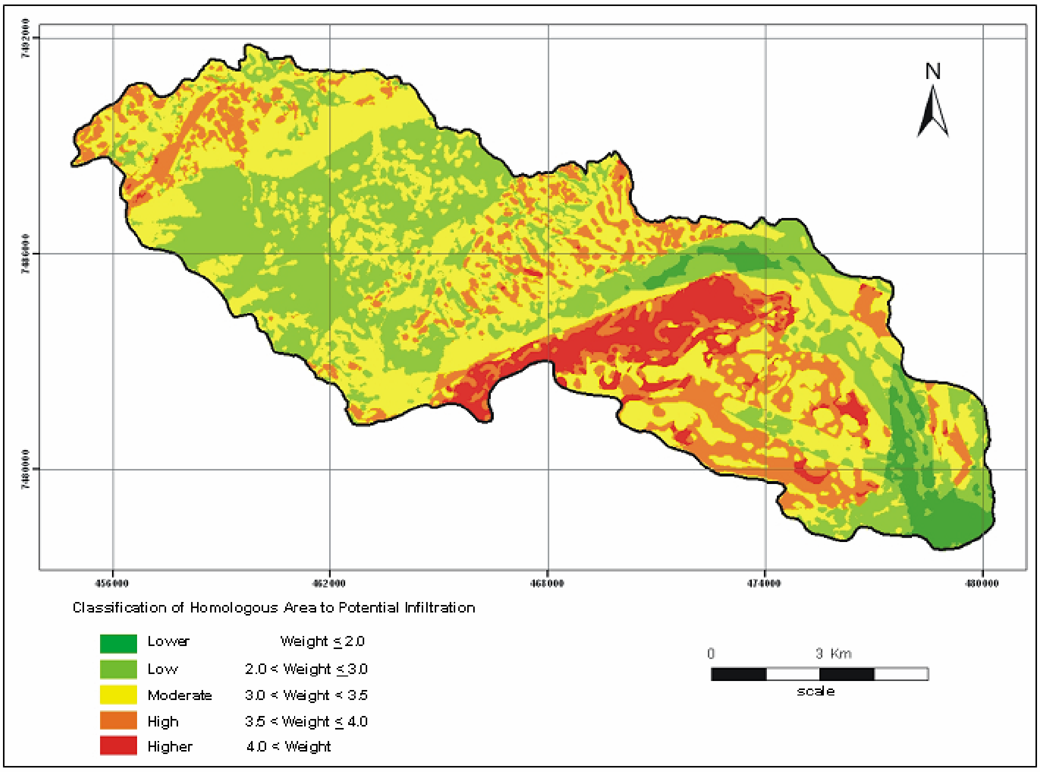

Fig. 2 - Homologous Areas for potential areas of infiltration in Guaratinguetá river Basin (1:50,000)

Keywords: potential infiltration area, water, GIS, land use.

The Tiretaine groundwater basin: volcanic and substratum regolith interactions (Chaîne des Puys, France)

[1]Sébastien LOOCK, [1]Hélène CELLE-JEANTON, [1]Guillaume BERTRAND, [1]Benjamin VAN WYK DE VRIES

[1] Laboratoire Magmas et Volcans, UMR 6524, OPGC, Université Blaise Pascal, 5 rue Kessler, 63038 Clermont-Ferrand, France, e-mail : S.Loock@opgc.univ-bpclermont.fr, H.Celle-Jeanton@opgc.univ-bpclermont.fr, G.Bertrand@opgc.univ-bpclermont.fr, B.vanwyk@opgc.univ-bpclermont.fr

ABSTRACT

The volcanic system of the Chaîne des Puys is quite unusual. Due to the basement morphology where lava flows have emplaced, these have followed former thalwegs. Such a geometry favors water circulation at the base of the flows along the substratum. Within the framework of our global study, it is fundamental to differentiate each lava flows from petrographic and geochemical evidences, but also to characterize the nature of the substratum on which they have emplaced.

As water chemistry is a direct function of the crossed terrains, we propose to use this relationship to specify the nature of these crossed terrains.

We have focused on the Tiretaine groundwater basin which has been the subject of two subsequent studies: major chemistry concerning five sampling places (Frémion, 2001) and electric soundings (Gagnière, 1980). We have completed these bibliographic data with a field study.

Results of the field campaign that was carried out in 2006 are displayed in fig. 1. The Tiretaine valley appears to be filled with four 45,000 years old stacked basaltic lava flows (F1 to F4). The enlargement of La Tiretaine basin was also mapped. The borehole of La Vacherie and the water catchments of Fontanas, Marpon and Les Grottes collect water from the clinkery (scoriaceous) base of the second flow (F2) whereas Kuhn is drilled in F3.

By using new geological data and electrical soundings performed by Gagnière (1980), the cross-section of La Tiretaine basin has been established (fig. 2). The latter confirms previous results by underlining that F2 and F3 have followed two different thalwegs. A direct relation between Kuhn and La Vacherie water catchments seems to take place in the altered part of the anatexite basement (fig. 2).

To achieve the chemical characterisation of groundwater, dataset (major ions) from 1992 to 1997 has been used (Frémion, 2001). This study was done to better constrain the water flow from the F2-thalweg to the F3-thalweg. The Ca^{2+}, Mg^{2+} and Na^{+} contents of Kuhn is higher than La Vacherie. This suggests circulation in a crystalline environment and confirms the relation between F2 and F3 aquifers through the sandy regolith (see the blue arrow on fig. 2). Consequently pumping up in Vacherie would lower the piezometric elevation in the sandy regolith and could lead to the drying of the Kuhn catchment (Frémion, 2001).

Potassium and calcium data are plotted in fig. 3. Fontanas water catchment shows intermediate values between La Vacherie and Kuhn, which could be considered as an artificial collector of both F2 and F3 aquifers. This K^{+} versus Ca^{2+} highlights two chemical trends: (1) La Vacherie-Fontanas-Kuhn water catchments (VFK) are characterised by a decrease of K^{+} and enrichment in Ca^{2+} contents; (2) Fontanas-Marpon-Les Grottes (FMG) show enrichment in K^{+} and Ca^{2+}. According to the chemical evolution and geological observations, these two trends could be attributed to the basement type: VFK reveals anatexite trend whereas FMG is due to a granite trend.

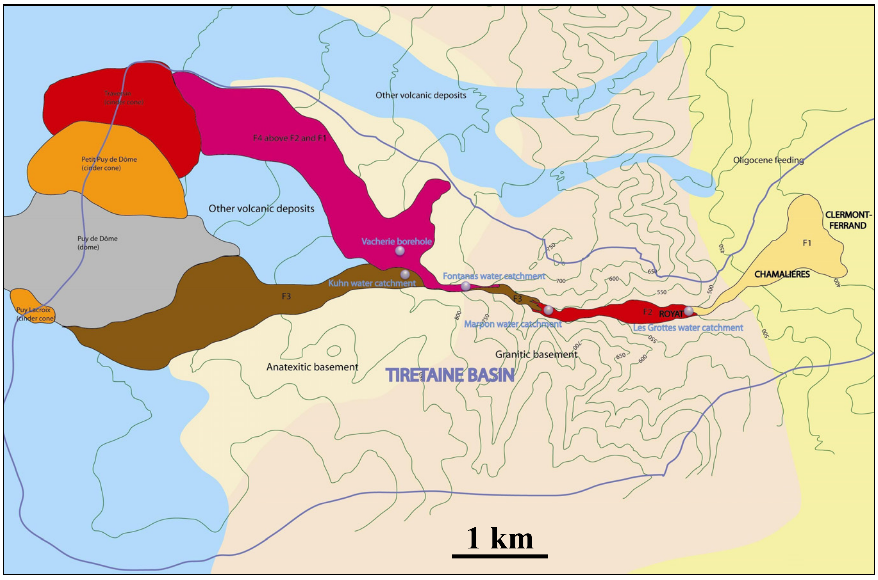

Fig. 1: Map of the Tiretaine groundwater basin showing the four lava flows stacking (F1 to F4), the water catchments location and basement petrography.

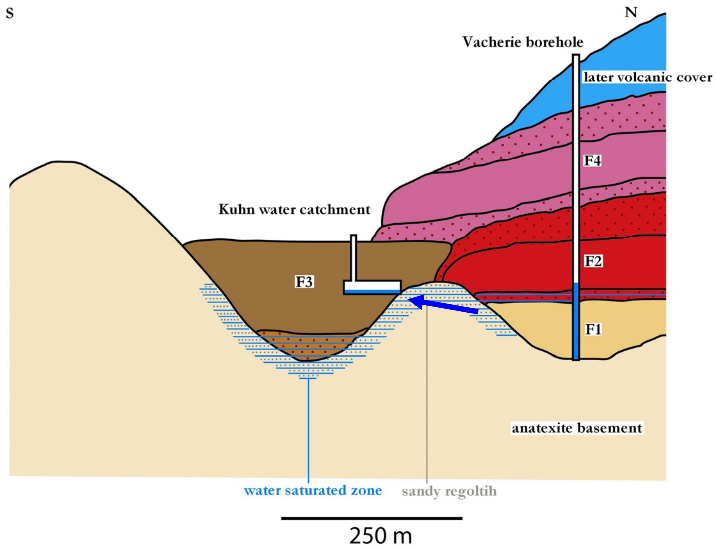

Fig.2: Cross -section through the Vacherie borehole and the Kuhn water catchment (modified, from Gagnière, 1980).

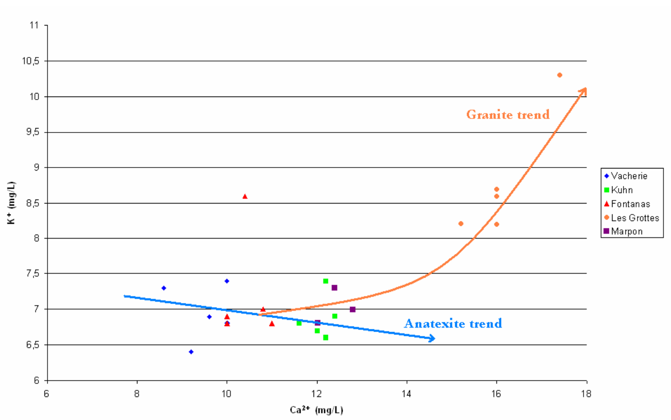

Fig. 3: Potassium versus Calcium diagram for La Tiretaine water catchments.

Keywords: volcanic aquifers, major ions, Chaîne des Puys, geological data, substratum.

Types and hydrogeologic features of surface and groundwater interactions in Uzbekistan

[1]Jusipbek KAZBEKOV, [2]Shavkat RAKHMATULLAEV, [3]Frédéric HUNEAU, [3]Philippe LE COUSTUMER

[1] International Water Management Institute, 123 Apt., Home 6 Murtazaev Street, Tashkent 700000, Uzbekistan, e-mail: j.kazbekov@cgiar.org
[2] Tashkent Institute of Irrigation and Melioration, 39 Kary Niyazov Street, Tashkent 700000, Uzbekistan, e-mail: rakhmatullaev@rambler.ru
[3] Université Bordeaux-1, CDGA, UFR Sciences de la Terre, B18 avenue des Facultés, 33405 Talence, France, e-mail: f.huneau@cdga.u-bordeaux1.fr, plc@lnet.fr

ABSTRACT

Uzbekistan is a landlocked country in Central Asia, with a total area of 447 400 km². It is bordered in the north by Kazakhstan, in the east by the Kyrgyz Republic and Tajikistan, and in the south by Afghanistan and Turkmenistan. The cultivated land is estimated at 5.2 million ha. Mainly because of water shortage, the cultivated area is only 20% of the cultivable area, estimated at 25.4 million ha. From a hydrogeologic point of view, the territory of Uzbekistan is divided into two parts – mountain and plain. Tectonically it is orogenic (post platform and mobile) belt of the Western Tian Shan and has complex geology. Hydrogelogically this zone represents a significant zone for groundwater development. The plain zone occupies the south-eastern part of the Turan plate and is characterized by almost horizontal arrangement of Mesozoic deposits on Palaeozoic base. Severity of the climate and plain relief causes the development of highly saline groundwater with limited resources in this place.

The average annual rainfall is about 264 mm. Two river basins are found in Uzbekistan. These basins form the Aral Sea basin: The Amu Darya basin in the south and the Syr Darya basin in the north. The total river flow generated inside Uzbekistan is estimated at 9.54 km^3/ year. The actual renewable water resources can thus be estimated at 50.41 km³/year. The largest lakes are: Lake Aydarkul storing about 30 km^3 in 1995; and the Sarykamish and Sudochie lakes storing 8 and 2 km^3 respectively. There are 52 reservoirs in Uzbekistan with a total capacity of about 19 km^3. In 1994, the total annual water withdrawal for agricultural, domestic and industrial purposes was estimated at 58.05 km^3. This amount included withdrawal from surface water (46.16 km³), from groundwater (7.39 km^3) and withdrawal from return flow collector-drainage for irrigation purposes, estimated at 4.5 km³. The total water withdrawal increased steadily from 45.5 km³ in 1975 to 62.8 km³ in 1985, mainly because of irrigation expansion. Since 1990, when the water withdrawal was 62.5 km³, the trend has been downward, due to agricultural water saving methods and a recession in the industrial sector.

Groundwater resources and particularly fresh groundwaters have a strategic importance for Uzbekistan. Nowadays groundwaters contribute to 10% of total water resources and groundwater withdrawals for drinking water supply are significant (60% of drinking waters come from groundwaters). So drinking water supply with fresh groundwater is vital today and will be even more strategic in future. There are 99 major aquifers in Uzbekistan, 77 of which provide fresh groundwater resources suitable for drinking water supply. Groundwater resources with mineralization up to 5 g/l are estimated to 24.09 km^3, and around 8.91 km^3 show mineralization up to 1 g/l. The most important groundwater resources are located mainly in Ferghana Valley (34.5%), Tashkent (25.7%), Samarkand (18%), Surkhandarya (9%), Kashkadarya (5.5%) provinces. Others represent only 7% of the resources in total. Renewable resource of groundwater is 8.34 km^3, of which 50% is for drinking purposes.

In 2002, the total water volume pumped for all purposes was 17.37 mln.m^3/day, of which 6.91 was pumped for drinking, 1.85 for industrial, 4.49 for irrigation and 3.82 drainage purposes. The analysis of the demand and resources indicate that Ferghana, Namangan, Andijan, Tashkent and Samarkand provinces have the capacity to develop its own water supply systems based on currently available explored fresh groundwater resources. The main shortage of water falls in the western and southern provinces, where the groundwater resources are decreased due to extensive agricultural development and because there are no options for detecting and developing new aquifers exploitation. From 1992 to 2002, the total amounts of withdrawals decreased (from 28 to 17.37 mln.m^3/day) and till 1998 the withdrawals for drinking purposes constantly decreased too (up to 5.2 mln.m^3/day). From 1975 to 1992, withdrawals of the fresh groundwater resources had increased from 12 to 28 mln.m^3/day due to drinking water supply and irrigation developments. The extraction of fresh water in western provinces has decreased owing to depletion of fresh groundwater resources and its removal with surface reservoirs such as Tuyamuyun, Kuyimazar and Talimardjan; poor technical conditions of the pumping stations; lack of maintenance; and unreliable electricity supply.

In 2002, Uzbekistan had 45,000 wells drilled, of which only 27,000 (60%) are operational. The rest is not operated due to above mentioned and other reasons. The groundwater resources have been decreasing continuously for last 30-35 years: if in 1965 its resources were 40.7 mln.m^3/day, in 2002 it has decreased to 16.3 mln.m^3/day, that is to say diminished by almost 40%. Hence, the understanding of the types of surface and groundwater exchanges will be extremely useful in recovering the diminishing aquifers and developing the fresh groundwater resources via available surface waters. The paper discusses the specific features of each type of water exchange and its evolution conditions; particular attention is given to the discussion of valley and pre-mountain types of water exchange since it has valuable practical (irrigation and drinking purpose) importance for research.

In the territory of Uzbekistan there are 5 types of water exchange concerning various hydrogeological structures. The duration and the intensity of water exchange between surface waters structures and accompanied aquifers characterize the sensitivity of the resources to indicators of influence (natural and anthropogenic factors of groundwater development and use). Rapid reaction is observed in the hydrogeologic zones of the Lower Amudarya, along fresh lenses of groundwater in the length of seasonal irrigation canals. Their resources are estimated to be 12% from total resources of groundwater in Uzbekistan. The artesian basins (artesian basins develop in the plain-depression parts of Uzbekistan, e.g. western and north-western and confined aquires are presented by Mesozoic and Cainozoic periods. These are Central Kizilkum, Eastern Kizilkum and North-Eastern Artesian Basins) enclose the 13% of all groundwater in Uzbekistan has reverse response, e.g. delayed – from 100 to 1500 years. Average duration of water exchange of 20-50 years is also calculated in intermountain troughs, river valleys, piedmont chains and debris cones.

Keywords: Groundwater resource, Drinking water supply, Surface-Groundwater relationship, Central Asia

Use of multi-depth electrical conductivity time-series data for understanding the interactions between groundwater and seawater in coastal aquifers

[1]Kue-Young KIM, [1]Ki-Hwa PARK, [2]Yoon-Suk PARK, [3]Nam-Chil WOO

[1]Korea Institute of Geoscience & Mineral Resources, Republic of Korea, e-mail: kykim@kigam.re.kr, pkh@kigam.re.kr
[2]Jeju Provincial Water Resources Management Office, Republic of Korea, e-mail: pys7992@provin.jeju.kr
[3]Yonsei University, Republic of Korea, e-mail: ncwoo@yonsei.ac.kr

ABSTRACT

Coastal aquifers have specific characteristics created by the interactions between fresh groundwater and seawater. Peculiar properties include tide-induced groundwater fluctuation and the existence of fresh-saltwater interface due to density contrast between the salt water and fresh groundwater. This study is concerned with the application of multi-depth sensors to record the temporal variations in electrical conductivity (EC) and temperatures by depth to characterize the transport of saline water in a multilayered coastal aquifer on Jeju volcanic island, Korea. Among the 36 seawater intrusion monitoring wells, two monitoring wells on the eastern part of the island, JD-1 and SS-1, were selected which are located at a distance of about 1 km from the shoreline. Eight multi-depth sensors for each monitoring well were installed to monitor EC and temperature and delineate where the fresh-saltwater interfaces occur and how they change by depth. Precipitation, tide level, water level, EC, and temperature data were recorded at 30-minute intervals during a period of June 1-July 31, 2006.

Approximately monthly profiles of EC and temperature at JD-1 and SS-1 were observed by the borehole geophysical logging system. The EC profile of JD-1 showed that the freshwater and saltwater had EC values of approximately 1,000 µS cm^{-1} and 50,000 µS cm^{-1}, respectively and the fresh–saltwater interface varied from –15 to –35 m. The EC profiles from SS-1 showed that fresh-saltwater interface formed at about -30 m varying within a range of 5 m. However, the EC value started to decrease from the depth of about -80 m and reached 10,000 µS cm^{-1} at the bottom of the borehole, implying that groundwater flows under the saltwater zone.

The time-series data obtained from multi-depth sensors, the EC value varied due to semidiurnal tides and the spring and neap tides. The end-member mixing analysis (EMMA) was carried out to determine the fraction of variations of chloride concentration in the groundwater. The result from JD-1 showed that the percentage of water derived from seawater varied from 23.6 to 31.6 at depth of -30 m during neap tide and varied from 1.3 to 41.3 during spring tide. The data from SS-1 revealed that the percentage of seawater varied from 27.6 to 38.2 at depth of -30 m during neap tide and varied from 3.1 to 78.7 during spring tide.

The effect of rainfall on EC variation showed that the interactions between groundwater and seawater are governed by different hydrological systems. Two periods of heavy rainfall during the observation period caused a significant decrease of EC value at specific depths of JD-1 monitoring well while EC value increased at specific depths by the effect of heavy rainfall at SS-1 monitoring well.

Integrating the results of EC profile, time-series data from multi-depth sensors, and EMMA, a conceptual model of freshwater and saltwater interactions is proposed. The continuous time series data quantified the variations of EC and temperature due to tidal fluctuations and this monitoring system may be used as an early warning system of the movement of saltwater into fresh water areas.

Keywords: Coastal aquifer, electrical conductivity, end-member mixing analysis, fresh-saltwater interface, multi-depth sensors

TOPIC 02

Groundwater quantity, baseline quality and main threatening processes in dependent ecosystems

A conceptual model for Flores Island (Azores) hydrogeology

José M.M. AZEVEDO

Centre of Geophysics & Department of Earth Sciences, Coimbra University - jazevedo@dct.uc.pt

ABSTRACT

Flores Island is one of the nine Azorean Islands. It is a volcanic building associated with the Middle Atlantic Rift activity. The present day subaerial volcanics expresses radiometric ages that fall between 0,0003 My and 2,11 My Bp.

Conceptualization of global and sectorial models for hydrogeological processes within this particular Island was mainly supported on:

- Detailed geological mapping (1:15.000) and the consequent deep knowledge about the spatial organization of rocks and volcanic structures;
- Characterization of surface hydrology, focussed to the evaluation of water input and balance.
- Outline of infiltration and aquifer recharge zonography.
- Localization and characterization of the island springs.
- Hydrogeochemical analyses and results interpretation.
- Comparison with proposed models to other volcanic islands, particularly the Canary and Hawaiian Islands.

The global model (Fig. 1) expresses a division of the insular volcanic building in:

- 3 Transversal and sub-horizontal hydrogeological domains (layers): upper, middle and lower
- Longitudinal hydrogeological compartments: nuclear and peripherals

The double-directional spatial organization admitted in this hydrogeological model allows the explanation of the distribution of the insular aquifer units and systems, as well as the groundwater circulation, storage and discharge. The hydrodynamics within the nuclear compartments are mainly vertical and includes localized discharge points for the peripheral compartments. Otherwise, in the external compartments the sub-horizontal water circulation prevails and usually supplies subaerial and submarine springs.

The model assumptions should contribute, not only to a correct and efficient management and exploitation of the restricted Island water resources, but also to the preservation of the endemic ecosystems once these specific habitats are mostly dependent on the spring discharge or grow on the main recharge domains.

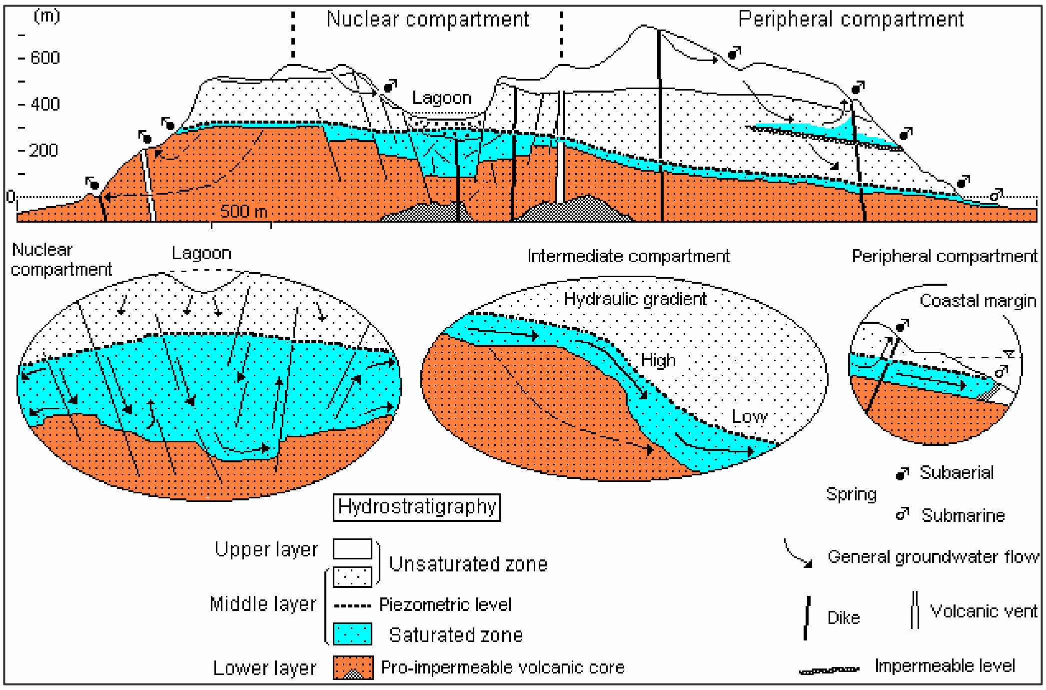

Fig.1. Sketch of the conceptual model proposed for hydrogeologic processes in Flores Island, Azores.

***Keywords**:* Volcanic Island, Conceptual model, Hydrogeological layers and compartments

A Toolbox for Assessing the Environmental Water Requirements of Groundwater Dependent Ecosystems in Australia.

[1]Richard S EVANS, [2]Peter G COOK, [3]Paul HOWE, [1]Craig A CLIFTON

[1]Sinclair Knight Merz, 590 Orrong Road, Armadale, VIC, 3143, Australia, e-mail: revans@skm.com.au ,
[1]Sinclair Knight Merz, P O Box 952, Bendigo, VIC 3552, Australia, e-mail: cclifton@skm.com.au [2]CSIRO Land and Water, Private Bag 2, Glen Osmond, SA, 5064, Australia,
e-mail: peter.g.cook@csiro.au
[3]REM, Suite 12, 15 Fullarton Road, Kent Town, SA, 5067, Australia, e-mail: paulhowe@rem.net.au

ABSTRACT

A technically focussed "toolbox' has been developed to provide Australian water and environmental managers with a range of techniques to assist in determining the environmental water requirements (EWR) of groundwater dependent ecosystems (GDE). In addition to providing details of the various techniques for identifying GDEs and estimating their EWR, the tools also indicate data requirements, the level of effort and expense required and the level of confidence in outputs and outcomes. The toolbox has been developed to assist in making informed decisions on water allocation that affect the health and function of groundwater dependent ecosystems. GDE assessment tools have been reviewed in the context of three broad types of GDE; terrestrial (or phreatophytic) vegetation communities, wetlands and river systems with a baseflow component. The tools themselves represent groupings of methods that can be used in some part of the GDE assessment process. A total of 14 tools have been included in the toolbox.

Keywords: Groundwater Dependent Ecosystems, Assessment Methods

Chemical status, natural background levels and threshold values for groundwater bodies in the Upper Rhine Valley (France, Switzerland and Germany)

[1]R. KUNKEL, [2]G. BERTHOLD, [3]A. BLUM, [3]L. GOURCY, [2]J.-G. FRITSCHE and [1]F. WENDLAND

[1] Research Centre Jülich (FZJ), Jülich, Germany (Email: f.wendland@fz-juelich.de)
[2] Hessian Agency for Environment and Geology (HLUG), Wiesbaden,, Germany
[3] Bureau de Recherches Géologiques et Minières (BRGM), Orléans, France
[4] Federal Environmental Agency (UBA), Dessau, Germany

ABSTRACT

According to the requirements of the EU Water Framework Directive (EU-WFD, article 17.2a) criteria for the assessment of the chemical status of groundwater have to be developed. These may serve as starting points for a trend reversal (article 17.2b) where the status is not good. Against this background in the EU project BRIDGE an EU-wide applicable approach to assess natural background levels (NBLs) and threshold values (TVs) for the definition of the groundwater -chemical status has been developed by the authors.

The procedure developed here has been applied to the aquifers of the Upper Rhine Valley Germany and France, i.e. aquifers with high relevance for water supply (Loose-rock sediments of Quaternary). In total, data from about 1700 monitoring stations were used. The natural background levels (NBLs) are assessed, based on observed concentration distributions for up to 50 different hydrochemical parameters (e.g. electric conductivity, O_2, pH, DOC, Ca, Mg, Na, K, NH_4, Fe, Mn, HCO_3, Cl, SO_4, NO_3).

In order to assess NBLs for each of the investigated parameters, the observed concentration distributions are separated into a natural and an influenced component. This is done by excluding samples with purely anthropogenic substances (e.g. PAC, pesticides) as well as samples, for which indicator substances for anthropogenic inputs (e.g. nitrate) exceed a certain value. The remaining groundwater samples are evaluated statistically. The NBLs are defined as the concentration range between the 10% and 90% percentiles of the concentration distributions in the selected samples.

The threshold values (TVs) are derived on the base of NBLs. In order to guarantee that the TV should be higher than NBL, but lower than "a not acceptable reference value" (REF), e.g. drinking water standards, ecotoxicological values etc., the TV is regarded as being the concentration value which is half of the difference (50%) between NBL and the reference value.

In this contribution, the methodology developed will be described, and selected results for the Upper Rhine Valley will be presented. This will be followed by the discussion of possible consequences for water resources management issues arising from the requirements formulated in the EU water directive with regard to the definition of the "good groundwater chemical status".

This project has been founded by the European Commission within the 6th EU Research Framework Programme.

Keywords: EU water framework directive (article 17), groundwater quality, natural background levels, threshold values, Rhine valley

Coastal Groundwater Discharge in the Ria Formosa identified as a major source of nitrogen to the lagoon's internal nutrient mass balance

[1]Catarina LEOTE, [1]Juan Severino IBANHEZ, [1]Carlos ROCHA

[1]Biogeochemistry group-CIMA, Universidade do Algarve, Campus de Gambelas, 8000 Faro, e-mail: cleote@ualg.pt, jibanhez@ualg.pt, crocha@ualg.pt

ABSTRACT

Coastal groundwater discharge (CGD) can be defined as any and all flow of water on continental margins from the seabed to the coastal ocean, regardless of fluid composition or driving force. It occurs every time that a continental aquifer is connected to the sea, and its hydraulic head is above the sea level, which turns it into a relatively common event. Most estimates of terrestrially-derived fresh groundwater discharge range from 6 to 10 % of surface water inputs, but this is not a well studied input, mostly due to its difficult identification and quantification. This event has already been detected and quantified in several places, usually showing a high temporal and special variability.

Frequently, these discharges are associated with nutrients of continental origin, representing a source of contamination to the coastal area. Depending on the coastal zone characteristics this contamination can cause different levels of the impact.

The Ria Formosa is a coastal lagoon located in the southernmost part of Portugal, in a region economically dependent on activities like tourism and fisheries. A high productivity is associated with the lagoon and there are several indicators that the Ria is nutrified. Numerous studies have mentioned the decrease in the water and sediment quality and in fisheries and shellfish stocks, as well as changes in the dominant primary producers.

A one-year field work period on the Ancão Península, located in the westernmost part of the Ria Formosa, revealed the presence of groundwater discharge in the inner side of the peninsula during the whole year. The groundwater discharge was measured using Lee-type seepage meters placed along the beachface. Several physical and chemical analyses were performed on the collected samples.

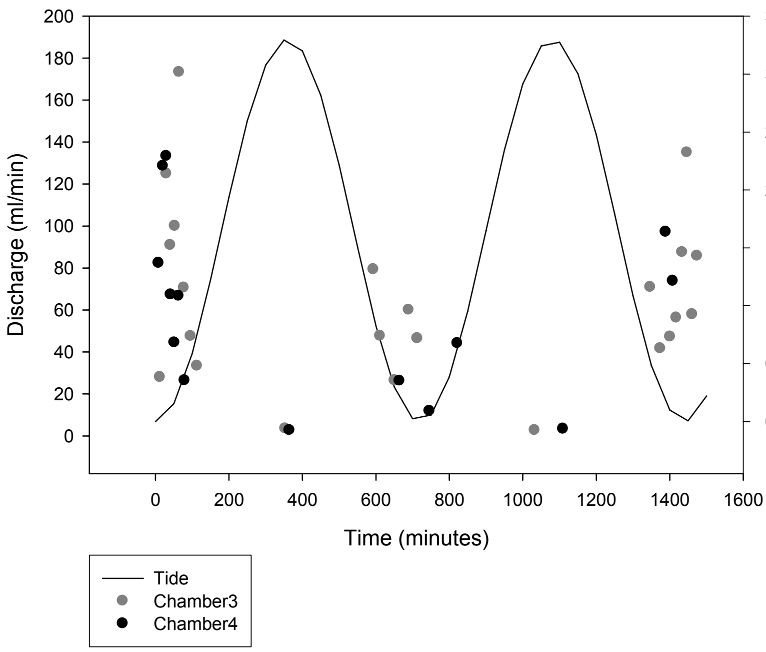

Fig. 1 – Discharge variation compared with the local tidal curve in March 2006.

The discharge is directly related with the tidal cycle, increasing over the low tide period (Fig.1), but also appears to be correlated with precipitation and inversely related to salinity (Fig.2).

The annual contribution of fresh groundwater to the coastal zone per meter of coast line was estimated as 106.51 m^3 $year^{-1}$ m^{-1}, which corresponds, considering a 50.5 km of barrier island coastline, to $5.38x10^6$ m^3 $year^{-1}$.

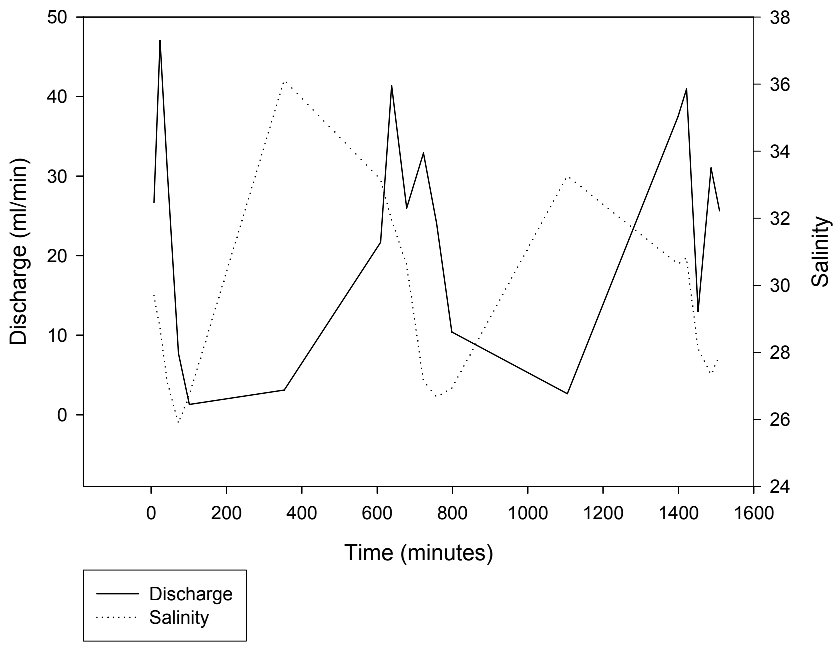

Fig. 2 – Relation between salinity and discharge in February 2006

We therefore will provide the first estimate of CGD-borne DIN discharged into the lagoon and compare it with previous estimates of non-point sources, which identify a non-determined source of nitrogen to the Ria's nutrient mass balance.

Keywords: Coastal groundwater discharge, Ria Formosa, sandy sediments, intertidal zone

Conservation of trial dewatering discharge through re-injection in the Pilbara region, Western Australia.

[1] Lee R EVANS, [2] Jed YOUNGS

[1] Pilbara Iron, PO Box 22, Tom Price WA 6751 Australia, lee.evans@riotinto.com
[2] MWH, PO Box 7031, Cloisters Square, Perth, WA 6850 Australia, Jed.Youngs@au.mwhglobal.com

ABSTRACT

Groundwater is an important resource supporting many ecosystems in the semi-arid Pilbara region of Western Australia. Large scale dewatering programs are a widespread feature of iron ore mining in the Pilbara. Innovative techniques such as aquifer reinjection of mine dewatering discharge are increasingly being investigated as practical solutions for the preservation of groundwater, where appropriate conditions exist.

Pilbara Iron, a member of the Rio Tinto Group, with the aid of MWH, recently completed a closed trial dewatering program which demonstrated how ecosystem protection can be furthered by innovative approaches to mine dewatering. A temporary drop-cut was dewatered to allow blasting, bulk sampling and backfilling. The approved trial program was run within the terms of a licence to take water granted by the Water and Rivers Commission of the Government of Western Australia. During three months of operation the discharge of over 6 ML/d was returned to the dewatered aquifer by re-injection through several bores along-strike.

Groundwater mounding and depression in the dewatered aquifer was limited in extent, both laterally and vertically; with full recovery of the aquifers occurring within months. Water levels within an aquifer associated with potential groundwater dependent ecosystems were relatively unaffected. The project demonstrated how small scale trial mine dewatering and large scale aquifer testing can operate with practically no net water usage, thus, no significant impact on aquifers or potential groundwater dependent ecosystems. Comprehensive monitoring of aquifer response during the program led to improved parameterisation of the existing groundwater model to develop it as a tool for future groundwater management at the site.

Keywords: Dewatering, mining, re-injection, modelling, management.

Derivation of natural background levels and groundwater threshold values for N and P in the Odense Pilot River Basin (OPRB), Denmark

Klaus HINSBY, Mette DAHL, Lisbeth F. JØRGENSEN and P. RASMUSSEN.

Geological Survey of Denmark and Greenland (GEUS), O. Voldgade 10, 1350 Copenhagen, Denmark.
E-mails: khi@geus.dk, md@geus.dk, lfj@geus.dk, pr@geus.dk

ABSTRACT

The EU Water Framework and Groundwater directives stipulate that the EU member states have to set groundwater threshold values to assess the chemical status of groundwater and to protect human health and the environment. We present an example of derivation of groundwater threshold values for nutrients (N and P) in Quaternary sand and gravel aquifers in the OPRB, based on environmental objectives for dependent aquatic ecosystems and a methodology for derivation of groundwater threshold values proposed by the EU project "BRIDGE". The derived groundwater threshold value for total dissolved N (DIN = NO_3-N + NO_2-N + NH_4-N) based on environmental objectives/quality standards for Odense Fjord Estuary, taking attenuation (mainly nitrate reduction in aquifers) into account, is 4.6 mg/L. This corresponds to a threshold value for NO_3 of 18 mg/L since NO_3-N generally accounts for 85-90 % of the DIN. The derived threshold value for total P (particulate P (PP) + dissolved reactive P (DRP)) is 0.08 mg/L corresponding to about 0.04 mg/L PO_4-P since PP in the investigated setting generally constitute about half of the TP. Dilution and attenuation is not taken into account for phosporus since data are currently not available for quantification of the effect of these processes.

Keywords: groundwater, threshold values, ecosystems, nutrients

Determination of groundwater background values in the Prims catchment (Saarland, Germany)

Thomas WALTER

Landesamt für Umwelt- und Arbeitsschutz, Don-Bosco-Str. 1, D-66119 Saarbrücken, Germany,
e-mail: t.walter@lua.saarland.de

ABSTRACT

When elaborating the status report on the quality of surface waters for the federal state of Saarland (Germany), as required by the European Water Framework Directive, a regionally widespread, elevated Nickel content was detected in some catchment areas. To investigate the reasons of this phenomenon, a study on natural background values of sources was carried out in a pilot basin (catchment of river Prims with 734 km², of which 608 belong to Saarland). 27 sources were selected and, when possible, for each source an additional surface water sampling point, at a distance of not more than 1 km downstream, to analyse possible changes of the composition under atmospheric conditions. For every monitoring point a detailed fact sheet describes geological setting, hydrogeological conditions, land use etc., so that possible anomalies should easily be attributed to local natural or anthropogenic conditions. Three samples were taken at every point at different times, combined with discharge measurements, and analysed (major ions, minor and trace constituents).

The catchment area consists mostly of clastic sediments of different genesis: headwaters belong to marine Devonian schists and quartzites (DSQ, 5 sampling points), while the lower part of the catchment is formed by continental postvariscan debris. These were deposited under tropical (Upper Carboniferous and lower Permian coal seams, shales, sandstones and conglomerates, 11 sampling points) or desertic conditions (Middle Permian sandstones and conglomerates, 6 sampling points), further down (abbreviated as CLP and MPS). Intercalated and intruded into the Younger Palaeozoic sediments there are Permian volcanic rocks (PVR) of mostly andesitic composition (4 sampling points). Marine, Triassic carbonaceous sandstones (TCS) form only a very small portion of the catchment area and are represented by one sampling point, while, within the Lower Triassic sandstones no appropriated sampling point could be detected. Different sedimentation conditions originate different geochemical fingerprints with especially high values of trace elements for the carboniferous sediments and the volcanic rocks. Groundwater composition of these rocks should therefore also reflect an elevated background of trace elements.

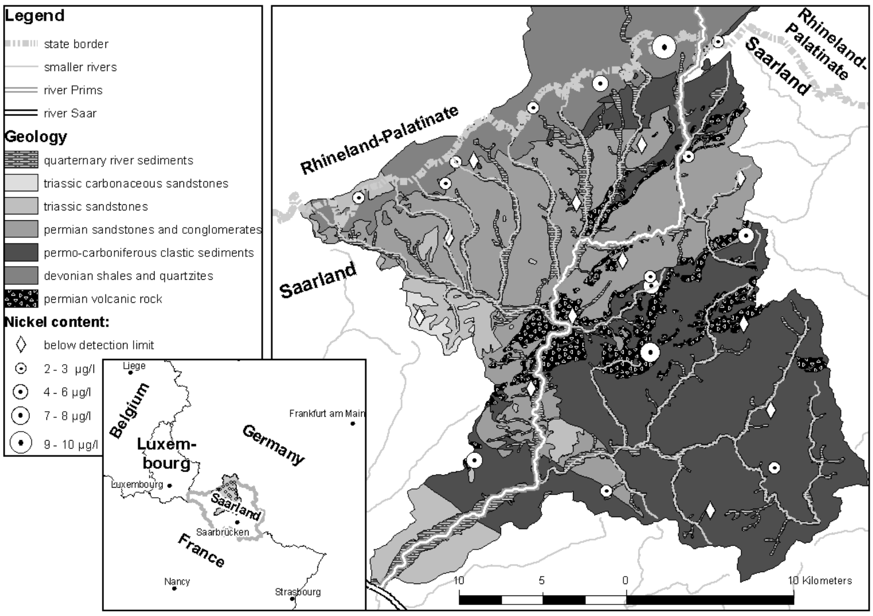

Fig. 1: Prims catchment with sampling sites and respective nickel contents.

In exploration geochemistry, cumulative normal or lognormal probability graphs are standard practice (Lepeltier, 1969; Sinclair, 1976), but have also been used recently in hydrogeology to determine background values in groundwater (Folkes et al., 2001; Panno et al., 2006).). In cumulative normal probability graphs, normally distributed data plot on a straight line. Mixed distributions or other deviations from normality can easily be detected by the presence of inflection points. The procedure thus consists basically in fitting a line to the longest straight segment of data, representing the bulk of data. Anomalies at the upper or, if present, also on the lower end of the data distributions are thus filtered out. For this purpose, a self-developed, semi-automated Excel-tool was used, which already has been employed for other studies in Saarland (Walter 2004). As background level the 95th percentile of the normal population was assumed.

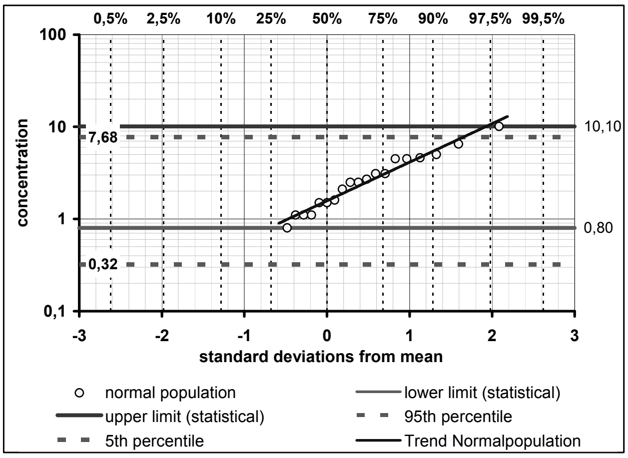

Fig. 2: Cumulative lognormal probability plot of Nickel. 8 values below detection level were taken into consideration. Data fit very well to the straight line and no data could be identified as anomalous. Solid lines = statistically defined thresholds of the distribution, dashed lines = 5th and 95th percentiles for normal population.

In the case of Nickel, a fairly high background value of 7.68 µg/l (mean = 1.57µg/l) has been detected for the Prims catchment. Tests on deviations from normality gave no evidence of possible deviations from lognormal distribution. This background value thus would be representative for the whole catchment. However, inspection of Fig. 1 shows that the highest value belongs to DSQ and a series of elevated values lie within PCR and group around the outcrops of PVR, whereas the lowest values occur mostly within MPS. A contrasting calculation for the analyses from PCS sources results in a background value of 7.21 µg/l (mean = 2.22µg/l), thus not far from the results of the calculation for the whole catchment. The PCS, probably influenced by volcanogenic mineralisation, therefore seem to control the Nickel concentration in the Prims catchment. Probably the several groups superpose in a way that again results in a normal distribution. Unfortunately, the amount of data for the other geological groups does not yet allow for a determination of their respective background values. When analysing the neighbouring catchment areas, more data will be available for the different lithological groups and the underlying pattern of element distribution will be studied further.

For the assessment of background values in a certain area, the geological setting must be taken into consideration, even when statistically conclusive results should have been attained not doing so. However, for certain purposes it might be justified to apply the statistics to the whole area. An example is in the present case, when it concerns an investigation of background values for surface water assessment, because all waters mix linearly downstream. But even so, grouping the sampling points into lithochemical groups, determining the background values and recalculating the final values based on area and baseflow ratios seems to be best.

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Keywords: European Water Framework Directive, background values, normal cumulative probability plot

Estimating background values in shallow aquifer of Potiguar Basin - Rio Grande do Norte state – Brazil

[1]Paula STEIN, [2]José Braz DINIZ FILHO, [3]Edeweis R. CARVALHO JÚNIOR, [4]Germano MELO JÚNIOR, [5]Fátima B. CARVALHO, [6]FÁTIMA F. do ROSÁRIO

[1] Geology Department, UFRN, Brazil. E-mail: paula.stein@gmail.com
[2] Geology Department, UFRN, Brazil. E-mail: brazdf@geologia.ufrn.br
[3] Security, Environment and Health, UN-RNCE/PETROBRAS, Brazil. E-mail: edeweis@petrobras.com.br
[4] Geology Department, UFRN, Brazil. E-mail: germano@geologia.ufrn.br
[5] Environmental Monitoring and Assessment, CENPES/PETROBRAS, Brazil. E-mail: fatc@petrobras.com.br
[6] Biotechnology and Environmental Treatments, CENPES/PETROBRAS, Brazil.
E-mail: fatimarosario@petrobras.com.br

ABSTRACT

The petroliferous industry (Onshore) in the Potiguar Basin undertook a series of interventions that could affect the environment. It was considered necessary to do the environmental monitoring under different natural compartments that could potentially be affected by these activities.

In this context it was necessary to establish the background values for the ground waters compartment in the basin without the possible influence of the oil activities under geologic, pedologic and climatic similar conditions.
This study area is situated in a semi-arid region of Brazil and partially involves Mossoró, Assu and Macau municipalities.

Several hydrogeologycal studies were performed, including the private wells cadastre and percussion bore, with the aim of defining the underground flow.

The main aquifer in this basin corresponds to the Jandaíra Formation limestone, which presents the occurrence and saturated thickness uniform spatially.

The groundwater flows are similar to the superficial waters drainage, indicating the free nature of the aquifer, which is influenced by the local relief.

Using the potenciometric dates, the sites for the monitoring wells installation were indicated. So too, groundwater sampling was done to establish the background values in upstream sectors to indicate the areas of petroliferous activities.

A total of 15 monitoring wells were installed and ground waters sampling will be accomplished two climatic periods: the waterless period (January of 2007) and the rainy period (May of 2007). For the groundwater sampling the Method of Low Flow was applied, which showed that an efficient methodology capable to supply water samples that are representative of the hydrogeologic environment in which they circulate.

Keywords: background values, groundwater, petroliferous activity, low flow sampling.

Geochemical behavior of major elements in Triassic aquifer (South eastern Tunisia)

[1] Fadoua HAMZAOUI, [1] Rachida BOUHLILA, [2] Moncef GUEDDARI

[1] Laboratoire de Modélisation en Hydraulique et Environnement (LMHE)-Ecole Nationale d'Ingénieurs de Tunis, Tunisia, e_mail : fadoua_fst @yahoo.fr; e_mail: bouhlila.rachida@enit.rnu.tn
[2] Unité de Recherche de Géochimie-Faculté des Sciences de Tunis, Tunisia,
e-mail : moncef.gueddari@ fst.rnu.tn

ABSTRACT

The chemical composition of groundwater is controlled by many factors that include geological structure and mineralogy of the watersheds and aquifers, and geochemical processes within the aquifer. Ground-water in southern Tunisia is an important source of drinking water.

The study consists in identifyING natural and anthropogenic factors that influence the water quantity and quality parameters in the Triassic aquifer, located in South–East of Tunisia (Fig.1).

Major elements concentrations as well as temperature, pH and salinity, were monitored from 2004 and 2005 in 16 wells capturing the Triassic aquifer (Fig.2). Water of the Triassic aquifer is used unevenly by different economic sectors. However, drinking water supply remains the primary use. Anthropogenic activities in this region rely mainly on agricultural activities.

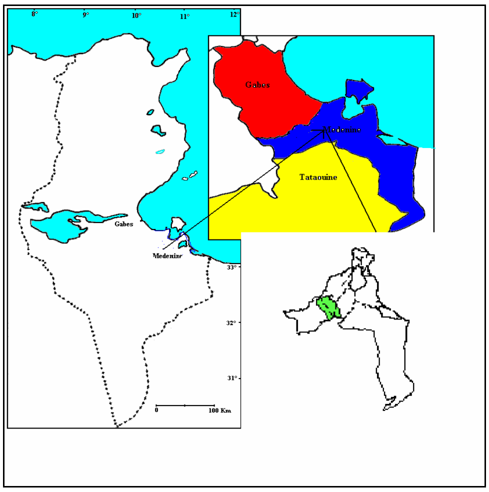

Fig.1: Location of study area

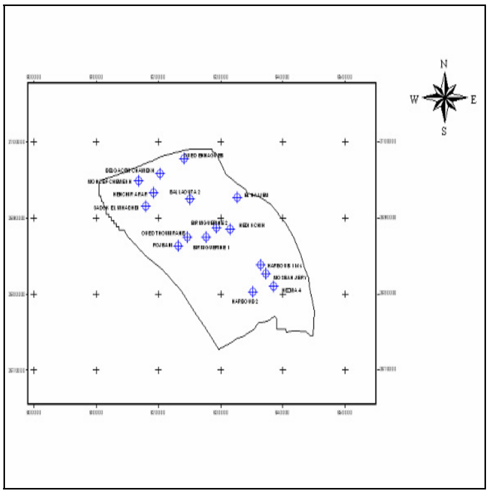

Fig. 2: Sampling point's location

The stratigraphic layers in the study area range from the Permian to the Quaternary. The region is bordered by three main structures that define South-East Tunisia: the Dahar monocline, West and North-West; the Medenine Tebaga monocline, South, and the plain of the Djeffara, East and North. The hydrographical network is quite dense and the main wadiis in the region are Smar, Zeuss, Om Ezzassar, Morra. The general flow runs from the South-West to the North-East,

Exploratory analyses of experimental data have been carried out by statistical analysis (PCA and CA), geographic information system (GIS) and graphical representations in an attempt to discriminate sources of variation of water quality.

The application of PCA has achieved a meaningful classification of wells waters samples based on seasonal and spatial criteria.

Results reveal that salinity and the major elements concentrations, with the exception bicarbonates, increase towards groundwater flow. The saline load of these waters is in first place controlled by sulfphate, chloride, calcium and sodium concentrations.

The distribution of the salinity rations shows the same regional zonation as the one observed for chloride, sodium, sulphate, magnesium and calcium. Salinity spatial distribution indicates that waters in Mguerine, Ballouta, Rojbani and Mhadbi wells are characterized to be the lowest in dissolved salts. This fact can be explained by the significant rain infiltration along the wadiis. The chemical composition interpretation clearly evidences tow main geochemical facies SO4-Cl-Na and Cl-Na.

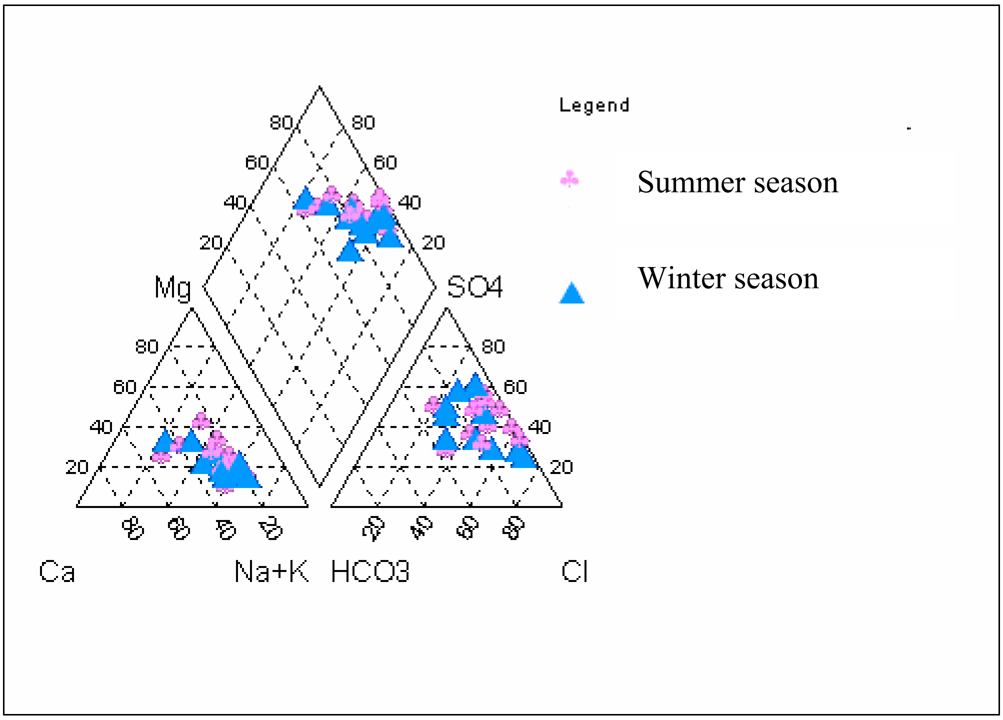

Fig.3. Piper diagrams

The results of this study show that detailed hydrochemical data can help to elucidate the hydrologic and geologic factors controlling water chemistry on a Triassic aquifer.

Keywords: Groundwater, geochemistry, major elements; multivariate data analysis, Triassic aquifer

Geochemical groundwater evolution in Cuatrocienegas closed semi-arid basin: origin of the missing saline water

[1]Antonio CARDONA, [2]Carlos GUTIÉRREZ-OJEDA, [2]Manuel MARTÍNEZ-MORALES, [2]Luis GONZÁLEZ-HITA, [2]Ismael MATA-ARELLANO, [1]Arturo PÉREZ-MORÁN, [2]Alvaro A. ALDAMA, [2]Javier APARICIO, [2]Miguel A. MEJÍA-GONZÁLEZ

[1] Ciencias de la Tierra, UASLP, Av. Manuel Nava No. 8, Zona Universitaria, 78290, San Luis Potosí, Mexico
[2] Instituto Mexicano de Tecnología del Agua, Paseo Cuauhnáhuac 8532, 62550 Jiutepec, Morelos, México

ABSTRACT

Since the 1960's, the Cuatrocienegas basin has been well known to be an important center of floral and faunal diversity and endemism. In the last five years an important debate taken place in this region. It is thought that groundwater extractions and diversions, invasive species and impacts of increasing tourism are threatening its great biotic richness. Fortunately, in 1994, Cuatrocienegas was declared a Natural Protected Area that is now managed locally by the office of the Area de Proteccion de Flora y Fauna Cuatrocienegas (APFFCC), under the direction of CONANP, a unit of SEMARNAT, the federal Secretary for the Environment, Natural Resources and Fisheries in Mexico. It is part of the Chihuahuan freshwater xeric ecoregion, located from southeast Arizona across New Mexico and west Texas and southward deep into Mexico; and characterized by river basins remarkably different from one another, each containing unique species that have evolved over time following a series of tectonic events and resulting geographic isolation. The Cuatrocienegas basin includes a plain region with around 300 springs (water temperature between 29-31°C in the warmest, more than 12°C above mean annual air temperature in the basin) supporting a diverse subtropical desert basin fauna with a high degree of local endemism. Biologists have identified more than 70 endemic species; for example, half of the 20 species of fish, and 23 of the 34 species of freshwater mollusks are endemic. In this habitat there are 89 species listed in the federal Mexican endangered species list, 16 as in danger of extinction, 39 as threatened, and 34 subject to special protection. Also it is important to mention that it is one of few places in the world with living stromatolites (reef-like mineral deposits left by aquatic bacterial colonies).

In this investigation, the hydrochemical and isotopic evolution of groundwater in the Cuatrocienegas basin are described. Groundwater in the Cuatrocienegas basin actually evolves from HCO_3-Ca to SO_4-Ca-Na type over a distance of less than 50 km. This region was investigated using a combination of different indicators including groundwater flow direction and hydraulic properties of geologic units, chemical and isotopic that data were combined with chemical equilibrium and mass balance relationships. This information was used to explain the chemical reactions and processes responsible for identified geochemical evolution from recharge areas north of the basin to discharge areas in the plain.

Groundwaters in the Cuatrocienegas basin have salinities generally below 4000 mg/l and are aerobic and oxidizing. A small component of modern (< 50 years) was identified in the recharge area of the eastern part of the basin from tritium data; it has low salinity (< 500 mg/l) and HCO_3-Ca type in equilibrium with calcite. Groundwater mineralization increases down-gradient along the karstic aquifer and the sedimentary basin fill, gypsum dissolution from layers within the carbonate sequence produces a SO_4 rich water, the $\delta^{34}S$ composition is consistent with the dissolved oxygen content suggesting that no SO_4 reduction takes place along the flow path and confirms dissolution of Mesozoic gypsum to be the main source for SO_4. Discharge zones in the plain are characterized by saline soils with abundant phreatophyte vegetation; discharged waters in the main springs are in equilibrium with gypsum; degassing of CO_2 and evaporation as evidenced by δ^2H and $\delta^{18}O$ data produces additional carbonate precipitation. Trends in both major and trace elements (Li, B, Br, Rb, Sr, I, Cd, Mn, Fe) demonstrate a progressive evolution along the flow path. Nitrate is present at baseline concentrations, but evidence suggests that in some regions of the basin, actual agricultural practices are producing a detrimental impact of high NO_3 from irrigation return flow, about 0.5-0.7 m^3/s of water derived from springs are used for irrigation purposes within the basin, as well as additional abstraction from wells. Mineral/groundwater equilibria and estimation of mass transfer indicate that groundwater composition is largely controlled during flow along the aquifer by carbonate and sulphate dissolution, dedolomitization and cation exchange. Discharge areas are characterized by concentrations of salts due to evaporation processes, producing additional carbonate (calcite, magnesite, stroncianite and dolomite) and sulphate (gypsum, celestite and barite) as well as kaolinite and silica precipitation. Considering prevailing semi-arid conditions, the expected geochemical evolution of groundwater should reach SO_4-Na (as in the adjacent El Hundido basin) or Cl-Na facies (salinity higher than 30,000 mg/l). It

is inferred that the observed incomplete geochemical evolution is related to the man-made aperture (in recent times) of the originally closed basin to irrigate neighboring La Madrid basin; the Saca-salada canal delivers about 1 m^3/s to that basin. A modeling exercise was made to simulate groundwater composition produced by a continued evaporation processes in a closed basin. These results have important implications for groundwater management in the Cuatrocienegas basin, because it is hypothesized that final saline water composition obtained from the evaporation of groundwater, could represent the missing "ocean" that some biologists are looking, since they found that 50% of the phylotypes from total microbial communities in the area, are closely related to marine taxa.

Keywords: Ecosystems, Mexico, hydrochemistry, inverse modelling, stable isotopes.

Groundwater faunal responses to desiccation and water table change

Moya TOMLINSON, Peter J HANCOCK, Andrew J BOULTON

Ecosystem Management, University of New England, Armidale NSW 2351, Australia,
email:mtomlin2@une.edu.au, phancoc2@une.edu.au, aboulton@une.edu.au.

ABSTRACT

Recent water reforms in Australia have mandated environmental allocations in water resource planning. For groundwater this requires consideration of the water requirements of groundwater dependent ecosystems (GDEs), including aquifers. Surveys in Australia indicate diverse and endemic communities of specialised groundwater fauna (stygofauna) in shallow alluvial aquifers, but how are these communities affected by groundwater extraction which alters the frequency and amplitude of fluctuations in water level? We used experimental microcosms to investigate the ability of groundwater copepods and amphipods to survive desiccation in drying sediments. We also assessed their ability to move vertically with changes in the sediment moisture content. Results indicate that both groups of invertebrates can survive short periods of desiccation but have differing responses to water level fluctuations. Small copepods were able to track declines in the water level, whereas the larger amphipods became stranded, and did not move vertically through the sediments in both the control and the treatment microcosms. These results illustrate the varying sensitivities of stygofauna to water level fluctuations, and must be considered in guidelines and policies for the future management of groundwater resources and their sustainable use.

Keywords: stygofauna, desiccation resistance, groundwater management

Groundwater status in the two nitrate vulnerable zones of the Algarve – concerns for the adjacent wetland and agro-ecosystems

[1]Tibor Y STIGTER, [1]Amélia MM CARVALHO DILL, [2]Luís RIBEIRO, [3]Edite REIS

[1] CVRM/Geo-Systems Centre, FCMA – Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal, tstigter@ualg.pt, amelia.dill@ineti.pt
[2] CVRM/Geo-Systems Centre, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal, nlrib@alfa.ist.utl.pt
[3] Comissão de Coordenação e Desenvolvimento Regional do Algarve, Rua Dr. José de Matos, 13, 8000-503 Faro, Portugal, ereis@ccdr-alg.pt

ABSTRACT

In compliance with the Nitrates Directive 91/676/EEC, two nitrate vulnerable zones (NVZs) were designated in the semi-arid region of the Algarve, in the south of Portugal. The NVZ of Faro was designated in 1997 and the question is whether, in the decade that has followed, the implemented measures have effectively reduced the nitrate contamination levels. The NVZ of Luz-Tavira was designated only recently, in 2005, after a long debate between the Ministries of Agriculture and Environment as to the origin of nitrate in groundwater. Point source contamination is caused by leakage from septic tanks, but is of much smaller dimension than the diffuse source from agriculture. In 2001, locally extracted groundwater was substituted by regionally supplied surface water for irrigation, which had a large impact on the aquifer dynamics and hydrochemistry.

The aim of this paper is to show the present groundwater status in the two NVZs, under influence of changes in agricultural practices that occurred, partially within the scope of the Nitrates Directive. These changes had short-term impacts and may have long-term impacts on adjacent ecosystems, such as the agroecosystem of the areas or the wetland ecosystem of the Ria Formosa lagoon, that borders the areas to the south. Monitoring and investigating these impacts is an essential contribution to the preservation of these ecosystems.

In the NVZ of Luz-Tavira, an area of intensive citrus culture, an immediate consequence of the shift in irrigation supply was a sharp rise in the water table, followed by an almost complete attenuation of interseasonal oscillations. Groundwater discharge greatly increased, due to: i) the deactivation of a large number of wells and ii) the additional recharge from excess irrigation with surface water. In the short-term, the increased discharge led to the reactivation of several springs that constitute local aquifer outlets. During a field campaign in the summer of 2004 average spring discharge was measured to be 5.8 l/s, comparable to average aquifer yield values. These springs were previously only active in periods with large amounts of rainfall. Groundwater recharge could further increase in the future, as although studies on global climate change generally predict a decrease in rainfall amount in semi-arid regions such as the Algarve, they also foresee an increase in rainfall intensity. In the absence of groundwater extractions, a further rise of the water table could have a direct impact on the agroecosystem, as the root zone becomes increasingly saturated and drainage is complicated, thereby potentially damaging the citrus trees.

In the NVZ of Faro the action programme was officially implemented in 2001, but so far has not led to the desired lowering of nitrate levels. In fact, time series analysis reveals that in the south, nitrate concentrations are increasing, whereas in the centre, the observed decrease of nitrate levels is caused by a dilution effect (higher recharge), rather than a reduction of the actual nitrogen load. The increasing nitrogen load is contrary to the salinity trend as indicated by the conservative chloride ion, which points to mineral fertilisers as the main source, since domestic effluents are clearly a source for both nitrate and chloride. These are important findings that may contribute to the discussion on the role of wastewater in nitrate contamination of groundwater in the areas.

The absence of an overall decreasing trend in the upper aquifer leads to the conclusion that thus far the action program implemented in compliance with the Nitrates Directive (including the mandatory application of the Code of Good Agricultural Practices) has not been successful. The existence of a time-lag is inevitable, since the groundwater residence times are high (in the order of decades). However, there may be a continuing lack of adequate fertilisation plans, as the farmers often lack the knowledge and/or technical support to improve their practices. On the other hand, the agricultural lobby fears that the production and consequently the financial situation of many farmers will be seriously affected by the imposed measures of the Nitrates Directives.

Groundwater monitoring in the NVZ of Faro shows that the diffuse, well-defined nitrate contaminant plume, with concentrations exceeding 300 mg/l, is moving southwards towards the Ria Formosa lagoon, an extremely valuable and sensitive wetland ecosystem. There is an ongoing research project that studies the

appearance of green ulvoid algae blooms in the lagoon, as well as on the sandy beaches of the adjacent coastal zone. More specifically, the project seeks to identify the species-specific nitrogen metabolism of the blooms and to relate them with the nitrogen mass balance between the lagoon and the adjacent terrestrial and coastal zones. The role of groundwater as a nutrient source for these algae is also being studied and some results are presented in another paper of this congress.

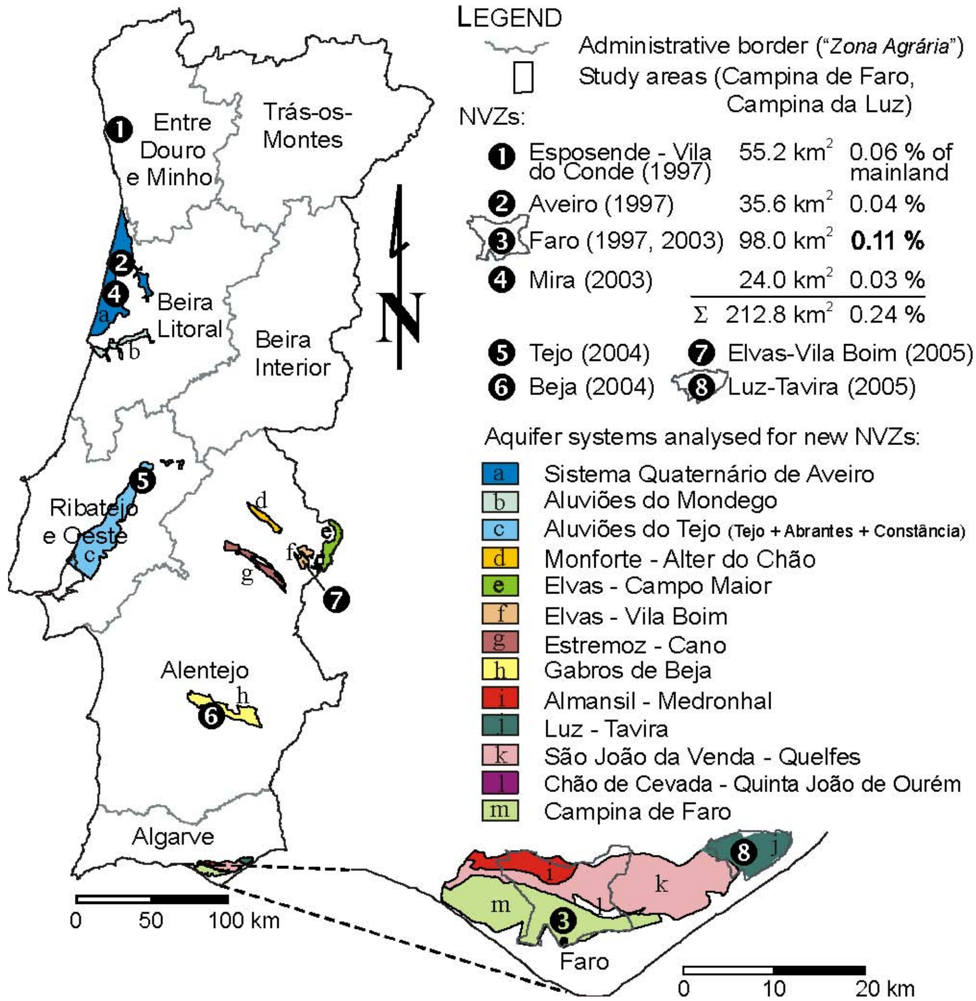

Fig. 1. Location of the NVZs designated on the Portuguese Mainland and the aquifer systems analysed with regard to the risk of agricultural pollution; modified from Stigter *et al*. (2006b).

Keywords: Nitrates Directive, groundwater monitoring, time series analysis, Ria Formosa, agro-ecosystem

Impact of longwall mining on surface water-ground water interaction and changes in chemical composition of creek water

[1]Jerzy JANKOWSKI, [1]Brian SPIES

[1]Sydney Catchment Authority, Level 2, 311 High Street, Penrith NSW 2750, Australia,
e-mail: jerzy.jankowski@sca.nsw.gov.au
[1]Sydney Catchment Authority, Level 2, 311 High Street, Penrith NSW 2750, Australia,
e-mail: brian.spies@sca.nsw.gov.au

ABSTRACT

Longwall mining, also known as the full extraction method, is the most common method of underground coal mining in Australia and other parts of the world. This method of coal mining is the most economic and efficient and provides predictable subsidence impact. Twenty-seven longwall mines are operating in Australia producing about 78 million tonnes of raw coal in 2005.

In the vicinity of creeks and rivers mine subsidence movements result in reactivation of existing fractures, joints, lineaments and faults, and development of new fractures or fracture zones. This impact is widespread in many catchments affected by longwall mining. Mining-induced fracturing depends on a number of factors including: depth of cover and proximity of the mining to a river, panel width and extracted thickness, topographic factors associated with the river valley such as valley depth and steepness, local, near-surface geological factors such as bedrock lithology, thickness of bed strata, orientation and dip of strata, degree of cross-bedding and existing jointing, and in-situ horizontal stresses in the bedrock. Longwall mining can have a significant impact on surface hydrology, groundwater system and water quality as a consequence of the subsidence, additional fracturing or reactivation of existing joints. Horizontal rock movements due to subsidence are often detected up to 1500 m from the edge of longwall panels and sometimes distance is up to 3 km from the edge of the panel. Ideally, a 1-km mining-free save zone is required to prevent river from cracking and losing water into groundwater routes, compared to the more frequent 100 m buffer zone.A research study on the impact of longwall mining on water resources has been conducted in a small catchment in New South Wales, Australia (name of the catchment and colliery withheld). The surface water system is affected by longwall mining activities with consequent subsidence in the valley. The specific impact of longwall mining in the researched catchment is subsidence and development of new fractures/fracture zones, fracturing of riverbeds and rockbars, decrease of surface flow due to flow diversion from the surface to the subsurface routes, alteration of surface water pattern, increased exchange of surface water and groundwater, lowering the water table and potentiometric surface in groundwater system, additional ponding and flooding, additional erosion of a riverbed, changes to stream alignment, deterioration of surface and groundwater quality and reduced biodiversity of aquatic ecology. Subsidence from longwall mining panels directly underneath the creek produces significant impact on low flow through fracturing of creek-beds and rockbars and development of ponds in the waterway channel. A significant proportion of the low flow is lost into subsurface routes with some groundwater re-emerging downstream. Intensive interaction between surface water and groundwater occurs along the fractures and fracture zones across a creek channel. Surface waters recharge the subsurface system and flow underground for distances of a few hundred metres. They partially re-appear on the ground surface where groundwater discharges from a set of fractures under artesian pressure. The volume of water that recharges the aquifer and discharges downstream to a creek is presently unquantified but appears to be substantial. During high flow conditions, loss of water is relatively minor as stream capacity exceeds that of the subsurface pathways. By contrast, during low flows most of the surface water disappear into the underground system. The system diverts surface flow to subsurface flow resulting in dry creek-beds and leaking pools.

Comparison of chemical composition of surface water samples upstream of a longwall panels and downstream indicates that significant changes in water chemistry and quality. Surface water downstream contain much higher EC, pH and content of major, minor and trace elements, and significantly lower Eh and concentration of DO. Subsidence leads to the development of new fractures in the creek channel increasing exposure of fresh rock to inflowing surface water. Where subsurface cracks and new fracture networks allow surface water to mix with flowing groundwater, the resulting mixture may enhance chemical processes and water-rock interaction. Deterioration of water quality occurs through elevated content of metals and increased salinity and aesthetic change of the river channel through precipitation of reddish/brownish iron-oxides/hydroxides. The occurrence of metal precipitates and iron-oxidising bacteria is particularly evident where groundwater discharges through surface cracking into surface water. Iron- and manganese- oxidising bacteria

commonly occur together with metal precipitates in areas where seepages discharge from fractured rock that contain iron-rich minerals.Chemical reactions increase the concentration of Ca, Na, Mg, HCO_3, Cl and SO_4 in water discharging from subsurface routes to surface channel. The pH and HCO_3 increase due to chemical reactions involving carbonate minerals calcite, siderite, rhodochrosite, strontianite and barite, which are the main carbonates in the aquifer matrix. The presence of metal carbonates enable iron, manganese, strontium and barium to mobilise, significantly increasing the concentration of these elements downstream where subsurface flow re-emerges at the ground surface. The highest rates of chemical reactions occur during and after rainfall events when acidic rain water and surface run-off infiltrate into the subsurface system and mobilise elements from carbonate minerals.Concentrations of iron and manganese initially increase as groundwater discharges from the subsurface. However, a few hundred meters downstream dissolved metal concentrations decrease as Fe, Mn and Zn oxides and hydroxides are precipitated causing yellowish through orange/red to brownish stains in the creek channel. Discharge of groundwater rich in iron and manganese into the creek causes the development of thick mats of iron/manganese-oxides/hydroxides together with large quantities of iron oxidising bacteria during laminar flow conditions at low stages. The bacteria grow thick mats of iron/manganese-oxides/hydroxides, which reduces the interstitial habitat, clogs the stream, reduces available food and causes development of toxicity through decrease of oxygen content. Loss of native plants and animals occurs directly via iron toxicity, or indirectly via smothering.

Barium and strontium remain in solution and act as natural tracers, which can be used to indicate locations where groundwater re-emerges to the creek channel. Both elements are present only in the rock matrix, unless they are mobilised during subsurface flow. Oxidation of traces of pyrite (FeS_2) during subsurface flow increases the concentration of sulphate. Calcium, magnesium and bicarbonate are supplied from the dissolution of traces of the carbonate minerals calcite and dolomite, and water is generally undersaturated with respect to these minerals.Hydrogeochemical modelling has shown that carbonate minerals magnesite, strontianite and siderite are strongly undersaturated. These minerals are dissolved from the rock mass by the addition of Mg, Sr, Fe and HCO_3 into the aquatic system. Only $CaCO_3$ was found to be slightly supersaturated in a few water samples that re-emerged from subsurface routes due to higher pH values gained during chemical reactions in subsurface water-rock interaction. Carbonate minerals of trace metals such as smithsonite (Zn), rhodochrosite (Mn) and witherite (Ba) are also undersaturated keeping these metals in solution as long as oxidation does not remove Zn and Mn from the aquatic system. All iron oxide/hydroxide-minerals are strongly supersaturated, including magnetite, hematite, maghemite, goethite, lepidocrocite, ferrihydrite and magnesioferrite, which quickly remove iron from the aquatic system.

During rainfall events, acidic water and surface run-off with pH values ranging from 3 to 6 re-mobilises iron and manganese oxides and hydroxides, eroding them from rocks and creek channel and returning these metals again into aquatic system further causing pollution. During high water stages when turbulent flow prevails, iron mats are transported with flowing water from pools and meanders that have been immobile during low flow conditions downstream, resulting in contamination through increased content of iron and manganese as mats are dissolved in acidic conditions.

The highest correlation coefficient between TDS and HCO_3 indicates that the main influence on the TDS (and EC) content is from the dissolution of carbonates; and the second highest is between Ca and Sr indicating high mobilisation rates of these elements, even when they are present as tracers in the aquifer matrix. High correlations between Ba and Sr indicates high availability for mobilisation of these ions from the rock mass.

Keywords: Longwall mining, hydrology, water chemistry, chemical processes

Impacts and Magnitude of Ground-Water Depletion

[1] L. F. KONIKOW and [1] C. E. NEUZIL
[1] U.S. Geological Survey, 431 National Center, Reston, VA 20192 USA

ABSTRACT

Effects of human activities on Earth systems, such as climate, are gaining recognition and spurring mitigation efforts. However, the significance of the irreversible and accelerating transfer of large volumes of groundwater from long-term sequestration in the subsurface to the surficial hydrologic system remains largely ignored or viewed simply as a local water management issue.

Development of ground-water resources for agricultural, industrial, and municipal purposes greatly expanded during the 20th century. Economic gains from ground-water use have been dramatic. However, in many places, groundwater reserves have been depleted to the extent that well yields have decreased, pumping costs have risen, water quality has deteriorated, aquatic ecosystems have been damaged by reduced ground-water discharge to springs, streams, estuaries, and wetlands, and land has irreversibly subsided. Some causes and effects of ground-water depletion, however, are neither obvious nor easy to assess. For example, the construction of drainage canals in surficial systems can lead to regional lowering of the water table, and land drainage is frequently ignored as a source of long-term ground-water depletion. Also, the source of much ground water pumped from confined aquifers is derived from leakage from adjacent confining beds, but depletion of low-permeability layers is difficult to estimate, rarely monitored, and usually overlooked. We have developed, tested, and applied a new simplified method for estimating depletion from confining layers. Results indicate that depletion of storage in confining layers can greatly exceed the depletion from the confined aquifer itself.

Worldwide, the magnitude of groundwater depletion from storage may already be large enough to constitute a measurable contributor to sea-level rise, and severe ground-water declines in many parts of the world are likely to continue in the future. For example, the net amount of water removed from storage in the High Plains aquifer in the central U.S. is estimated at 270 km^3 through 1999, and the depletion is continuing. The total depletion in the Central Valley of California and the alluvial basins of Arizona is about 82 km^3 and 114 km^3, respectively, although depletion rates in these basins has stabilized. The total depletion in the U.S. during the 20th century is about 800 km^3. If this volume were spread over the surface area of the oceans, it would be equivalent to about 2.1 mm of sea-level rise, or nearly 1.5 percent of the sea-level rise observed during the entire 20th century. Presumably, the volume of ground-water depletion globally is several times that amount. Although depletion is observed in many areas outside the U.S., such as China, India, and Mexico, the magnitude is poorly documented, particularly in developing countries. Improved efforts to monitor regional water-level declines throughout the world should be implemented; more comprehensive and accurate assessments of rates and effects of ground-water depletion and overexploitation may provide an incentive to improve management of limited ground-water resources.

Interlinkage of social and natural variables to groundwater pollution management in periurban areas: Naples (Italy) and Mar del Plata (Argentina)

[1] Daniela DUCCI, [2] Héctor MASSONE, [3] Emilia BOCANEGRA

[1] Sez. Geologia Applicata, Dip. Ing. Geotecnica, Università di Napoli Federico II, P.le Tecchio 80, 80125 Naples, Italy, e-mail: daniela@unina.it
[2] Centro de Geología de Costas y del Cuaternario, University of Mar del Plata, Funes 3350, CP 7600, Argentina, e-mail: hmassone@mdp.edu.ar
[3] CIC- Centro de Geología de Costas y del Cuaternario, University of Mar del Plata, Funes 3350, CP 7600, Argentina, e-mail: ebocaneg@mdp.edu.ar

ABSTRACT

This study examines and compares trends in the relation groundwater exploitation- land use and water quality in periurban areas of two medium cities: one of them in a developed country (Naples, Campania Plain - southern Italy), and the other in a developing one (Mar del Plata, Pampean plain – South East of Buenos Aires Province, Argentine).

In both cities, and in their nearby periurban areas, the continuing urbanization causes many social, economic and environmental changes, which have a considerable impact on the groundwater resources. The rapid population growth and the irregular urban development determine the presence of landscape between urban spaces and consequently the coexistence of urban, industrial and agricultural/livestock activities. In this context, nitrate groundwater contamination occurs very often. Results of recent scientific studies demonstrate that the high nitrate concentrations have increased, and numerous wells in the periurban areas are well over the WHO threshold of 50 mg/l, also recognised by Italian and Argentine drinking water legislation.

Groundwater quality represents a specific case for geoindicators due to the rapidity and frequency of the changes; the adopted procedure is based on the one developed for the project ELANEM (Euro-Latin American Network on Environmental Assessment and Management); thus, indicators for pressure, state and response for the function human support services were analysed and compared.

In assessing the changes in this function, we need to take into account all changes in biological and non-biological factors. The changes that can occur in less than 100 years can be described in terms of these geoindicators, under a new framework developed to assist in their monitoring and reporting. Changes in water quantity (piezometric levels and spring flows) and water quality are the best *geoindicators* for groundwater and could be used as early alarm warnings of environmental problems that should be solved or improved.

Keywords: geoindicators, groundwater, nitrate contamination, Naples, Mar del Plata

Nitrate pollution in different hydrogeological zones of the groundwater flow system in the volcanic structure of Mt. Vulture (Basilicata, Southern Italy)

[1]Giuseppe SPILOTRO, [1] Filomena CANORA, [1] Francesco CAPORALE, [2]M. Dolores FIDELIBUS

[1]Applied Hydrogeology Laboratory, Università della Basilicata, Italy, e-mail: giuseppe.spilotro@unibas.it
[2] Dep. Civil and Environmental Engineering, Politecnico di Bari, Italy, e-mail: d.fidelibus@poliba.it

ABSTRACT

A survey on groundwater quality of Mt. Vulture volcanic structure, undertaken from 2003 to 2005, indicates that nitrate pollution is a serious problem affecting the groundwater. The Mt. Vulture, inactive volcano, is located on the northern border of the Basilicata region and it formed in an area of strong tectonic instability. The analysis of geological, stratigraphical, hydrogeological and hydrochemical data contributes to the delineation of the groundwater hydrodynamics of Mt. Vulture. The volcanic structure represents a huge aquifer characterized by precious mineral spring waters: groundwater circulates from the highest altitudes according to radial streamlines with flow anomalies in NW-SE directions. The preferential drainage axis is defined by the tectonic discontinuity along the direction Valle dei Grigi – Fosso del Corbo.

Groundwater circulation is conditioned by the structures created from the magmatic and piroclastic sequences of the volcano, their successive arrangements and tectonic and pseudo-tectonic deformations: such factors govern the permeability and anisotropy features of the aquifer. The main points of groundwater emergence are located in the vicinity of Monticchio Lakes and at the contact point of volcanic rocks with the sedimentary basement, and to the extremities of a long fault that coincides with the escarpment of a probable wide calderic collapse.

The intrinsic groundwater pollution vulnerability has been defined on the base of the thematics overlying maps related to the lithological, hydrogeological and climatic features of the above mentioned area.

The rapid expansion of agricultural activities has greatly increased the use of nitrogen (N)-fertilizer. During the study, many water samples were collected from wells and springs to determine the water chemistry and the extent of nitrate pollution.

High concentrations of nitrate, that occur especially in the south area of Monticchio Lakes, along an area caracterized by low permeability and then poor groundwater circulation, but also in the vicinity of urban areas and locally in other parts of the basin, pose a serious problem for the mineral water drinking supply.

In some places, the nitrate concentration greatly exceeds the maximum concentration of 50 mg/L, prescribed by law.

The N-E sector is characterized by low nitrate pollution risk because of the abrupt increase of altitude gradient that does not allow agricultural land use, notwithstanding the high intrinsic groundwater pollution vulnerability of this area. In this area, nitrate concentrations less than 25 mg/l were detected. Relatively high nitrate concentrations are found in the discharge area, near important springs and by the Atella River.

This study allowed reconstructing the map of the nitrate concentrations in groundwater. The comparison between the winter-summer nitrate data and the pollution vulnerability map evidences the determining role of the groundwater flow system in the seasonal variations of the concentrations and in the total dilution of the pollutant.

Keywords: Nitrate pollution, Groundwater flow system, Mt. Vulture

Nitrates in groundwater from the upper zone of an Alluvial Aquifer System in Central Portugal

Ana I S ANDRADE
Centro de Geofísica da Universidade de Coimbra, Earth Sciences Department, University of Coimbra, 3000-272 Coimbra, Portugal, e-mail: aandrade@dct.uc.pt

ABSTRACT

The upper zone of an area, part of the Mondego River Alluvial Aquifer System (central Portugal), was monitored for nitrates from October 2000 to September 2002. The area is located westward of Coimbra city and comprehends an area approximately 16 km in length and 3 to 4 km wide (Fig. 1). The west side of this region is close to the upper limit of the Mondego river estuary. It is an agricultural region, with rice and corn as the main crops; vegetable, nursery garden, tobacco and sugar beet are some of the minor crops. These crops are essentially seasonal, cultivated between April and October. In the main part of the area, the water used for irrigation comes from the river and is distributed through an irrigation system composed essentially of a main channel located along the river side and underground pipes; the water is deviated from the river to the channel at a place located nearly 3 km eastward of the studied area.

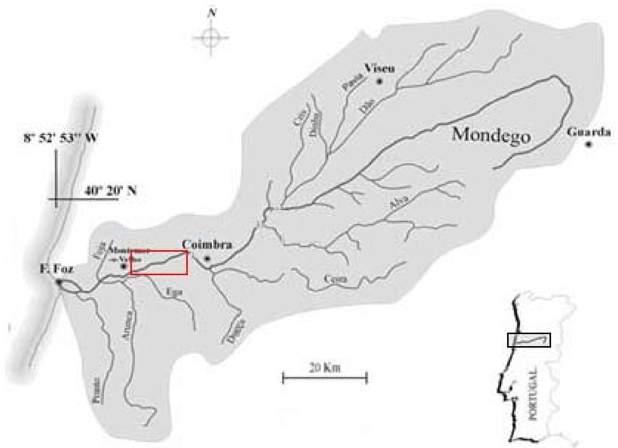

Fig. 1. Location of the study area at the Mondego drainage basin (Central Portugal)

For this study 29 piezometers, with a depth between 2.3 m and 5.1 m were implanted in the area. Groundwater samples were collected in these piezometers, in 20 campaigns. In 18 of these campaigns, the river water was also sampled in two points located at both extremities of the study area. Nitrate concentrations were measured in the laboratory by UV/VIS spectrophotometry. The obtained results oscillate between less than 0.5 mg/l (method detection limit) and 466 mg/l (Figs 2 and 3); only 4 of the values were over 100 mg/l, 3 of them in the groundwater from one single piezometer (number 35). The average and standard deviation of the values are 11 mg/l and 31 mg/l, respectively. It was verified that values over 25 mg/l were more frequently obtained in groundwater from piezometers implanted in coarser alluvium levels (medium and coarse sand) located in the central and east parts of the area. However, not all the piezometers located in these coarser alluvium levels presented high values of nitrate in the collected groundwater samples. In the south part of the area, some high values of nitrate (generally less than 75 mg/l) were also obtained in samples collected in two piezometers (number 33 and 39) implanted in finer alluvium sediments (fine to medium silt). These piezometers are located near caprine stables, poultry-yards and vegetable hothouses or close-by a small village, which implies a high contaminant charge in these specific areas. The groundwater samples collected in the piezometer located nearby the small village seems to be the one having the more persistently high nitrate values. It should be noticed that in the samples collected in this piezometer, high values of phosphate, ranging from 1.33 and 3.44 mg/l, were also obtained.

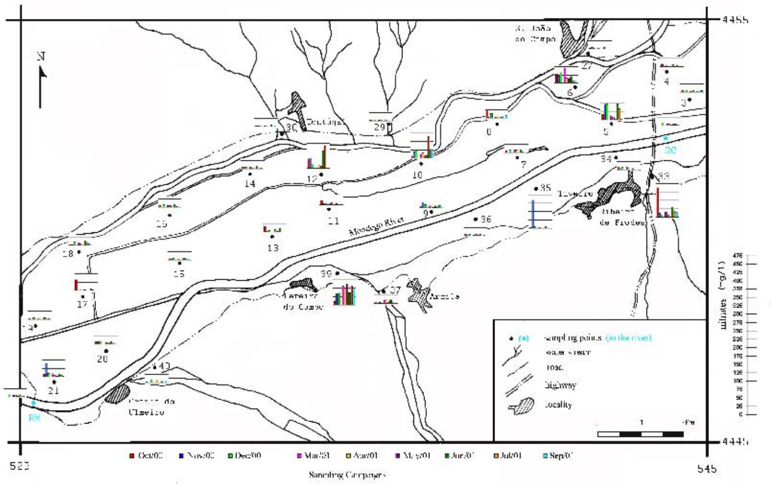

Fig.2. Nitrate values in groundwater and river water (RM and RC) in 2000/01

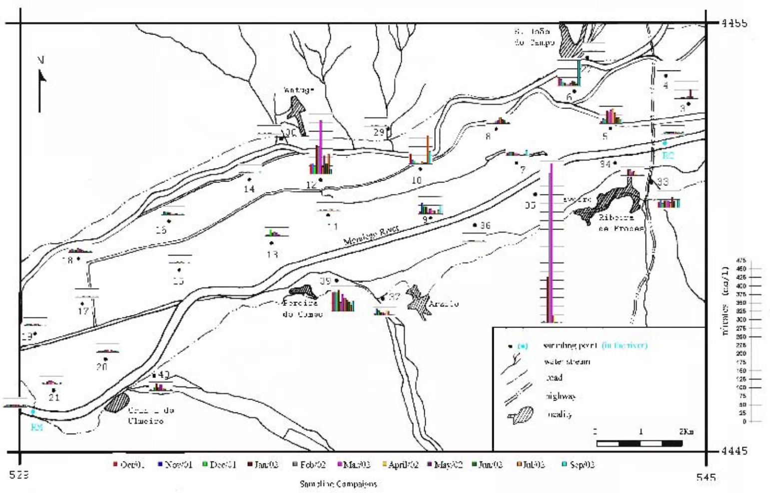

Fig.3. Nitrate values in groundwater and river water (RM and RC) in 2001/02

The highest values in the range from less than 0.5 to 150 mg/l were obtained mainly in specific sampling campaigns which allowed us to relate the nitrate concentrations with contamination from agricultural fertilization. The values over 150 mg/l were related to punctual and accidental spill of fertilizers in a piezometer (number 35) surrounding area. It was verified that the higher values diminished somewhat rapidly from one sampling campaign to the next.

Correspondence Analysis allowed us to demonstrate the influence of the agriculture practices in nitrate concentrations in groundwater, namely the relation of higher values to the presence of crops other than rice and corn. Nitrates in the river water samples were very low. The maximum value obtained was 8.40 mg/l, with an average of 4.76 mg/l and a standard deviation of 1.57mg/l, which represents a favourable factor for the non-permanent occurrence of high nitrate values in the upper zone of the Alluvial Aquifer System where the irrigation system is installed (central area – from piezometer 3 to 19). The use of river water with low nitrate values prevents the possibility of nitrate concentrations increment, associated to land cultivation that could result in case of water recirculation for irrigation, and then reduces the possibility of having a nitrate contamination problem in the area. For the same period of time, 2000-2002, some nitrate values for surface water sampled in 3 points of the ditches crossing the area were the irrigation system is implanted (east, central and west located) are available – monitoring project from the ABOFHBM (Association that manages the irrigation system). These values are always under 25 mg/l, which indicates the occurrence of a natural phytoremediation process as the ditches have a vegetal cover that is periodically cleaned.

Keywords: Groundwater, nitrate, contamination, alluvium.

Non-point pollution in the hydrosphere due to agricultural practices at Sete Cidades (Azores, Portugal): I. the unsaturated zone

[1]J Virgílio CRUZ, [2]M O SILVA, J Lopo MENDONÇA, [3]Isabel DIAS, Isabel PRUDÊNCIO

[1]Geosciences Department, Universidade dos Açores, Complexo Científico, 2º Piso, 9501-801 Ponta Delgada, Portugal, e.mail: jvc@notes.uac.pt
[2]Geology Department, Centro de Geologia, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, Edifício C6, 1749-016 Lisboa, Portugal, e.mail: mosilva@fc.ul.pt
[3]Chemistry Department of Chemistry, Instituto Tecnológico e Nuclear, Estrada Nacional 10, 2686-953 Sacavém, Portugal, e.mail: isadias@itn.mcies.pt

ABSTRACT

In order to characterize agriculture impact on groundwater quality a field study was developed at Sete Cidades volcano, located in the westernmost sector of São Miguel, the largest of the nine volcanic islands that made the Azores archipelago. The research methodology covers characterization of soil-water composition at several depths, as well as the study of the groundwater composition in the saturated zone, and the present paper describes results obtained in relation to the unsaturated zone.

São Miguel is located between 37º55´N to 37º04´N of latitude and 25º52´W to 25º08´W of longitude, and has an area of about 747 km^2 and approximately 125000 inhabitants. It belongs to the Azores Eastern group, and like, in the remaining islands, agriculture is one of the main economic activities in the archipelago, as shown by the gross value added to regional product (7,3%; year 2003) due to agriculture. Livestock is the main agricultural activity, as about 94% of the land occupied by agriculture corresponds to pastures and in 2003 more than 200000 bovines were identified.

Groundwater is a strategic resource in the Azores as about 97% of the water supply is supported by aquifers. However, and despite the environmental and economic value of groundwater in the archipelago, aquifers support an increasing pressure, which is reflected on the groundwater quality deterioration. The effects of groundwater pollution due to agricultural impact have been reported in the majority of the nine islands, as shown by the high content of nitrogen species, as nitrate, derived from synthetic and organic fertilizers use, and from animal wastes leaching, or also by microbiology parameters. This is a result of some cases of failure to comply with EU and national water quality regulations.

Sete Cidades volcano is the westernmost of the three active central volcanoes of São Miguel island. This volcano occupies an area of 110 Km^2 and presents a subaerial volume of 45 Km^3. This steeply volcanic cone, with an average slope of 12º, has a maximum altitude of 845 m and an average basal diameter of approximately 12 Km.

The main work of the field study was done inside the Sete Cidades volcano caldera, a 5 Km diameter circular shaped depression, with an average deep of 300 m. This summit caldera is the result of several distinct collapses. The three main phases of collapses are dated from 36000 years to 16000 years and are due to major eruptions giving rise to important fall and flux pyroclastic deposits. Steep walls from 30 m high up to 400 m high limit the referred depression. Several volcanic features can be observed inside the caldera, namely pumice cones, maars (s.l.) and a few domes. Inside the caldera are also observable four lakes, which are related to the volcanic centres craters due to post-caldera eruptions. The two main lakes lie on the caldera floor, and are the so-called Lagoa Azul (3.58 Km^2) and the Lagoa Verde (0.82 Km^2). These main lakes are connected and receive a direct input by rainfall as well as the superficial drainage of the Sete Cidades caldera drainage basin with an area of approximately 18 Km^2.

About 24% of the drainage basin area (18 Km^2) corresponds to grazed pasture land and the local economy is strongly dependent on agriculture.

Water in the unsaturated zone was sampled by means of ceramic suction cups. Before the installation of the ceramic cup they were all subjected to several stages of washing, first in the laboratory with supra pure water, until aliquot conductivity stabilized, and in the field then.

Five pasture locations were selected and monitored, as well as a site with the same physical conditions, but without agricultural activity. From the 5 pasture lands are discussed further results obtained in the so-called Pavão I (Pa I), which corresponds to the most extensive data set. On this site, 6 ceramic suction cups were installed, at several depths (0.35 m, 0.70 m, 1 m, 1.30 m, 1.60 m, 1.90 m). The site without agricultural activities is located near the Sete Cidades village, and two ceramic cups were there installed, respectively at 0.25 and 0.50 m depths.

Vadose zone water at the Sete Cidades village site present a pH range between 5.45 and 8.44, without significative differences being observed with depth: pH at 0.25 m ranges between 5.64 and 8.44, and at 0.50 m varies between 5.45 and 7.93. The small research depth on this site, as well as the high precipitation and soil hydraulic conductivity, favours the homogenization of values.

Water conductivity ranges from 40 and 495 μS/cm and the maximum value at 0.25 m depth (495 μS/cm; median=90.5 μS/cm) is higher than the observed at 0.50 m depth (292 μS/cm; median=78 μS/cm). in both suction cups conductivity values are rather variable and in summer are generally higher. This suggests the effect of salts leaching following precipitation episodes, while during winter leaching occurs all along the period.

Facies are of the Cl-Na type and despite median values for all major species being similar in range, Cl content is generally higher at 0.25 m depth, which suggests the influence of sea salts deposition by precipitation. The SiO_2 content shows the contribution of hydrolysis (median equal to 29.1 mg/L at 0.25 m and to 43.01 mg/L at 0.50 m)

At Pa I vadose zone water is mainly from the HCO_3 to HCO_3-Cl types in the anionic field and with a Ca-Mg trend for cations. Cl and HCO_3 content is higher at suction cups near the surface, showing the effects of the sea salts deposition and the CO_2 dissolution at the upper layers of the soil. The pH presents a decreasing trend with depth, from a median value of 8.25 at 0.35 m depth to median values between 6.99 and 7.15 from the 0.70 m depth to the water table, where median value is equal to 6.88 This suggests acid neutralization by means of silicate weathering, which also explains the high SiO_2 content.

In the summer period the water conductivity, where median value for the suction cups on Pa I varies between 141 and 357 μS/cm, is higher, especially at the more superficial cups. This suggests salt washing by precipitation episodes, which occur during this dryer period, when evapotranspiration reaches the highest values (monthly actual evapotranspiration ranges between 77.3 mm to 83.1 mm from June to September and from 46 mm and 46.5 mm from November to April).

Comparing NO_3 contents from the pasture site and the village sites it is possible to show a marked difference. The maximum value observed in the village site, where agriculture is absent, range between 2.80 mg/L at 0.25 m depth (median=1.15 mg/L) and 5.40 mg/L at 0.50 m depth (median=1.40 mg/L). In the Pa I pasture land NO_3 content ranges between 1.95 and 87.67 mg/L, and at the suction cup installed at 1.90 m depth the median value is equal to 39.40 mg/L, which reflects several applications of inorganic fertilizers, as well as the leaching of animal wastes.

Acknowledgement: Financial support from the Fundação para a Ciência e Tecnologia POCTI program to the project "Non-point pollution in the hydrosphere" has to be acknowledged.

Keywords: Non-point pollution, unsaturated zone, groundwater quality, Azores.

Non-point pollution in the hydrosphere due to agricultural practices at Sete Cidades (Azores, Portugal): II. the saturated zone

[1]J Virgílio Cruz, [2]M O Silva, J Lopo Mendonça, [3]Isabel Dias, Isabel Prudêncio

[1]Geosciences Department, Universidade dos Açores, Complexo Científico, 2º Piso, 9501-801 Ponta Delgada, Portugal, e.mail: jvc@notes.uac.pt
[2]Geology Department, Centro de Geologia, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, Edifício C6, 1749-016 Lisboa, Portugal, e.mail: mosilva@fc.ul.pt
[3]Chemistry Department of Chemistry, Instituto Tecnológico e Nuclear, Estrada Nacional 10, 2686-953 Sacavém, Portugal, e.mail: isadias@itn.mcies.pt

ABSTRACT

In a companion paper a field study developed at Sete Cidades volcanic caldera, in order to characterize groundwater pollution due to agricultural activities, was presented (Cruz et al., 2007). The developed methodology covers the collection of water samples in the unsaturated and saturated zones, and in the present paper results from the saturated zone are presented.

Sete Cidades volcano is the westernmost of the three active central volcanoes of São Miguel island. Located in the western end of the island, this volcano occupies an area of 110 Km^2 and presents a subaerial volume of 45 Km^3. This steeply volcanic cone, with an average slope of 12º, has a maximum altitude of 845 m and the summit has a large caldera that has been the result of several explosive volcanic eruptions.

Inside the Sete Cidades caldera, a 5 Km diameter circular depression at the volcano summit, agricultural activities are intense, with a large area occupied by grazed pasture land, and these aspects are not discussed further as they were already presented in the companion paper. The impact of agriculture on water quality motivates the study, as surface water bodies located inside the caldera are eutrophic and some springs historically have high nitrate content.

Groundwater in the saturated zone was sampled and characterized with a coupled approach, namely by studying water composition in springs and in piezometers. Therefore, a regional groundwater quality survey was made in all Sete Cidades volcanic edifice, along which 28 springs were sampled. A set of four springs located inside Sete Cidades Caldera were monitored fortnightly, and 7 piezometers were installed in selected pasture lands and in one site, near Sete Cidades village, where agriculture is absent. Piezometers installed in pasture lands had a depth range from 1.23 m to 3.23 m (Pz I: 2.19 m; Pz II: 2.45 m; Pz III: 1.52 m; Pz IV: 1.23 m; Pz V: 3.23 m; Pz VII: 2.66 m), while the piezometer installed near the village (Pz VI) had a depth of 0.57 m

Groundwater sampled in the 4 monitored springs (so-called Seara, Tanque, Pedras Brancas and Moinhos) corresponds to cold waters, with a pH range between 5.69 and 8.60, and low mineralization, as shown by the electrical conductivity values (176-686 µS/cm). Water types are mainly HCO_3-Na and Cl-HCO_3-Na, which are similar to facies in groundwater sampled all over the volcano along the regional hydrogeochemical survey.

Samples of groundwater collected in the piezometers present a pH range between 5.27 and 8.12, with median values for each piezometer ranging between 6.38 and 6.98. Water conductivity varies between 95 and 232 µS/cm, respectively in Pz IV and Pz V.

Nitrate content in piezometers ranges between 0.08 and 49.6 mg/L, and the median values observed in PzV and Pz VII, respectively equal to 37.8 and 49.6 mg/L, are clearly higher than the results of the remaining piezometers (1.10-8.30 mg/L). Values observed in Pz VII, at the so-called Pavão I pasture, are compatible with vadose zone water median content at 1.90 m depth (39,4 mg/L), sampled by means of a ceramic suction capsule, and presented in the companion paper (Cruz et al., 2007). It was also on this piezometer that the maximum nitrite content is observed (3.30 mg/L).

Data gathered is as a result of the agricultural impact at sites where agriculture activity is absent (Pz VI), or corresponds to a low scale exploration, nitrate content is much lower.

Spatial variability was also observed in the monitored springs or shown by the regional hydrogeochemical assessment. Nitrate content range in Pedras Brancas (0.82-4.83 mg/L) and Moinhos (0.37-3.64 mg/L) springs are substantiality lower compared to values observed at Tanque (19.88-40.74 mg/L) and Seara (38.88-78.34 mg/L) discharges. On a regional scale, NO_3 content ranges from 0.20 to 53.5 mg/L (median=7.20 mg/L) with the highest values observed in areas where grazed pasture land is the predominant use of soil.

References

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Keywords: Non-point pollution, groundwater quality, Azores.

Overcoming data shortfalls to locate groundwater-dependent ecosystems and assess threats to groundwater quantity and quality

[1]Jenny F. BROWN, [2]Leslie BACH, [2]Allison ALDOUS, and [2]Abby WYERS

[1] The Nature Conservancy, 34307 SE 39th Pl., Fall City, WA 98024, jfbrown@tnc.org
[2] The Nature Conservancy, 821 SE 14th St., Portland, OR 97214,
lbach@tnc.org, aaldous@tnc.org, awyers@tnc.org

ABSTRACT

The quantity and quality of groundwater is critical to the conservation of aquatic biodiversity and yet, around the globe, this supply of water is increasingly threatened. In the Northwestern United States, where population growth in some areas is predicted to exceed 25% over the next decade, water demand is intensifying and water management agencies and water users are increasingly turning to groundwater as little surface water remains available for use. In addition, much of the groundwater in this part of the country has been, or is highly susceptible to being, contaminated by nutrients or chemicals. Consequently, groundwater depletion and contamination pose a looming and potentially widespread threat to aquatic ecosystems in this region.

In response to this threat, The Nature Conservancy is working to identify conservation actions that will protect groundwater-dependent biodiversity in the Northwestern United States. To develop effective strategies to protect groundwater-dependent ecosystems and species, it is critical to understand where they occur, their groundwater requirements, and whether their groundwater supplies are impaired. Unfortunately, little of this information is readily available. To address these data gaps, The Nature Conservancy developed new methods, relying on a suite of surrogate indicators and GIS mapping, to identify those ecosystems that are likely to depend upon groundwater, and the human activities that pose the greatest risk to groundwater quality and quantity. These methods were implemented in a regional analysis to 1) locate priority areas for conserving groundwater-dependent ecosystems, 2) evaluate potential threats to groundwater quantity and quality, and 3) identify actions to address the most pressing threats to these ecosystems across the region.

Groundwater contamination and depletion are common global threats to groundwater dependent biodiversity, and many countries have similar data shortfalls that impede appropriate groundwater management. Thus the general approach described here can be applied elsewhere to identify both the location of groundwater-dependent ecosystems and threats to their condition.

The diversity of ecosystems and hydrogeologic settings across the Northwestern United States provides an excellent testing ground for the development of tools to understand the ecological importance of groundwater. This area includes the states of Oregon and Washington (421,000 km^2) and encompasses a spectrum of habitat and climatic conditions ranging from temperate rain forests (> 4.6 m of annual precipitation) and coastal conifer forests along the Pacific coast, to mesic prairies and grasslands in the Puget Trough and Willamette Valley, to montane forest and grasslands in the Cascade Mountains, to xeric grassland and shrublands and desert playas (<0.2 m of annual precipitation) in the eastern portion of the states. These ecosystems occur in a variety of hydrogeologic settings underlain by geologic deposits that vary from Jurassic marine-derived sedimentary rocks to relatively recent volcanic and glacial deposits. Captured within this region are many miles of rivers and streams, thousands of springs, a variety of wetlands, and hundreds of lakes, many of which have the potential to rely on groundwater for a significant portion of their water supply.

In the first part of the analysis, we located river, lake and wetland ecosystems and rare species that depend upon groundwater. These locations were used to identify priority areas for the protection of groundwater quality and quantity to support biodiversity. Lacking specific information on where groundwater is ecologically important, we used the following approaches to fill this gap:

- To identify groundwater-dependent rivers and lakes, we used GIS data to examine the hydrogeology of the surrounding watershed (mean size of 800 ha; range of 81-3642 ha). We used high permeability of surficial geologic deposits and high infiltration capacity of soils as indicators that groundwater could provide a significant supply of water to these ecosystems. These conclusions were then compared with those drawn from three additional indicators of the importance of groundwater within a watershed: the presence of springs, a low density stream network, and high baseflow relative to mean annual flow. Together these surrogates were used to assign groundwater-dependence to each watershed in the region. Lower elevation lakes and all rivers within groundwater-dependent watersheds were classified as groundwater-dependent.

- To identify groundwater-dependent wetlands, we used information describing the local hydrogeologic conditions. Regional soils information and an analysis of topography (based on DEMs) identified wetlands with organic soils, on sloped terrain, or at major breaks in slope. These conditions were used as indicators that groundwater discharge into a wetland is likely.

- To identify groundwater-dependent species and communities, we analyzed the habitat requirements of over 1350 species and nearly 70 communities of conservation concern. Review by experts in various taxonomic groups suggested that over 100 of these relied on groundwater for some part of their life cycle. An additional 400 species were aquatic and therefore could rely on groundwater if their native ecosystem did so. Mollusks and bryophytes were the taxonomic groups with the greatest proportion of species dependent upon groundwater.

In the second part of the analysis, we evaluated the risk that the quantity and quality of groundwater had been impaired in the priority areas. In the Northwestern United States, a significant portion of agriculture is irrigated with groundwater and over 40% of the total population and more than 90% of rural residents use groundwater for their drinking water. The risk of reductions in the quantity of groundwater discharging into a groundwater-dependent ecosystem was assessed by mapping existing irrigation, municipal, and household well locations and then projecting where future growth in groundwater extraction is likely to occur. To estimate the locations of irrigation and municipal groundwater wells, we used information on the presence of a legal right to groundwater. Household wells producing less than 18,925 liters/day are not regulated so we used well-driller logs, required by management agencies, to locate these low volume wells. Cities and counties with high future water demand were identified based on expected population growth. All of these factors were then mapped; their proximity to the priority areas was used to identify where actions are needed to ensure adequate groundwater supply to ecosystems.

The risk of contaminating groundwater that feeds groundwater-dependent ecosystems was based on both the susceptibility of the particular site to groundwater contamination, should the contaminants be present at the surface, and the vulnerability of a particular site to groundwater contamination given the existing land uses. The physical characteristics of the landscape - permeable surficial geologic deposits, soils with high infiltration capacity, high precipitation, and flatter topography - were used to indicate an increased susceptibility of an area to groundwater contamination. In more susceptible areas, the vulnerability posed by existing land uses and human activities was then evaluated. Conditions that raise the vulnerability of groundwater to nutrient contamination included confined animal feed operations, urban use of fertilizers, irrigated agriculture, and high population densities outside of urban boundaries (as an indicator of septic system density). Vulnerability to pesticide contamination was evaluated based on recent mapping of the use of agricultural pesticides that are most likely to reach groundwater due to their high solubility, low volatility, and longevity. Areas vulnerable to other industrial contaminants, including petroleum products and solvents, were located with government databases of regulated underground storage tanks, reported spills, gas stations, landfills, dry cleaners, and underground injection wells. We then mapped all areas that are both susceptible and vulnerable to groundwater contamination. This permitted us to identify the most prevalent risks to groundwater quality from an ecological perspective.

In the third part of the analysis, we are identifying actions to address the major risks to groundwater-dependent ecosystems and species. Using the surrogates discussed above, we have been able to overcome the absence of data and information on where and how ecosystems in the Northwestern United States depend on groundwater and how that supply is threatened. We have prioritized where to focus on ensuring the ecological needs for groundwater quantity and quality are met. At three specific conservation areas we are beginning to develop and test the effectiveness of specific policy and management actions such as changes in irrigation management and use of agricultural chemicals.

Keywords: conservation, groundwater contamination, groundwater quantity, groundwater-dependent ecosystems

Regional scale assessment of groundwater resources quantity with respect to water supply issues and the ecological role of groundwater

[1]Roland BARTHEL, [1]Aleksandar TRIFKOVIC

[1]Universitaet Stuttgart, Institute of Hydraulic Engineering, Pfaffenwaldring 7a, 70569 Stuttgart, Germany, Tel. +49- 711 685 66601, Fax +49 711 685 66600, e-mail: roland.barthel@iws.uni-stuttgart.de

ABSTRACT

Recognition of climatic change and the obligations enforced by the European water framework directive (WFD) have brought the assessment of the state of water resources in the centre of focus of water related sciences. The assessment of climate change and the WFD approach for the management of water resources demand a regional and integrated assessment on a river basin scale (> 10,000 km^2) in order to bridge the gap between the global effects predicted by Global Climate Models and to meet the environmental, social and economic objectives of modern water resources management. Local and regional scale groundwater resources assessment, however, require completely different approaches. It should also be noted that the widely used hydrological assessment approaches (hydrological models, water balance approaches) are not sufficient to describe groundwater systems since they neglect the vertical differentiation of the subsurface. Furthermore, in comparison to surface water systems the state of groundwater resources is more difficult to assess because of their three-dimensional nature, the less well defined boundaries, the limited accessibility and the resulting lack of data.

Groundwater resources assessment can be divided in two branches: groundwater quantity and groundwater quality issues. The question of which branch is in the centre of focus depends mainly on the regional climatic and socio-economic conditions. In most of the states of the European Union it seems that much more work was recently dedicated to groundwater quality issues than to quantitative aspects, leading to a lack of quantity related approaches. A reason might be that the main goal of the WFD is the restoration of the natural (past) state of water bodies, i.e. a focus on minimizing human impacts (withdrawal, over-use, contamination) on water resources. Upcoming natural influences brought upon by climate change are of minor concern in the WFD. However, scenario based predictions published by IPCC indicate that there will be severe changes to the hydrological cycle including, of course, changes of groundwater quantity. Here it is very important to remember, that groundwater quantity is not only important for water supply but also plays a very important role in ecology. The role of groundwater in ecology is most well known from cases where decreasing groundwater tables have already led to damages or destruction of wetlands. Furthermore, groundwater quite often contributes a large portion of river discharge in dry periods (baseflow or groundwater discharge). That means if groundwater quantity decreases for any reason, river discharge decreases as well with all the known ecological, economic and social consequences ranging from problems with water supply and irrigation, navigation, fishery, hydropower generation, cooling water for industry and nuclear power plants to touristic attraction of regions. All the problems just mentioned were observed in central Europe, i.e. a sub-humid to humid region, in the exceptionally dry summer of 2003. It is now very important to investigate whether such extreme events will occur more often and how the general climate change might influence the groundwater quantity in the future.

In order to do this, two main things must be accomplished:

1) to evaluate the actual state of a groundwater resource and its connections to neighbouring systems (i.e. surface water bodies, wetlands)
2) to predict future changes as a consequence of changing boundary conditions (climate – groundwater recharge, river discharge)

Groundwater resources assessment and the prediction of future states is not a new task in hydrogeology. However, related research was usually carried out where signs of problematic situations had already been observed. A prime example is the High Plains Aquifer in Colorado, Kansas, Texas, and Nebraska (e.g. Sophocleous, 2005). In such areas the relationship between cause (pumping) and effect (groundwater depletion) is well known. The situation is completely different in regions where groundwater resources are less intensively used or climatic conditions have until now provided sufficient natural groundwater recharge. In such areas the in-out-storage relationships and, in general, the reactions of the systems to changes of the boundary conditions are much more difficult to evaluate.

The first inherent problem in the assessment of groundwater resources is the lack of well defined boundaries. The extent (width, depth ..) and storage volume of a groundwater resource cannot exactly be defined since connections to other resources (subsurface and surface) may exist in all directions. A second problem is related to the main parameters that can be used in the assessment: groundwater (piezometric) levels and groundwater recharge. Even if they can be determined very accurately, the actual values of both parameters

cannot directly be related to the actual quantity stored in a groundwater body or to the amount available in the future. A trend analysis is usually required to evaluate the system changes. This trend analysis however has to be carried out and interpreted aquifer specific, since every aquifer reacts differently to changes of outer boundary conditions (withdrawal, climate change …) depending on a large number of geometric and hydraulic characteristics. This means that general indicators such as the often used head change per year are not sufficient to meaningfully describe past changes and to derive reliable future predictions. The resulting task is therefore to generate simple, yet meaningful indicators that can be used in decision making or presented to stakeholders from very complex, case specific analyses.

In this paper an integrated approach to assess groundwater availability for water supply purposes as well as for ecological demands under conditions of climatic and socioeconomic change is presented. This approach is embedded in the DSS DANUBIA which was developed by the GLOWA-Danube research cooperation during the past six years. DANUBIA is a fully coupled system that is comprised of 16 individual models to describe all compartments of the hydrological cycle (natural and socioeconomic) of the Upper Danube catchment (Germany, 80.000 km^2). The approach presented here allows for the assessment of 405 groundwater bodies (hydrogeological response units) within the Danube catchment which are delineated by intersecting 150 surface watersheds and four main aquifer systems. The assessment results in a classification of each groundwater body in five status categories (good … very bad) which are called “groundwater quantity flags”. Those flags are mainly used by the six socio-economic models contained in DANUBIA which are based on a common multi-actor approach. Here individual actors can interpret and use the flag values according to their attributes and preferences in order to simulate decisions. The groundwater quantity flags are calculated monthly based on three exchange variables provided by two natural science models in DANUBIA: groundwater recharge, groundwater level and infiltration from groundwater to surface water (“baseflow”) – aggregated monthly for each groundwater body. The calculation includes the individual characteristics of the groundwater bodies by using a combination of response times and weights for each exchange variable.

In the conference contribution, after a definition of the problem, the three main aspects of the developed approach will be introduced: 1) the delineation of groundwater bodies, 2) the assessment methodology and the required parameters, 3) the integration of the results in socio-economic models.

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Keywords: Groundwater, Climate Change, Quantitative Assessment, Groundwater Modelling, GLOWA-Danube

Relationships between wetlands hydrology and the Doñana coastal aquifer (SW Spain)

[1]Marisol MANZANO, [2]Emilio CUSTODIO, [3]Edurne LOZANO

[1]Technical University of Cartagena, Cartagena, Spain; e-mail: Marisol.manzano@upct.es
[2]Technical University of Catalonia, Barcelona, Spain; e-mail: Emilio.custodio@upc.edu
[3]GEOAQUA S.C., Zaragoza, Spain; e-mail: Elozano@icog.es

ABSTRACT

The Doñana aquifer system, located near the Guadalquivir River mouth (SW Spain), consists of detrital Plio-Quaternary sediments lying above a thick sequence of Miocene marls. The aquifer area is around 3400 km^2 and hosts the Guadalquivir river marshes and two large protected natural areas of international relevance (Biosphere Reserve in 1981; RAMSAR site in 1982; Natural World Heritage Site in 1994). The sediments are mostly sands, silts and clays settled in fluvio-marine and eolian environments up to the present. Their spatial arrangements display two different geomorphological regions which are, however, hydraulically connected: a sandy area and a clayey one. The clayey sector holds fluvial marshes (tidal marshes originally), and the sandy area holds natural reserves, rural settlements, agriculture and hundreds of small-to-medium size wetlands.

The wetlands are mostly groundwater-related, and their hydrological patterns are controlled by the particular location within the regional groundwater flow net. A systematic classification work has been performed within the framework of research studies; this classification is the background of the Andalusian Government Wetlands Management Programme (2002).

The Doñana wetlands have very different geomorphic origins and hydrologic regimes, and they are responsible for most of the internationally appreciated ecological values of the area. The hydrogeological, hydrogeochemical and isotopic studies performed since 1985 up to now contributed significantly to knowledge of the aquifer functioning at a regional scale, as well as to the proposal of the above mentioned classification of wetlands. However, because of their close relationship to the aquifer the original hydrology of most wetlands is modified, as it is the aquifer original regime. Intensive groundwater pumping in the aquifer discharge areas nearby the marshes since the end of the 1970's has changed groundwater flow and regime in many areas, and consequently many wetlands have been affected. Accumulated inter-annual lowering of the most exploited deep aquifer piezometric levels has produced a water-table drawdown, which results in a decrease of natural discharge through seepage and phreatic evapotranspiration, and has modified wetland water regime. Other human activities disturbing the aquifer natural regime and that of the related wetlands are groundwater recharge changes and sediment relocation due to deforestation, introduction of foreign plant species (e.g. eucalyptus) with greater annual water consumption than native Mediterranean species, and groundwater pollution by urban, industrial and agricultural wastes.

Detailed hydrochemical, isotopic and modelling studies developed in the last years showed the relevance of these techniques to assess the particular hydrological pattern of individual wetlands, which has contributed to insight about wetlands funtioning and about the contribution of groundwater pumping in the modification of wetlands hydrology. The system needs about 30 years to reach midway between a previous state and the final state after a change has been produced. Currently the system is in an unsteady state, and springs, seepages and river flows tend to a reduction if pumpage persists, although in some areas this is partially compensated by the eradication of eucaliptus trees plantations.

Keywords: Doñana, wetlands, hydrology, isotopes, hydrochemistry

Streamflow/baseflow variability in contrasted climatic regions: detection of climate-like fluctuations

Johanna MESQUITA*, Nicolas MASSEI, Benoît LAIGNEL and Bernard DELCAILLAU

Contact* : johanna.mesquita@univ-rouen.fr

Laboratory of Geology, UMR 6143 M2C « Morphodynamique Continentale et Côtière»,
IRESE A, 76821 Mont-Saint-Aignan Cedex.

ABSTRACT

The influence of climate fluctuations on hydrologic regimes are of primary importance for water resources management. On small watersheds, these fluctuations can be detected in long-term streamflow time series, although anthropogenic effects may substantially affect streamflow variability as well. They directly impact flood risk assessment, but also agricultural yields, water management activities, fish inventories, etc. In this study, we investigate the possible relationships between some selected climate indices and hydrometeorological time series (precipitation and streamflow). Although precipitation remains a very heterogenous variable, the use of the corresponding time series is rendered possible due to the small size of the watersheds studied. Small watersheds (i.e., area smaller than 1000 km^2) from two definitely different climatic regions (Haute-Normandie, France and the Austin area, Texas, USA) are studied. The lithologic contexts are similar, consisting of carbonate subtrata, although the very nature of the underlying geologic formations are not the same (chalk in Haute-Normandie, limestone in Texas). One major difference between the two regions lies in the fact that streamflow in Haute-Normandie is strongly sustained by the chalk aquifer, which is not the case in Texas (mainly temporary streams). The method chosen for characterizing the statistical properties of the time series is continuous wavelet analysis, which allows detection of possible instationarities in the signals to be analyzed. Continuous wavelet spectra for both French and US watersheds reveal obvious pluriannual fluctuations, respectively in the 2-3̃yr and 6̃yr energy bands, and 2-3̃yr and 5-6̃yr bands. These fluctuations have been compared to well-known climate forcing fluctuations such as ENSO (El Niño/Southern Oscillation), NAO (North Atlantic Oscillation)and AO (Arctic Oscillation), also referred to as NAM (North Annular Mode). All streamflow time series exhibit climate-like fluctuations, which tends to show that streamflow variability clearly integrates major climate changes and disturbances. Those climate-like patterns in streamflow can be reconstructed and their contribution to streamflow variability quantified. Reasonable relationships between land–water cycle oscillations and climate forcing are then suggested, even though correlations remain very complex to establish.

Keywords**:** streamflow variability; climate fluctuations; continuous wavelet analysis, watershed, baseflow.

Temporal patterns in the groundwater invertebrate communities in two alluvial aquifers in New South Wales, Australia

Peter J HANCOCK, Moya TOMLINSON, and Andrew J BOULTON

Ecosystem Management, The University of New England, Armidale, New South Wales, Australia, 2351

ABSTRACT

Eastern Australia is currently experiencing the worst drought on record. Human demand for groundwater from alluvial aquifers is increasing because of dwindling surface water supplies but the effects on groundwater-dependent ecosystems such as river baseflows, vegetation, and aquifers are poorly known. Our study surveyed the stygofaunal communities over two years in one alluvial aquifer, and one year in another. Our research uncovered rich and previously unknown invertebrate communities in these two alluvial aquifer systems. We examined correlations of community structure and taxa richness with physical, chemical, and hydrological variables. We also examined community structure seasonally for two years in one aquifer to determine if there were any temporal patterns. Each of the aquifers sampled contained a unique assemblage of invertebrates. Although we have only just begun to look, the high levels of endemism in our two study sites suggest that the state of New South Wales could have a very rich invertebrate fauna living in alluvial aquifers. Our results suggest that stygofauna communities are influenced by their proximity to recharge areas, which allow the rapid influx of nutrients and organic matter. Temporal sampling of stygofaunal communities indicates that abundances of most taxa are higher during spring and autumn. This on-going survey has highlighted the high taxonomic diversity present in two alluvial aquifers of New South Wales, and continued to uncover new taxa with each sampling occasion. Our results and recommendations will be made available to water resource managers in New South Wales to assist in the determination of environmental water requirements of groundwater dependent ecosystems.

Keywords: stygofauna, Australia, alluvial aquifers, groundwater communities, groundwater management

The application of early warning indicators to assess the condition of groundwater resources.

[1]Jehangir F. PUNTHAKEY

[1]PO Box 496, Roseville, NSW 2069, Australia, e-mail: eco@ecoseal.com

ABSTRACT

A key strategy in the UN's World Water Assessment Program is the development of a set of indicators for the water sector. These indicators are supposed to incorporate the complexities of interacting and competing forces in the water sector, and to present the information in a simple and straight forward manner so that decision-makers and the wider community can understand it. They must establish benchmarks to help analyse changes both spatially as well as temporally so that they can be used to promote effective governance of the resource. Good indicators help water sector professionals to step 'outside the water box', in order to take account of the social, political and economic issues affecting water.

This paper demonstrates the powerful techniques of technical analysis that can be applied to trend analysis of groundwater levels and drawdowns. A set of indicators were developed and applied as part of a research programme for extending modelling results to understand the condition of groundwater resources and to be able to provide early warning on the onset of stress on the groundwater system.

Sustainability Bands are a technical tool based on Bollinger Bands which are widely used in equity markets for analysing trends. The use of Bollinger Bands for analysing equity trends has been established over several years but their application outside the realm of financial markets is unknown. Bollinger Bands are bands drawn in and around the price structure on a chart. Their purpose is to provide relative definitions of high and low prices. When prices near the upper band, they are considered to be high and conversely, are low when prices approach the lower band. Bollinger Bands are used to define how the aquifer is responding to stress and to set boundaries for expectations. The use of Bollinger Bands (or Sustainability Bands in a groundwater context) is a first cut attempt at examining aquifer responses in a relative framework. It is in the interpretation of the bands, along with other indicators that, help us to understand the changing groundwater regime and to set relative definitions of high and low stress being imposed on the groundwater system. Bollinger Bands are but a tool – they are not meant to replace monitoring or the need for groundwater models. They can however be used in conjunction with monitoring and modelling to provide powerful insights into aquifer responses, providing bands that indicate the level of stress that an aquifer may be experiencing be it over a short, intermediate or long time frame.

A number of indicators were developed and adapted for this work, including Bollinger Bands or Sustainability Bands in a groundwater context, MACD, Volatility and the Relative Stress Indicator. The use of Bollinger Bands along with technical indicators such as MACD and volatility, were applied to cells, zones and aquifer layers to determine the relative stress levels during the simulation. In each case the onset of stress is clearly identifiable and demonstrates that technical analysis applied to groundwater levels offers new opportunities for sustainable management of groundwater resources. During the calibration period, the flat nature of the Bollinger Bands, MACD and volatility prior to 1995 shows that pumping stresses were minimal. When pumping stresses increase post 1995 the decrease in heads, along with a decrease in MACD and increase in volatility marks the onset of higher stress levels on the aquifer. Selected examples are presented to demonstrate the application of indicators at varying scales from a single model cell to zones to aquifer layers.

There is a great need for the use of real time data for monitoring the condition of groundwater resources and it is precisely because such data are not widely available in Australia that this work relied on simulated modelling data for analysis. Some examples of the application of these techniques using continuous monitoring of heads are demonstrated the Lower Murray Region in Southeastern Australia. As this work becomes more widely known it is hoped that it will provide the impetus for improved monitoring strategies including continuous monitoring data particularly for stressed aquifers or high risk aquifers. The use of real time data together with the application of indicators described in this paper would be a major leap towards improved management of fragile or high risk groundwater resources and will provide Resource Managers and communities that rely on these resources with the necessary tools to develop a sustainable framework for managing groundwater resources.

Keywords: Indicators, Sustainability Bands, Aquifer Stress, MACD.

The role of geophysics in enhancing our understanding of surface-water-groundwater interactions across a salinising floodplain in the Lower Murray Basin, South Australia , with implications for managing groundwater dependent ecosystems

[1]Kevin CAHILL, [2]Andrew FITZPATRICK, [3]Tim MUNDAY

[1]Australian Resources Research Centre,
26 Dick Perry Ave, Kensingtion,
WA 6151 Australia,
e-mail: kevin.cahill@csiro.au

[2] Australian Resources Research Centre,
26 Dick Perry Ave, Kensingtion,
WA 6151 Australia, e-mail: andrew.fitzpatrick@csiro.au

[3] Australian Resources Research Centre,
26 Dick Perry Ave, Kensingtion,
WA 6151 Australia, e-mail: tim.munday@csiro.au

ABSTRACT

In the southeast of Australia, the floodplains of the Lower Murray River have become extensively salinised. This is, in large part, related to an increase in recharge to the naturally saline groundwater system that flows into the River Murray from the irrigation that flanks the river, the regulation of river flow by weirs, increased water extraction from the river, and a marked reduction in flood events along its course. The result has been the accumulation and concentration of salt within the floodplains along the river and an increase in salt loads to it. The floodplains of the lower Murray represent a zone in which groundwater is shallow, and groundwater - atmosphere interactions through evapotranspiration are most pronounced. Where the groundwater system is particularly close to the surface, evapotranspiration concentrates salt resulting in extensive salinisation, vegetation dieback or health decline. In many floodplain areas, ecologically important *Eucalyptus* woodlands and forests that inhabit the floodplain are dying from soil water salt concentrations that often exceed those of seawater.

In order to manage the problem and to protect the ecology and biodiversity along the river, a range of management strategies are being employed including the development of salt interception schemes (SIS) and artificial flooding or environmental irrigation. The effectiveness of these strategies is particularly reliant on the availability of biophysical data that permit their consequences to be measured and monitored. We report on the use of a combination of ground and airborne geophysical, particularly electrical, methods that assist in the provision of detailed spatial-temporal information on the distribution of salinity in soils and groundwater. In this paper we review their value at various scales and comment on their use in the validation of groundwater models. Specifically, a combination of technologies including airborne, ground and “in river” electrical methods are considered including high resolution frequency domain helicopter EM data. We demonstrate that these techniques provide detailed spatial data on the distribution of salt concentrations in floodplain sediments. Fine scale studies using ground EM techniques are proving an effective way of discerning changes in groundwater quality, particularly those linked to artificial flooding events. By mapping spatial-temporal variations across the floodplain as a consequence of remedial management strategies, airborne EM data provide an insight into the scale of surface water-groundwater interactions in floodplain settings and are now being used to provide constraint to groundwater models, significantly improving our ability to predict the consequences of current and future floodplain management practices on vegetation health.

Keywords: Salinisation, evapotranspiration, salt interception, electrical methods, flood plain management.

The role of low flow and minimum-purge sampling methods used for the definition of groundwater background values in Potiguar Basin, Rio Grande do Norte, Brazilian northeast region.

(1)José B. DINIZ FILHO; (1)Paula STEIN; (2)Edeweis R. CARVALHO JÚNIOR, (1)Germano MELO JÚNIOR, (3)Maria DE FÁTIMA B.DE CARVALHO, (3)Fátima F. do ROSÁRIO

(1) Departamento de Geologia, Centro de Ciências Exatas e da Terra (CCET), Universidade Federal do Rio Grande do Norte (UFRN), Campus Universitário, Lagoa Nova, CEP 59.072-970, Caixa Postal 1639, Natal-RN/Brazil; e-mail brazdf@geologia.ufrn.br; paula.stein@gmail.com, germano@geologia.ufrn.br
(2) PETROBRAS/Unidade de Exploração e Produção do Rio Grande do Norte e Ceará/Gerência de Segurança, Meio Ambiente e Saúde (UN-RNCE/SMS), Natal-RN/Brazil; e-mail: edeweis@petrobras.com.br
(3) PETROBRAS/Centro de Pesquisas e Desenvolvimento/Gerência de Avaliação e Monitoramento Ambiental (CENPES), Rio de Janeiro-RJ/Brazil; e-mail: fatc@petrobras.com.br, fatimarosario@petrobras.com.br

ABSTRACT

A partnership has been formed between the Environmental Geochemistry Laboratory of Rio Grande do Norte Federal University (UFRN)/Brazil, and Petrobras/SMS-UN-RNCE/Brazil, with the goal to conduct the environmental monitoring and so to establish the *background values* for the shallow groundwater of the Potiguar Basin through the application of LOW FLOW and MINIMUM PURGE sampling methods.

In general, the petroliferous industry could be affected itself by a series of interventions that could have an impact on the environment. In this case, it is necessary to do the environmental monitoring under different natural compartments, potentially vulnerable to those interventions, and so choose the compartments more representative of the natural conditions of occurrence of groundwater. These natural conditions are essentials to establish the *background value*, considering only the hydrogeologic site where the groundwater flows.

The studied area partially involves the north part of Rio Grande do Norte State, including part of Mossoró and Areia Branca municipalities (Canto do Amaro Site), Assu (Estreito Site) and Macau (Salina Cristal Site).

The environmental monitoring has been developed by sampling nineteen (19) wells (of which 15 wells were located in the main aquifer in the studied area – Cretacic limestones of Jandaíra Formation; and 4 wells located in the Terciary-quaternary sedimentary material deposited over the limestones).

The wells sampling has been planned to cover two climatic periods: Dry Period (January/2007); Humid Period (Maio/2007). The decision as to what method should be used in each well (pattern LOW FLOW method or MINIMUM PURGE method) followed the classification made of the wells. This was done according to the rapidity of recuperation of water level in the wells and should be at least of 90% of the original water table value.

Using field tests and references in the literature about this theme, the wells were also classified according to: Wells with Fast Recharge (recovery time less than 1 hour); Wells with Medium Recharge (recovery time between 1 and 2 hours); Wells with Slow Recharge (recovery time over 2 hours).

For the Wells with Fast and Medium Recharge, the pattern LOW FLOW sampling method was applied, and for the Wells Slow Recharge the MINIMUM PURGE method.

The pattern LOW FLOW method consisted of first pumping of the well, and then sampling of water when the stabilization of the field physical-chemicals parameters were reached (pH, Eh, Eletric Condutivity, Salinity, Temperature, and Turbidity ≤ 10 NTU).

The MINIMUM PURGE method consisted of pumping the well for 48 hours, followed by pumping a volume of water similar to the sampling system volume (pump, tubes). So, the sampling process was initiated without stabilization of the field physical-chemicals parameters.

The dry period sampling was completed, eleven (11) wells had been sampled by the LOW FLOW method, and eight (08) wells by the MINIMUM PURGE alternative method.

Following this study, the Humid Period Sampling will be done. Thus the *Background Values* of the groundwater will be established, taking into account the results and values of physical-chemicals parameters of field and laboratory; inorganic chemicals parameters; organic chemicals parameters; hydrocarbon; and biological parameters.

Keywords: background values, low flow, environmental monitoring.

Underground Drinking Water of Georgia

[1]Guram BUACHIDZE, [2]Paata GIORGADZE[2]

[1] 31 Rustaveli Av., Tbilisi, 0108 Georgia
[2] 33 Shanidze Str., Tbilisi 0117, Georgia

ABSTRACT

Georgia is one of the richest countries in the world with its water source including glaciers, rivers, lakes, swamp and ground waters. The total number of rivers exceeds 26000. Every year, water formation in sq. km of surface is 820000 m^3 and the river flow exceeds 65 km^3. This amount of water is closely related to the underground system, which results in the possibility of using water supply mostly ground water for the supply of water.

The amount of drinking groundwater with salinity of 0,3-1,0 g/l equals to 573 m^3/sec or 18 km^3. Acceptable exploitable volume exceeds 9,5 km^3/year, or 26 mln m^3/day, or 300 m^3/sec. This huge amount of water is enough to satisfy a quarter of the internal requirements and Georgia can contribute to the world human programs with 11 billion litres of drinking water. The use of this renewable supply will be absolutely safe for ecology and environment.

Keywords: Different type of waters, resources of drinking waters, Georgia

TOPIC 02

Groundwater quantity, baseline quality and main threatening processes in dependent ecosystems

A methodology of sanitary risk assessment of wells applied to a poor community in the Municipality of Sao Paulo, Brazil

[1]Alexandra V SUHOGUSOFF, [1]Ricardo HIRATA, [1]Luiz Carlos KM FERRARI

[1] LAMO, Institute of Geosciences – University of São Paulo, Rua do Lago, 562 - São Paulo, SP, CEP 05508-080, Brasil, e-mail: suhogusoff@gmail.com, rhirata@usp.br, lf.modcom@gmail.com

ABSTRACT

The developing countries have an urgent need for cheap and efficient techniques for the detection of sanitary conditions in areas without public water supply and sewerage system. In suburban regions or irregular occupation areas, where there is a great lack of social assistance, the application of these simple methodologies by the community itself (which would be previously trained) could bring the awareness of the prevention of contamination of the water resources that are used for their supply.

The methodology of sanitary risk (MERISA) developed during this study is based on a questionnaire with 10 questions and 'yes' or 'no' answers. Its main purpose is to identify problems related to the bad construction and bad operation of the well and the presence of potential contamination sources at their vicinity. This technique was adapted from studies carried out by Lloyd & Helmer (1991) for the WHO (World Health Oganization). These authors developed a questionnaire with around 10 questions, which would result in a factor of sanitary risk related to the sources of water supply used by the rural communities inventoried and inspected by teams trained by the sanitary inspection agency.

The present study registered 175 houses at an irregular occupation area located at the District of Barragem, south region of the municipality of São Paulo. This area is characterized by the presence of surface water reservoirs used for public supply. The sewerage produced by the community is discharged to the surface water reservoirs but is mainly disposed in cesspits. Currently, there are 187 wells and 133 cesspits active in the area.

The following data was included on the inventory:

- Characteristics of the construction of cesspits and wells: type of external and internal casing (concrete ring, brick, earth, block, etc.); depth of the structure; type of surrounding pavement (cement, earth, flooring, gravel, etc.); type of cover (concrete, wood, roofing tile, metallic, etc.); if it has a cover, cracks, gap around the closure of the cover opening that provides access to the well, gap between the external casing of the well and the cover, origin of the effluent (toilet flush, shower, kitchen, total, laundry sink, etc.), in case it is a cesspit.
- Presence of potential contamination sources around the well: if there is water infiltrating into the well through the cover; if the well is located under a roofed area; if there is possibility of infiltration occurring through the casing due to certain characteristics of the well, such as the presence of electric wires and hose at the external casing; signs of infiltration through the casing; material suspended in the water column; unevenness on the surrounding ground (bioturbation, cracks, etc.) and probable contamination sources close to the well (cesspits, sewerage tubes, animal farming, served water, road gully, well of a neighbor, vegetable garden, etc.).

It was observed that around 80% of the wells were constructed with concrete rings, and none of them presented cementation for sanitary protection. The well was level to the ground in 20% of the cases. Possible infiltration was observed in 74% of the wells, and 45% of the wells actually presented infiltration. There was a possible contamination source in the direct vicinity of 70% of the wells and the presence of suspended material in the water, especially bubbles and foam, occurs in 58% of them.

The cesspits normally correspond to excavations of the ground, from which only a few present casing and do not have a sealed bottom and septic tanks are even rarer. The cesspits were constructed close to the wells and often higher than them, at distances as close as 5m from the wells, due to the lack of space in the allotment.

Almost 1/3 of the wells were selected as representative (that characterize the area as whole) for the collection of water for chemical (chloride and nitrate), physical-chemical and bacteriological analyses. Concentrations between 11 and 40mg/L of NO_3^- were obtained in 60% of the wells, and 10% of them presented concentrations higher than 40mg/L. Total and fecal coliforms were found in 97% of the wells, as wells as the indicator *Clostridium sulphite-reducing*. Regarding the physical-chemical properties of the samples, they presented the following average values: pH 5.61, 22.49ºC, Eh 297.79 mV and electric conductivity of 131.26 μS/cm.

After the inventory of the wells and the chemical/bacteriological analyses, these data were confronted by Cluster analysis. The objective of this treatment was to obtain the questions that would be more relevant regarding to the visual features of the sanitary conditions of the wells, in order to create a questionnaire able to indicate the risk of contamination of the well.

The analysis results demonstrate that the following questions would be recommended for the characterization of the sanitary risk of a well, applied in the following order:

1) Is the well exposed (without a cover)?
2) Are there cracks on the cover?
3) Is there a gap between the cover and the external casing of the well?
4) Is there a contamination source within a radial distance of 15m?
5) Is there evidence of infiltration of water into the well?
6) Is there material suspended in the water of the well?
7) Are there signs of infiltration on the internal wall?

The higher the number of affirmative answers, the greater the possibility that the well is contaminated. This does not mean that there is no contamination if all the answers are negative. It is interesting to mention that it is a limited assessment, due to the difficulty in controlling the variables not visible to the examiner. Examples of this are underground contamination sources, coming from a nearby contaminated well or underground abandoned pipelines whose existence is forgotten or unknown by the owner of the allotment. The importance of this questionnaire lies in the separation of wells that may present a greater chance of being contaminated from the wells that may not be. This may limit the groundwater sampling mesh for chemical analyses during the sanitary characterization of a certain area.

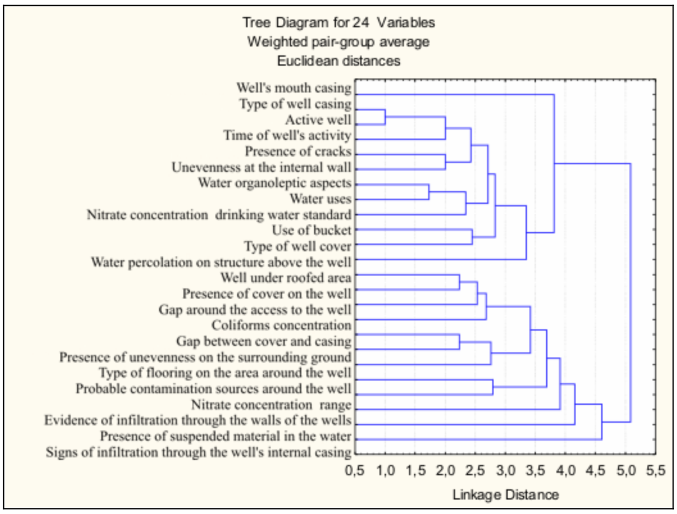

Fig. 1. Cluster analysis for all the information collected.

Fig. 2. Well downgradient of the cesspit.

Fig. 3. Cesspit.

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Keywords: questionnaire, cesspit, well, Cluster analysis, sanitary risk.

Characterization of subsurface brines in Fuente de Piedra lake hydrogeological system (Málaga, Spain) using hydrogeochemical and geophysical techniques.

[1]José Mª RUIZ, [1]Javier HEREDIA, [1]Alfredo GARCÍA DE DOMINGO

[1] IGME, Dirección de Hidrogeología y Aguas Subterráneas. Ríos Rosas, 23. 28003 MADRID
e-mail: jm.ruiz@igme.es, j.heredia@igme.es, a.garcia@igme.es

ABSTRACT

Groundwater hydrodynamics of The Fuente de Piedra lake system is characterized by great hydrogeological complexity due to the existence of marked density contrasts between fresh groundwater, brackish waters and dense subsurface brines. Groundwater flow system discharge into the lake, in combination with surface water generates an endorheic basin.

Fuente de Piedra lake is one of the first Spanish wetlands incorporated into the Ramsar Convention. It is the largest lagoon in Andalusia with an approximate surface of more than 1354 ha. With regard to biodiversity, it is a nesting site of the second largest flamingo colony in western Mediterranean, after The Camargue wetland (France).

The main objectives of the research conducted in the basin by the Geological Survey of Spain are the adequate hydrogeological characterization of the system, the development of a consistent conceptual model of groundwater flow and the evaluation of the relationship between groundwater and surface waters. This information should serve to improve wetland water management and its conservation.

One of the characteristics of this hydrogeological system is the presence of subsurface brines found below and around the lake floor. They present a large variation in salinity, reaching a TDS value about five times that of seawater. The major components are Cl-Na evapoconcentration processes and is caused by gypsum-salt matrix dissolution. Some results reached using hydrogeochemical an environmental isotopes characterization are presented in this paper. Also, some electrical profiles have been carried out in field work to check out the capacity of electrical resistivity tomography (ERT) method to locate and characterize brines and lithologies. For first time, it has been possible to find brines far away from the basin discharge area. Various range distance measurements of electrical profiles were located over banks and inside the lake on summer 2006. Consequently, electrical resistivity tomography (ERT) method is appropriate for brine definition and shows good correlation with another hydrogeological facts.

Keywords: Hydrogeochemistry, electrical resistivity tomography (ERT), wetland, brines characterization.

Chemical changes of groundwater in alluvium aquifers along season periodicity: The Drean-Annaba aquifer case study.

[1] L. DJABRI, [1] A. HANI, [1] R. LAOUAR, [2] J. MUDRY, [3] A.POLIDO BOSCH

[1] 11, Rue Asla Hocine, Annaba 23000, Algéria .E-mail:djabri_larbi @ yahoo.fr
Fax:00213.38.87.14.48
[2] Département de Géosciences, U.F.R Sciences et Techniques, 16 Route de Gray, Besançon 25000, France.
Jacques.mudry@univ-fcomte.fr
[3] Université d'ALMERIA- Espagne. apulido@ual.es

ABSTRACT

The Mediterranean climate is characterized by successive dry and wet seasons of unequal duration. For instance, the wet season can last three to nine months, depending upon the precipitation rates. The latter would influence the water resources both quantitatively and qualitatively. This has been the subject of many studies in the Annaba region, especially regarding their quantitative features. This study will be focussed on the impact of seasonal variations on the water quality; that is, the chemical variation of domestic water from wells in the Annaba plain which could be affected by climatic factors, particularly, the temperature and precipitations. The data obtained are reported on the Tickel diagram which shows the variation of the water chemical composition between the two seasons. Other methods, such as principal component analysis, ratios studies and thermodynamics, are also used and all confirm the influence of seasonal changes on water quality. The precipitations cause water dilution and hence lower the chemical element concentrations. In addition, the high evapo-transpiration coupled with temperature increase cause significant concentrations. Theses parameters condition chemical effects such as dissolution and leaching.

Contribution to the study of the Water Resources in Draa Valley (Province of Zagora, Morocco): Risks of Salinisation of Groundwater and Soil in the Oasis of Mezguita.

Samira OUYSSE, Noureddine LAFTOUHI

Cadi Ayyad University, Faculty of Sciences Semlalia,
Department of Geology, Laboratory of Hydrogeology, Marrakech, Morocco,
e-mail: ouysse_samira@yahoo.fr, noureddine.laftouhi@ucam.ac.ma

ABSTRACT

Generated by the Draa stream (1200 Km long), the valley of the middle Draa Knows, experiences a range of problems that are difficult to resolve due to difficulties in implementing the real plan.

From upstream to downstream, the valley shows a rosary of six palm groves of which each is supported by an individualized hydro-geological unit. Because of the Sub-Saharan (semi-ared) climate, the natural water resource is unreliable (unstable) and this becomes more pronounced toward the downstream palm groves where the problem reliability increases.

The objective of this survey is the assessment of the risk of soils salinity as a result of irrigation through the exploitation of the wells. The survey revealed that the palm grove of Mezguita is the most vulnerable because of the human density and its socio-economic stature in the valley.

The procedure includes the withdrawal of samples of waters and distributed soils in the grove of Mezguita, the "in situ" measurement of electric conductivity, pH and Temperature for water, the chemical analyses in the laboratory, and an analysis of the gathered data.

The physico-chemical analysis demonstrated that the waters of Mezguita aquifer are slightly alkaline and highly saline, and that this salinity originates in the central part of the groves because of the increase in the water level and the increase in evapotranspiration. Similarly, the measurement of salinity for the soils solutions showed an imbalance in the hydrogeo-chemical relationship because the quantities of salt brought in by the water are more than the quantities of salt exported. The use of these waters for agriculture means that tender wheat, already unfit to this type of climate, will be adversely affected. The resulting decrease in the intended production of wheat will not meet demand and cause a socio-economic problem.

The processes of hydro-chemical interactions are very variable for the cultivated soils. Consequently, the evolution of the high salinity will be specific for the scales of time and space.

Keywords: Salinisation, alkalinity, groundwater, soil, Draa (Morocco).

Groundwater baseline quality and main threatening processes in the semi mountainous area of the French Western Pyrenees

[1]Frédéric HUNEAU, [1,2]Fabrice REY, [1]Joëlle RISS, [2]Frédéric PRETOU, [3]Hélène CELLE-JEANTON

[1]Université Bordeaux-1, CDGA, UFR Sciences de la Terre, B18 avenue des Facultés, 33405 Talence, France
e-mail: f.huneau@cdga.u-bordeaux1.fr
[2]CETRA, 12 rue de l'Artisanat, 64110 Laroin, France, e-mail: f.rey@cdga.u-bordeaux1.fr
[3]Université Blaise Pascal, UMR 6524, 5 rue Kessler, 63000 Clermont-Ferrand, France,
e-mail: h.celle-jeanton@opgc.univ-bpclermont.fr

ABSTRACT

Carbonate rock aquifers are one of the main water supply sources for the French Western Pyrenees. The discontinuous structure of these reservoirs is a main obstacle to the development of such resources. Incidentally, since no other aquifer can be tapped, many communities have decided to improve their knowledge of the main springs over the whole region.

From 2003 to 2006 four sites have been considered and have been the object of multidisciplinary investigations including: geological mapping, geophysical investigations, dye tracing experiments. Stable isotopes have been analysed on both rainfall (^{18}O, ^{2}H) and spring's waters (^{18}O, ^{2}H, ^{13}C, ^{34}S) in order to evaluate the origin of groundwaters, their residence time within the systems and to appreciate the occurrence of exchanges with other aquifers. The hydrochemical survey and the in situ monitoring of groundwater quality have clearly demonstrated the huge potential of such aquifers in term of quantity and quality.

The main threat to the water quality is the risk associated with the existence of heavy rainfall in this area, that is, the generation of turbidity episodes. These episodes are able to reach more than 120 NTU whereas drinking water standards are limited to 1 NTU. Since turbid episodes are often correlated with bacteria contamination, groundwaters need to undergo strong treatment before distribution to the consumers. A better management of rainfall episodes able to entail important modification in groundwater quality could prevent the water supply disruption we observe each year.

Nevertheless, the development of carbonate rock groundwaters should be encouraged on the condition that protection perimeters around the catchment's areas would be strictly defined and respected, and that turbid episodes management would be anticipated.

Keywords: groundwater quality, carbonate aquifer, turbidity, Pyrenees

Groundwater bodies at risk. Further characterization – case study: Varazdin region, Croatia

[1]Ozren LARVA and [2]Tamara MARKOVIĆ

[1] Croatian Geological Survey, Sachsova 2, 10000 Zagreb, Croatia. olarva@hgi-cgs.hr

[2] Croatian Geological Survey, Sachsova 2, 10000 Zagreb, Croatia. tmarkovic@hgi-cgs.hr

ABSTRACT

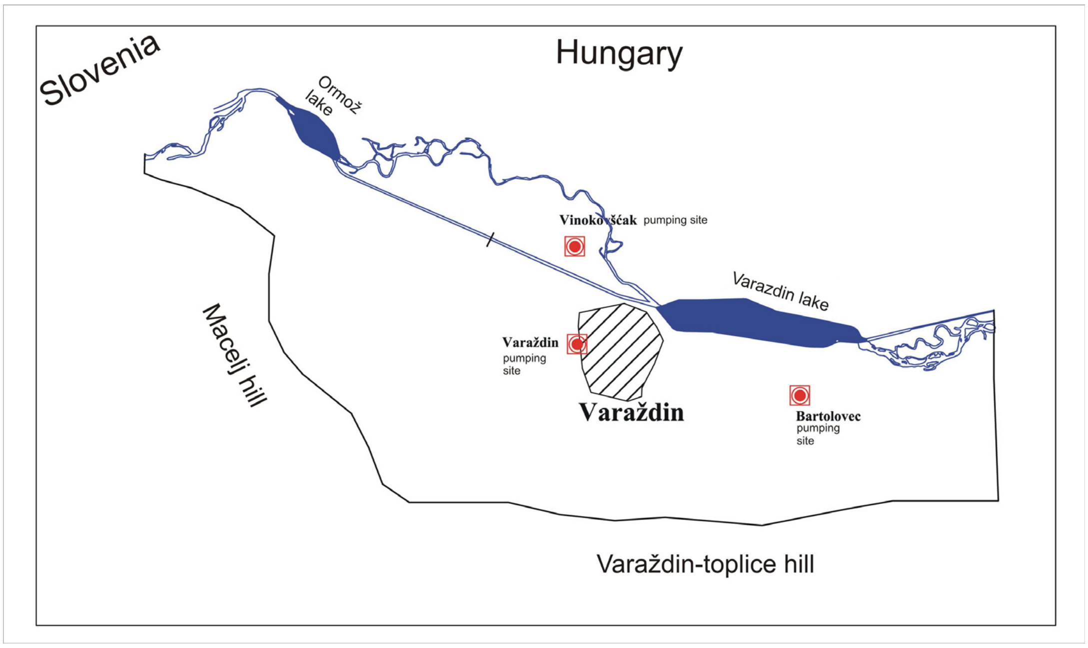
One of the most important characteristics of Republic of Croatia is its abundance of groundwater whose quality is still, in most cases good. To illustrate groundwater significance the fact that roughly 90 % of potable water that is consumed each day comes from underground storages. An extensive knowledge of quantitative and qualitative status of groundwater is the basis for the management of groundwater resources, especially in conditions of sustainable development. This is the basis of EU Water Framework Directive (WFD).

From a hydrogeological point of view, Croatian territory can be split in two contrasting parts. The Northern part belongs to the Black Sea catchment area with the most important aquifers characterised by intergranular porosity. On the other hand, the southern part of Croatia belongs to the Mediterranean Sea catchment area and the main aquifers are composed of rock masses characterised by karstic-fissured porosity. The process of initial characterisation of groundwater bodies, relating to implementation requirements of the EU WFD, was adjusted to the before mentioned division. The first step the Croatian Geological Survey carried out was the characterisation of groundwater bodies in the Black Sea catchment area and the second step the characterisation of groundwater bodies pertaining to the Mediterranean Sea catchment area was performed.

In total 363 groundwater bodies were delineated in the Black Sea catchment area and a few of them were marked as groundwater bodies being at risk or potentially being at risk. Agricultural activities, industrial point pollution sources or absence of waste waters systems are, in most cases, singled out as contaminant sources causing deteriorated groundwater quality. Further, more detailed characterisation of groundwater bodies at risk is necessary, together with designing optimal monitoring in places where there is lack of data. Well educated teams applying modern methodological approaches are necessary in order to achieve goals set by WFD.

Varazdin aquifer is located in the NW part of Croatia and represents the main source of potable water for the public water supply of Varazdin and surrounding settlements. The aquifer is composed of gravel and sand with variable portions of silt. It is formed during Pleistocene and Holocene as the result of accumulation processes of the Drava river. In the far north-western area its thickness is less than 5 meters and is gradually increasing in the downstream direction, reaching its maximum of roughly 105 meters in eastern part of investigated area. In the central part, near Varazdin town, a tiny aquitard appears, dividing the aquifer in two hydrogeological units. It has regional significance and can even be tracked downstream of the investigated area. It is composed of clay and silt and its thickness does not exceed 5 meters.

Favourable hydrogeological conditions enabled development of three pumping sites – Varazdin, Bartolovec and Vinokovscak. Natural groundwater quality is good and meets the standards for potable water but over the past two decades groundwater quality deterioration has been observed with high concentration of nitrates as a main concern. Extensive agricultural production, numerous poultry farms, together with lack of sewerage systems in settlements, is considered to be the main sources of contamination. Such circumstances led to gradual decreasing of groundwater abstraction rate at Varazding pumping site and directed the majority of abstraction to other pumping sites – Bartolovec and Vikonovscak. In the early stages of pumping sites development only the groundwater from first aquifer was abstracted. As a consequence of rising water demands and high nitrates concentration in the first aquifer, now groundwater from the second aquifer is also abstracted at pumping sites Varazdin and Bartolovec.



High concentrations of nitrates in groundwater in catchment area of Varazdin pumping sites was the main reason for putting the aquifer in category of groundwater bodies at status of risk. In last couple of years further characterization of aquifer has been carrying out. One of the aims of current research is assessment of aquifer vulnerability which would lead, in combination with results of hazard and aquifer sensitivity assessment, towards assessment of total risk. It is expected that results of such comprehensive research will provide decision makers with valuable layouts which will enhance groundwater management, land-use practices and enable reversal trend of parameters of groundwater quality and sustainable development of whole region.

In the paper preliminary results of further characterisation is presented. Since the vulnerability assessment requires extensive knowledge on physical and hydrogeochemical characteristics of aquifer, initial step included detailed investigation of geometry of the aquifer, chemical characteristics of groundwater in first and second aquifer, origin of nitrates in groundwater, hydrodynamics and boundary conditions.

Keywords: hydrogeology, intergranular aquifer, vulnerability assessment, risk assessment.

Groundwater salinization in the Upanema-Afonso Bezerra semi-arid region, RN, Brasil

[1]Jose G DE MELO, [2] Mickaelon B VASCONCELOS, [3]Jose I MEDEIROS,
[4]Franklin MORAIS, [5]Samara D MORAIS.

[1]Rua Pau Brasil, 457, N. Parnamirim, Natal, RN, Brasil, e-mail: jgmelo@ufrnet.br, jgmelo72@yahoo.com.br.
[2]Campus Universitario, Natal, RN, Brasil, e-mail: mickvasconcelos@yahoo.com.br.
[3]Rua Durval Porpino, 165, Neopolis, Natal, RN, Brasil, e-mail: jivan@ufrnet.br.
[4]CPRM, Recife, Pe, Brasil, e-mail: fraklin@cprm.br
[5]Alameda B. E. Apto. 103, N. Parnamirim, Natal, RN, Brasil, e-mail: samaradanielle.morais@yahoo.com.br

ABSTRACT

The study area is situated in the southern edge of the Cretaceous Potiguar Basin in the Central part of the Rio Grande do Norte State, in a semiarid region, covering an effective surface of about 1600 km^2.

The sandstones of the Lower Cretaceous Açu Formation are the main focus of this work which, in the southern zone of the area is limited by Pre-Cambrian crystalline rocks (represented by gneisses, granites and migmatites) and in the northern zone is limited by the limestone of the Upper Cretaceous Jandaira Formation. Ver Fig. 1.

The groundwater of the Açu aquifer is the main water source to supply the population and to irrigate lands.

The groundwater use has been limited due the occurrence of saline waters in some sectors of the area. The purpose of this study is to evaluate the groundwater potential, the recharge and water quality for human use and irrigation. In addition, it tries to evidence aspects in relation to the sources, mechanisms and distribution of the groundwater salinization using the structural geology and hidrogeochemical techniques.

The groundwater recharge was evaluated using the chloride balance. It was verified that the recharge in the eastern region of the area change from 0.4 to 4.0 % and in the western it changes from 3.3 to 6.6%. The aquifer transmissivity increases following the flux direction from south to north, changing from less than 50 m^2/d up to 450 m^2/d, characterizing the north zone of the area as the best hydrogeologic potential.

The salinization of waters depends on the geologic structure of the area. The salinity of the waters decreases to the flux direction as the transmissivity increases. The salinity of waters changes from 3450 µS/cm (south region) to less than 200 µS/cm (north region). Three types of waters were identified: Na^+ - Cl^- water type; Ca^{2+} - Cl^- water type and or Mg^{2+} and Ca^{2+} – HCO^{3-} water type. These are related to the geochemical processes like evaporation, minerals dissolution and ions exchange.

The groundwater quality of the Açu aquifer in the southern of the area is not good for irrigation. It is $C_4S_1T_3$ type water. In this case the waters have high salinity hazard (C_4), low sodium (alkali) hazard (S_1) and high toxicity hazard (T_3). In the north zone of the area the groundwater is good to irrigation and is $C_1S_2T_1$ type water. It means that the waters have a low salinity hazard (C_1), medium sodium (alkali) hazard (S_2) and low toxicity hazard (T_1).

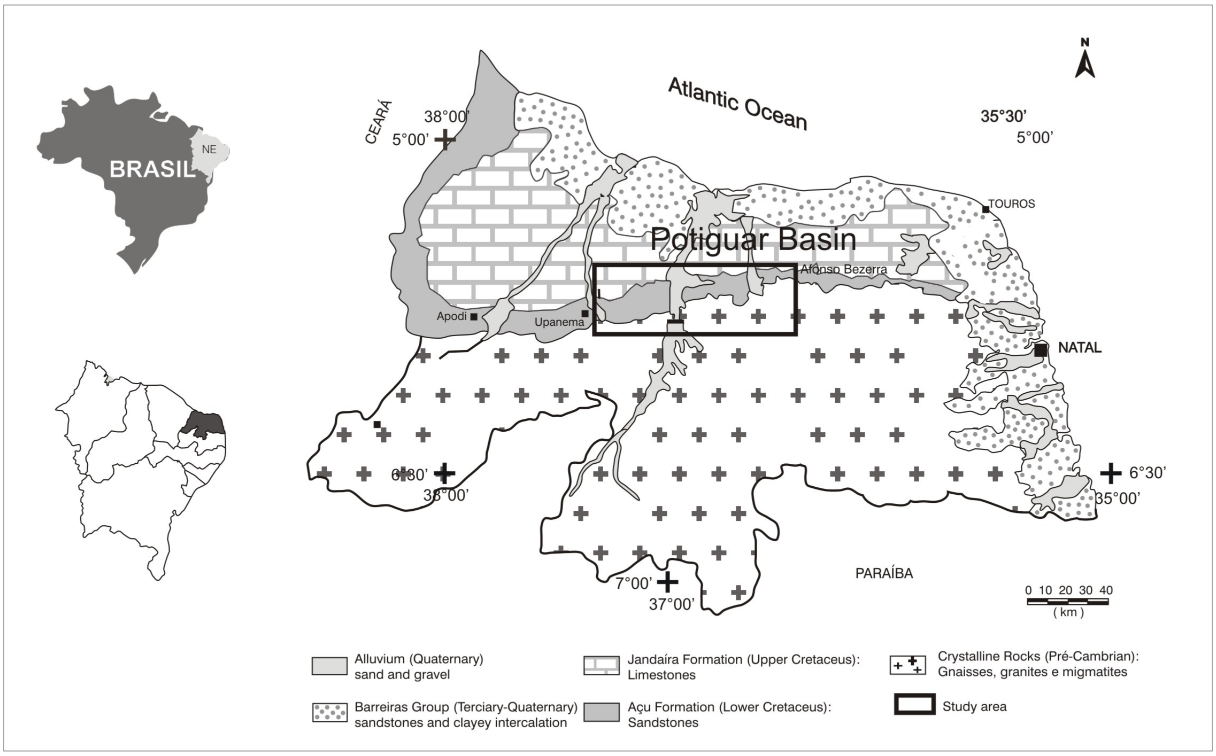


Fig. 1. Situation of the study area and Geology of the Rio Grande do Norte State.

Keywords: Groundwater flow, semi-arid region, salinization, groundwater quality, irrigation.

Hydrogeologic study and exploitation alternatives for potable water provision for the Villa de Merlo, Province of San Luis, Argentina.

[1] Norberto G. BUCICH, [1] Carlos A. J. TORRES, [1] Patricia LUNA.

[1] Instituto Nacional del Agua, Centro Regional de Agua Subterránea, Avda. José I. De la Roza 125 E – 5400 San Juan – Argentina. Tel. +54-264-4214826 Fax +54-264-4212415 – E-mail nbucich@ina.gov.ar - ctorres@ina.gov.ar - pluna@ina.gov.ar

ABSTRACT

The Villa de Merlo estimated population of 17,000 inhabitants has experienced an annual growth of about 8% during the last 20 years. This small city is situated in the Conlara Valley, which is a tectonic depression between two crystalline mountain blocks and filled with erosional material in the high regions and, in lesser proportion, by loess.

The Conlara valley, then, is in the central part of Argentina, within the geologic province known as Pampean Ranges, which is characterized by mountain chains where the crystalline metamorphic, migmatitic and intrusive basement crops out. This basement, Precambrian – Paleozoic in age, is constituted, then, by compact, impervious rocks, with scarce water.

As previously mentioned, these mountain ranges are separated by extensive depressions. These have a Quaternary cover made up by gravel, sands and silty clays deposited in alluvial and aeolian environments. It is in this cover where the greater part of the usable water accumulated.

On the basis of existing information, of the results of resistivity tests surveyed for the present research and of analyses of water sampled from known sources, two stratigrafhic units were identified: The lower one, the so-called Fine Clastic Formation and the upper one, the Coarse Clastic Formation. This subdivision is based on the different proportions of coarse and fine grain sizes in the sedimentary layers of each unit. The Fine Clastic Formation contains about 10% of coarse grained layers shereas in the Coarse Clastic Formation the coarse grained layers amount from 50% to 70%. This differential characteristic is important for making decisions in the design of water captation works. The Fine Clastic Formation shows strong variations in thickness in the studied area, from few metres to more than 400 metres. On the other hand, the thicknesses in the Coarse Clastic Formation have values slightly surpassing 100 metrs. In the studied area the sedimentary fill lies directly on the impermeable crystalline basement.

The Villa de Merlo has a continental pluviometric regime, with maximum rainfalls in the summer months, whereas in winter the precipitations are at their lowest. The recorded rainfalls have increased during the last 30 years, which is evidenced by a rise in the water table, which, in some areas near the Villa, rose more than 15 m.

The main recharge source of the aquiferous system derives from the temporary streams coming down from the mountains and discharging their water in the sedimentary fill. In no case are these streams in contact with the ground water saturation level. The direct recharge has been disregarded because it is considered that it can be null or nearly negligible with respect to the already mentioned discharges, and that the ground water table depths do not permit that the rainfall events can satisfy the field capacity of the aeration zone, except where the water table is very near the surface.

The potable water supply comes from a network fed by surface water from a series of streams draining the eastern mountain range (Sierra de Comechingones). The water consumption in the Villa de Merlo consists, fundamentally, of two main parts: the water consumed by humans and the water used for watering gardens and irrigating park spaces. The second part is the one that increased, due to the creation of residential zones, hotels and recreational areas.

Because of the population increase (in 1970, Merlo had only 1,500 inhabitants) the water supply has decreased because the permanent runoff contribution cannot meet the demand of the population in summer because of the influx of tourists visiting the Villa. A permanent ground water source of potable water has been identified in the area. In this way, it was possible to disregard other possible sources which could have an environmental impact.

In addition, exploitation alternatives were proposed by using solely ground water or with a well planified joint management with the surface resource, not only for the present day population, but also for a probable population in a near future.

This is intended to avoid the construction of a new hydraulic infrastructure which could significantly affect the natural regime of the streams, thus contributing to preserving their hydrologic and ecologic integrity.

Keywords: Hydrogeology, Ecosystem, Groundwater.

Hydrogeological and Geoelectrical Prospecting for Identification of Fracture System Conduits in Zlatibor Ultramafites, Western Serbia

[1]Zoran NIKIC, [2]Milenko BURAZER

[1] Faculty of Forestry University of Belgrade, Kneza Viseslava 1, 11 030 Belgrade, Serbia, e-mail: znikic@yubc.net
[2] NIS-Naftagas, Batajnicki drum BB, 11 070 Belgrade, Serbia, e-mail: burazer@eunet.yu

ABSTRACT

Bottled natural water is becoming increasingly an important source of potable water. Reservoirs of quality mineral waters are relatively abundant in Serbia.

Water from the Bijela Česma spring is good for bottling and commercial purposes. The area drained by this spring was prospected from 2004 to 2006 to identify hydrogeological parameters in terms of the spring quality and quantity for prospective future bottling plant construction.

The spring Bijela Česma is located in a gently rolling plateau of Zlatibor mountain, western Serbia, some 20 km SW of the town of Užice. The plateau has a surface area of about 22 km^2 within the altitude range from 920 m to 1150 m. There are few constant springs. Climate of the entire area is moderately continental, mountainous. The average annual amount of precipitations is 965 mm. Except for the tourist centre Partizanske Vode, there are no large communities on the plateau. Animal husbandry and, to a lesser degree, work on the land are the dominant occupations of the local population. Without industry and major transport routes, nature is well preserved in the area.

Geologically, the area belongs to the Inner Dinarides. The mountain massif of Zlatibor is built up dominantly of ultramafites that lie over the metamorphic diabase-chert formation of Jurassic age. Converging from the margin are firstly serpentinized peridotites, then harzburgite, and lherzolite in the centre. This generally tabular body has a thickness of about 1200 metres. In relation to the surrounding ground, the massif of Zlatibor rose in the early Miocene. Important tectonic events during the Neogene and Quaternary caused subsiding and the rising of tectonic elements.

Neotectonic study was made for identification of the fracture and fault features. The regime of the Bijela Česma springflow and water temperature were monitored over a period of twenty-two months (from 20 Oct. 2004 to 1 Aug. 2006), and five full chemical and fourteen bacterial analyses were performed. The springflow measurements did not register a recession period or any external weather or hydrologic influence. The chemical, bacterial and radiologic analyses indicated steady chemical composition, physical properties, and microbiological and radiologic qualities. Spring water is associated with a fracture-type aquifer in deep, tectonized part of harzburgite. Ground water recharge zones are neotectonic structures and faults between tectonic blocks.

Geoelectrical prospecting in Bijela Česma area clearly identified a block of solid rocks of very high electric resistance, located between lithologic members of far lower resistance. The natural spring of Bijela Česma emerges above this block of high resistance. Systems of fissures in coherent harzburgite operate as ground water conduits to the ground surface.

The investigation data indicated that Bijela Česma was an ascending type of spring from a neotectonic block of the lowest relief intensity and the highest relative subsidence.

Geoelectrical measurements indicated a minor block of coherent harzburgite with ground water filtering through its fissures. The systems of fissures are the preferential ways of ground water flow upward to the ground surface. This inference is confirmed by the Bijela Česma springflow observations.

Keywords: Fracture aquifer, harzburgite, spring, geoelectrical measurements, water quality.

Hydrological studies in the LIFE project "Mires" sites in Latvia

[1]Aigars INDRIKSONS, [2]Mara PAKALNE, [2]Liga BERNANE, [3]Agris ABOLINS

[1]Latvian State Forestry Research Institute "Silava", Riga Street 111, Salaspils, LV-2169, Latvia,
e-mail: indrikso@silava.lv
[2]Latvian Fund for Nature, Raina Blvd. 31-6, Riga, LV-1050, Latvia, email: mara@lanet.lv, liga.b.@navigator.lv
[3]Liepaja Academy of Pedagogy, Lielais Prospect 16-3, LV-3601, Liepaja, Latvia,
e-mail: agris.abolins@inbox.lv

ABSTRACT

Hydrological studies were carried out in four protected nature areas of Latvia – Cena Mire, Stikli Mires, Klani Mires and Veseta Floodplain Mire. These are the sites of the LIFE project "Implementation of Mire Habitat Management plan in Latvia". The sites are nationally and internationally important. Mire vegetation in the intact parts of the raised bogs includes labyrinths of bog pools and ridges. The sites are influenced by drainage and peat extraction that finds reflection also in the hydrology of the sites.

In order to reduce drainage influence on the raised bog habitats of Cena Mire, Vasenieku Mire from Stikli Mire Complex and Klani Mires, the existing bog hydrology was assessed. Hydrological studies were carried out in the areas where the dam building is planned. Estimation of groundwater flow directions in the raised bog was carried out by analyzing the topographic maps and the levelling of the mire surface. In total, 227 groundwater observation wells were established. From them – 101 in Cena mire, 25 in Stikli Mires, 28 in Klani Mire and 73 in Veseta Floodplain Mire. The groundwater wells are placed along transects –on average 10 wells along transect. The groundwater level in mires was characterised separately for each of the four seasons of the year.

To carry out the habitat monitoring, in 2005, there where 130 permanent plots established close to hydrological monitoring plots, in places where vegetation changes are most likely to occur before the planned management actions.

Cena Mire Nature Reserve is surrounded by large drainage ditches that do not allow the further growth of the mire. In the autumn of 2006, in Cena Mire there were 74 dams and 140 hand-made small ditch-blockage dams built.

On average, in the observation period before the dam building from January 2005 to October 2006, the groundwater level in the intact site of bog was 8.6 cm and in drained site 23.7 cm below the bog surface (Fig. 1). Thus, on average, in the drained site it was at 15.1 cm or 2.8 times lower than in intact site. In the observation period after the dam building in Cena Mire the groundwater level in the intact site of bog was 5.8 cm and in drained site 9.7 cm, on average just only 3.9 cm or 1.7 times lower. The data shows that the groundwater level differences after the dam building between the both sites have been decreased remarkably and can be considered as non significant. The groundwater level difference between the intact and drained parts of bog has been decreased 6 times (in winter season even 9 times). The dam building has reduced the range of groundwater level fluctuations.

Klani Mire Nature Reserve is strongly affected by hydro-technical drainage carried out in fifties and sixties of last century. During the twenties and thirties of the 20th century, the canal connecting Klani and Busnieki Lakes was dug and it caused the lowering of the water level in Klani Lake and a faster overgrowing of the lake. At an average, in the entire observation period from the February of 2006 till the February of 2007, the groundwater level in the intact site of Klani Mire was 1.6 cm, but in drained site 33.9 cm. The difference between the two sites was on average 32.3 cm. In the drained site the groundwater level was 21.2 times lower.

In Vasenieki Mire from Stikli Mires Nature Reserve, the groundwater level was analysed by comparing the intensive and less intensive drained areas of the bog. The average groundwater level in wells was measured that are placed in the shape of transect between 100 m distant drainage ditches, and in wells, placed in the shape of a transect between the 20 m distant ditches. This indicates the impact of different drainage intensities on the groundwater level and regime. On average, in the entire observation period, the groundwater level between the 100 m distant drainage ditches was 48.7 cm, but in the area with a more intensive degree of drainage (distance between the ditches 20 m) was 53.8 cm.

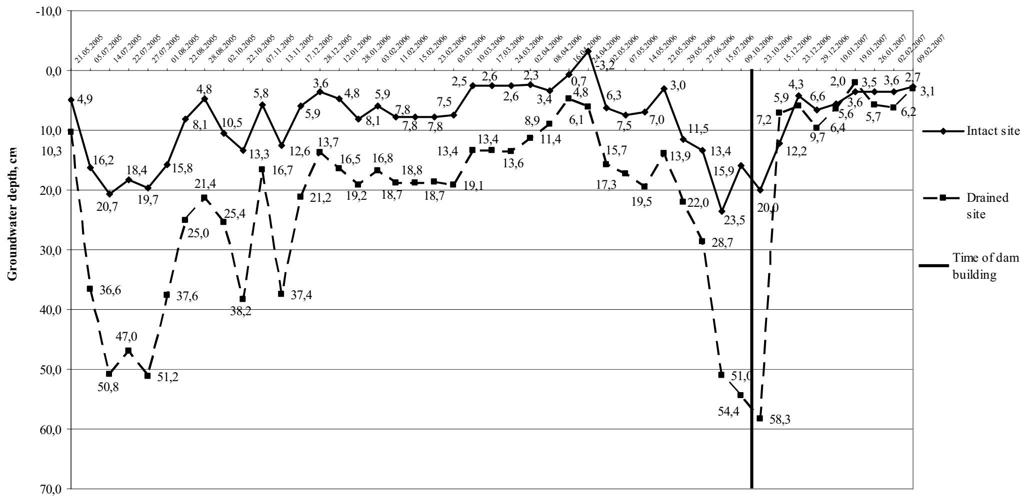


Fig.1. Fluctuation of groundwater level in Cena Mire

In the area of Veseta Floodplain Mire the following problems have to be solved: overgrowth of transition mires and spring fens by shrubs and trees; overgrowth of floodplains by shrubs and tall vascular plant species; earlier forest drainage carried out in the project territory and outside.

The groundwater observation wells in Veseta Floodplain Mire were established in the shape of transect across the Veseta River valley. Transect of wells crosses, at least, 4 different plant communities in the following order: transition mires and quacking bogs (7140), bog woodland (91D0) (dominant tree species *Pinus sylvestris* and *Betula pendula*), Fennoscandian deciduous swamp forests (9080*) (dominant tree species *Alnus glutinosa* and *Picea abies* and the open reed field. The lowest groundwater fluctuations are in the transition mire area. The average groundwater level there is 8.3 cm. The mire ecosystem keeps the water level stable all the year. The water level is significantly lower only during the drought period of summer, when in summer of 2006 it was 27.3 cm. The highest groundwater level fluctuations and range between the minimal and maximal values are in the open area in the middle of valley overgrown with reeds. The soils of open reed fields in Veseta floodplain in summer are almost dry in the river valley, whereas, in winter and during great rains are the most wet places. During the hot and dry summer, the water level is most shallow in deciduous swamp forest, where, possibly, the confined aquifer water discharges and the water level is kept constant by beaver.

In all the studied sites where the management activities are planned, the groundwater level difference between the drained and intact parts is significant. The range of groundwater fluctuations is wider in the drained part, but the fluctuations in both parts are synchronous, depending from the meteorological conditions. The low groundwater level and range of fluctuations are one of the causes for changes in the natural bog vegetation.

Keywords: mires, groundwater level, raised bog restoration

Hydrostratigraphical situation of the deep aquifers in the Venetian inland (NE Italy)

[1] T. CAMBRUZZI, [1] E. CONCHETTO, [2] P. FABBRI, [2] E. MARCOLONGO, [2] A. ROSIGNOLI., [2] P. ZANGHERI

[1] Autorità d'Ambito Territoriale Ottimale Laguna di Venezia (AATO LV), via Pepe 102, 30172 Mestre (Venezia), Italy
[2] Dipartimento di Geoscienze, Università di Padova, Via Giotto 1, 35127 Padova, Italy

ABSTRACT

The regional hydrogeological situation of the Venetian plain (NE Italy) is characterized in the north by an extensive alluvial unconfined aquifer some hundred meters thick. This area extends from the Pre-Alps (Montello Hill) to the "fontanili" zone. In this strip of plain the water table intersects the topographic surface forming numerous characteristic plain springs called "fontanili". The aforementioned "fontanili" zone covers a strip of plain 2 to 5 km wide and several hundred kilometers long from the Piemonte region (NW Italy) to the Friuli region (NE Italy). This strip of plain sets a boundary between the high and middle-low Venetian plain. This natural drainage system supplies numerous perennial streamflows, e.g. the Sile river (5 - 6 $m^3 s^{-1}$). In this strip the unconfined aquifer changes into a multi-layered confined or semi confined aquifer system to the south of the "fontanili" zone. The hydrogeological situation is determined by impervious or semi-pervious layers interbedded with sand and gravel layers (middle Venetian plain). It is seen that, in the distal part of the fans at various distances from the mountain region, the alluvial body consists of alternating layers of gravel, sand, silt and clay, which can be more than 10 m thick. The clay layers may be of lagoon or marine origin. The complete multi-layer aquifer can reach a thickness of up to 500 m with a progressive increase towards the Adriatic sea. The unconfined aquifer of the high Venetian plain is recharged by rains, artificial irrigation and by dispersion from the main rivers. The multi-layer confined aquifers of the middle Venetian plain are recharged by the unconfined aquifer present in the high plain, being hydraulically connected with it.

Part of this middle Venetian plain falls under the northern territorial jurisdiction of the AATO Venice Lagoon, which is one of the eight water authorities presiding in the Veneto region (NE Italy) and draws from 50 public wells about 97 Mm^3/year of drinking water.

The need for concise knowledge of the hydrostratigraphical situation of this strategic exploitation area in terms of hydrostructures and total flow rate for each aquifer, has prompted the exploration of the different aquifers through detailed cross sections. Six hydrogeological cross sections were made (three N-S and three E-W) in the northern part of the AATO LV territory, where its strategic reservoirs are located. Initially bulk cross sections were made with stratigraphies of wells belonging to public water companies of AATO LV, which provide the most reliable well stratigraphies. Secondly these cross sections were made more accurate by private well stratigraphies available in our data base, comprising about four thousand private wells. Data base also includes information on water well temperature and electrical conductivity, well pressure and flow rate and this information was also significant in determining the location of a multi-layer aquifer system composed of 10 superimposed confined aquifers 0 to 400 m in depth.

With the main aim being to obtain a better definition of the three-dimensional hydrostructures of the principal aquifers in the AATO LV northern territory, we drew up a drill plan of exploration wells up to 400 m and also a few up to 800 m in depth. The 800 m deep wells will explore unknown aquifers of the middle Venetian plain in qualitative and quantitative terms and both 400 m and 800 m deep wells will be used further as monitoring wells.

Keywords: public drinking waters, confined aquifers, middle Venetian plain, Veneto region, Italy.

Identification and quantification of sources of major solutes in a sandy, phreatic aquifer in Central Belgium through ionic ratios and geochemical mass-balance modeling

[1] Luk PEETERS, [2] Okke BATELAAN, [3] Alain DASSARGUES

[1,2,3] Applied Geology and Mineralogy, KULeuven, Belgium, luk.peeters@geo.kuleuven.be
[2] Dept. of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel, Belgium, okke.batelaan@geo.kuleuven.be
[3] Hydrogeology & Environmental Geology, ArGEnCo, University of Liege, Belgium, alain.dassargues@geo.kuleuven.be

ABSTRACT

In this study the processes affecting groundwater chemistry in the Eocene Brussels sands aquifer in Central Belgium are identified based on evaluation of ionic ratios of major solutes. Based on these results, in combination with mineralogical and hydrogeological information of the aquifer, a geochemical mass-balance model is created to quantify the contribution of each of the processes to the observed composition of groundwater.

After a rigorous validation process, a dataset of 99 groundwater samples is obtained from observation and pumping wells in the Eocene Brussels sands aquifer, which is one of the main aquifers for drinking water production in Belgium. The aquifer consists of heterogeneous alteration of calcified and silicified coarse sands, with local presence of clay drapes and glauconite-rich zones. The entire aquifer is overlain by Quaternary eolian deposits, mainly consisting of loam with the exception of the north east, where the Quaternary deposits are sandy loam. The groundwater in this aquifer is of Ca-Mg-HCO3-type with locally elevated nitrate concentrations.

Based on the evaluation of ionic ratios and the mineralogy of the aquifer, a conceptual geochemical model is developed for mass-balance modeling, including (1) concentration of precipitation by a factor 1 to 5 due to evaporation, (2) dissolution of a pure calcite phase and a calcite phase containing 25 % magnesium by both carbonic acid and sulfuric acid, (3) anthropogenic inputs for all major cations and anions except bicarbonate, (4) dissolution of glauconite, (5) cation exchange of sodium and potassium for calcium and magnesium. The two calcite phases can be thought of as end-members of a solid solution of magnesium in calcite.

The mass-balance modeling consists of a mole-balance equation for each considered element according to:

$$[Obs] = p[Prec] + p1[Phase\ 1] + ... + pi[Phase\ i] + a\ [Anthropogenic] +/- c[Cation\ Exchange]$$

This set of linear equations is additionally constrained by (1) defining a range for concentration factors p based on measured and calculated evaporation rates, (2) charge balance for the anthropogenic sources and (3) pi being positive or negative according to whether the phase dissolves or precipitates. The set of linear equations with the given constraints is solved using a least squares optimization.

Based on the possible processes and reactions several geochemical models are tested for each sample and a model is considered adequate if the root mean squared error (RMSE) between observed and calculated concentrations is less than 10^{-10} mol/L and the charge balance of the calculated composition is less than 5 %. If several models are able to explain the observed concentrations, the RMSE provides an objective measure to compare the quality of the models.

The best model for each sample is selected and the spatial distribution of these models is compared to the spatial variations in lithology and land-use to asses the feasibility of the proposed models.

Keywords: Groundwater chemistry, Mass-balance modeling, Belgium

Natural background hydrogeochemistry in the nature reserve of Zoersel Forest (Flanders, Belgium) - Testing of the BRIDGE methodology for determination of threshold values

[1]Kristine WALRAEVENS, [2]Marleen COETSIERS

[1]Ghent University, Laboratory for Applied Geology and Hydrogeology, Krijgslaan 281-S8, B-9000 Gent, Belgium, e-mail: Kristine.Walraevens@UGent.be
[2]Ghent University, Laboratory for Applied Geology and Hydrogeology, Krijgslaan 281-S8, B-9000 Gent, Belgium, e-mail: Marleen.Coetsiers@UGent.be

ABSTRACT

In the Flemish nature reserve of Zoersel Forest, a total of 88 groundwater samples and 15 surface water samples were taken during three sampling campaigns in May-June 2005, September 2005 and January 2006. The objective was the assessment of water quality, in view of its influence on the groundwater dependent terrestrial ecosystem of Zoersel Forest.

Shallow recharge-discharge cycles are influencing water quality in the nature reserve. The dominant reactions are pyrite oxidation and calcite dissolution in the infiltrating groundwater. Both processes are also reflected in the surface waters, to which the groundwater is discharging.

As for the nutrients, most groundwaters are low in nitrate, but their phosphate content is moderate to high. The latter elevated values are derived from the deep subsoil where phosphate concretions are present.

In the framework of the European BRIDGE project (Background cRiteria for the IDentification of Gourndwater thrEsholds) a methodology was developed for the derivation of pollutant threshold values for groundwater bodies, as imposed by the European Water Framework Directive and the Groundwater Directive, aiming at the assessment of good or poor status. Using this methodology, threshold values were derived for the groundwater body to which Zoersel Forest belongs, and these threshold values were compared to the natural background quality of the Zoersel Forest groundwaters.

Keywords: Hydrogeochemistry, natural background, nature reserve

Natural background of nitrate in the percolated water

[1]Branka BRAČIČ ŽELEZNIK, [2]Marina PINTAR, [2]Vesna ZUPANC

[1] Public water Supply company JP Vodovod-Kanalizacija d.o.o., Vodovodna cesta 90, 1000 Ljubljana, Slovenia, e-mail: bzeleznik@vo-ka.si
[2]University of Ljubljana, Biotehnical Faculty, Agronomy Department, Center for Agricultural Land Management and Agrohydrology, Jamnikarjeva 101, 1000 Ljubljana, Slovenia,
e-mail: marina.pintar@bf.uni-lj.si., vesna.zupanc@bf.uni-lj.si

ABSTRACT

Water field Kleče is, with total capacity of 1270 l/s, the heart of Ljubljana's fresh water supply system. About 35% of the capture area of the Water Supply Station's is used for agriculture, predominantly for intensive vegetable production. In the nineties nitrate (NO_3^-) concentration levels of the groundwater in Ljubljana aquifer were increasing. Disconcerting trends prompted Water Supply Station Kleče to set up several monitoring systems of nitrate concentration levels to gain an overview of the situation, determine trends and to identifying the main polluters as well as to take preventive steps to decrease the established pollution.

Since the year 2002 concentration of NO_3-N in percolated water has been monitored. On the premises of the Kleče water plant no fertilizers are used, therefore the results represent the nitrate natural background levels, which come from air to the soil.

Nitrate quantity in the percolating water changes over seasons and years and depends on the precipitation amount, season, plant uptake and soil processes.

The paper will present results of the nitrate concentration in percolated water sampled on the lysimeter station in Water Supply Station Kleče for period 2002-2006.

Keywords: percolated water, drinking water source management, nitrate concentration (NO_3^-), natural background

Occurrence of arsenic in groundwater of Korea

Joo Sung AHN, Kyung-Seok KO, Ki-Hwa PARK

Groundwater and Geothermal Resources Division, Korea Institute of Geoscience and Mineral Resources, Daejeon 305-350, Korea, e-mail: jsahn@kigam.re.kr, kyungsok@kigam.re.kr, pkh@kigam.re.kr

ABSTRACT

Korea has set guideline values of As in groundwater. These are 50 μg/L for drinking, domestic and agricultural uses, and 100 μg/L for industrial uses, which is much higher than 10 μg/L for drinking suggested by WHO and US EPA. Arsenic concentrations exceeding the current guideline from individual wells for drinking water have been frequently reported, whereas there is no large-scale As problem in groundwater in Korea. Arsenic contaminations of surface waters and some groundwaters were also revealed, particularly in the vicinity of abandoned gold mining sites. Water quality data for bottled mineral waters indicated about 19 % of the production wells exceeded 10 μg/L in 2002, suggesting the geogenic release of As. In this study, nationwide occurrence pattern of As in groundwater was investigated from the data of the groundwater quality monitoring stations (GQMSs) in Korea.

GQMSs, operated by the Ministry of Environment, have been managed since 1992 to collect groundwater samples twice a year and to assess the status of water quality in nationwide scale by analyzing 20 contaminant items including As. From the dataset during 2001-2005 of the GQMSs (about 20,000 data from 2,021 stations), arsenic content of more than 5 μg/L has been quantitatively detected in 2.8% of the total wells on an average at every semi-annual survey. Concentrations higher than the current guideline values were reported in only a couple of wells (up to 188 μg/L). However, if the WHO standard is adopted, about 1.0 % of the wells exceeded the value, and the exceeding ratio reached 2.0 % and 2.7 % at the first half in 2004 and at the second half in 2005, respectively. Geographical distribution of As suggests three groups in occurrence patterns as shown in Fig. 1.

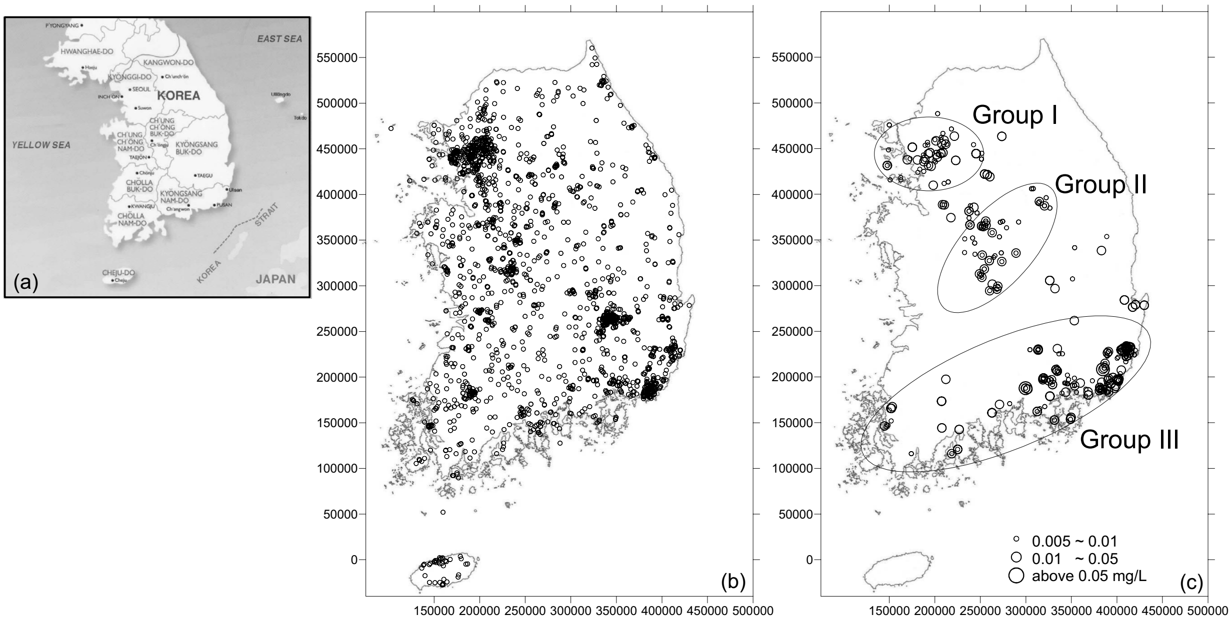


Fig. 1. Arsenic occurrence in groundwater in Korea; (a) index map of Korea, (b) locations of groundwater quality monitoring stations (2,021 wells), (c) occurrence of As from the data of monitoring stations from 2001 to 2005.

The first group corresponds to Seoul and its neighbouring province which is the most densely populated (around 23 million, 48 % of the total population) and urbanized area. The second and third groups are located in the mid and the south-end of the Korean peninsula, respectively. Presently, the exact model for As release in these groups cannot be drawn due to the lack of other related geochemical and geological data. However, in the first group, As seems to be released from various industrial activities and/or waste disposal, municipal sewage, etc., by anthropogenic sources. The second group is geologically matched with the Ogcheon Belt in which black shales and other metasedimentary rocks are well known with enriched As and heavy metals as sulfide phases. The third group corresponds generally to Cretaceous Gyeongsang Basin in which volcanic rocks have strong hydrothermal alteration, and also metallogenic (mainly Cu-Au) mineralization has made various ore deposits. Arsenic is present as sulfides and/or arsenides in these mineralized and altered zones. From the wells of the second and third group areas, As appears to be released by the intrusion of oxygenated surface water and subsequent oxidation of As-bearing minerals. Most of the ungrouped stations are also related to local gold mineralization or bedrock alteration in aquifers considering the regional geology of Korea.

Although the monitoring of some high As-containing stations was stopped due to closure of the wells, As concentrations in continuously measured wells remain generally unchanged over the period of 2001-2005. Precise mechanism for the release of As needs to be assessed by further systematic studies in these areas. 35.1 % of the As-containing wells are used for drinking, thus As in groundwater should be monitored particularly where groundwater is the only water resource.

Keywords: Arsenic, groundwater, Korea, monitoring

Radionuclides in Groundwater of the Serra Do Buçaco Region (Central Portugal)

[1]Cátia V.M. GONÇALVES, [2]Alcides J.S.C. PEREIRA

[1] Laboratório de Radioactividade Natural, Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia da Universidade de Coimbra, 3000-272 Coimbra, Portugal, e-mail: catiagoncalves@hotmail.com
[2] Laboratório de Radioactividade Natural, Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia da Universidade de Coimbra, 3000-272 Coimbra, Portugal, e-mail: apereira@dct.uc.pt

ABSTRACT

In most part the study of the natural radioactivity in Portugal had been done in regions where the geological bedrock is composed of hercynian granites and Pre-cambrian metasedimentary rocks; in the latest case, the rocks are integrated in the Complexo Xisto-Grauváquico Ante-Ordovícico. In the Buçaco region (Central Portugal) the bedrock is composed mainly of metasedimentary and sedimentary rocks, with their age ranging from the Pre-Cambrian to Triassic.

Previous studies done in the region of Buçaco have recognized the occurrence of several geologic units, of metasedimentary or sedimentary nature, with high uranium and thorium content (Gonçalves, 2006). The more enriched rocks are of Precambrian, Lower Ordovician, Carbonic and Triassic age. In the case of uranium the values ranging between 1 and 59 ppm, while the thorium values ranges between 2 and 173 ppm. Uranium bearing enriched faults have also been detected with uranium content several times higher than in that measured in the intersected rock..

The present study is to investigate the distribution of different radio-nuclides in groundwater that flows through the different geologic units in the same region. The Liquid Scintillation Counting technique was used. The liquid scintillation method is one of the oldest and most useful method for detection and spectroscopy of ionizing radiations. The scintillation technique is based on the phenomenon of fluorescence, and detects photons produced by the scintillator material. These light flashes are caused by exited states of the scintillator molecules after the absorption of energy from radioactive decay. Equipment of raised sensitivity, the Wallac Quantulus 1220 was used. Gross-alpha and gross-beta activity concentrations, uranium (^{238}U and ^{234}U), ^{226}Ra and radon gas values were determined for a set of nine groundwater samples.

The total alpha activity values vary between 0,02 and 0,83 Bq.L $^{-1}$, and represents a great variability. The same pattern was detected for the total beta activity with values ranging from 0,002 to 0,66 Bq.L $^{-1}$. The ^{226}Ra's activity varies between 0,01 and 0,44 Bq.L $^{-1}$. Some samples present values of activity below the limit of detection of the technique used. In general, the radon gas range from values 6 to 1251 Bq.L $^{-1}$. The measured values are close to those already observed in groundwater collected in springs and water-holes from the hercynian granitic rocks that outcrop in central Portugal, some of them having been een recognized as a source for the uranium ores.

***Keywords*:** Radionuclides, Liquid Scintillation Counting, Groundwater, Serra do Buçaco, Portugal.

Radon in groundwater from the Hesperian massif (Central Portugal)

[1] Alcides J.S.C. PEREIRA, [1] Luis J.P.F. NEVES, [1] Cátia V.M.GONÇALVES

[1] Laboratório de Radioactividade Natural, Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, Universidade de Coimbra, Largo Marquês de Pombal, 3000-272 Coimbra, Portugal, e-mail: apereira@dct.uc.pt

ABSTRACT

Radon is a radioactive gas that occurs in rocks, soils, air and water in variable concentrations, and is considered an environmental health hazard. Radon concentrations in groundwater are highly variable and the main source of variation are geological factors. In general, aquifers composed by rocks enriched in uranium also have higher concentrations of dissolved radon in the circulating water.

To evaluate the radon concentrations in groundwater from the Hesperian massif of Central Portugal, a set of 318 samples was collected in water points between Viseu (north limit) and Nisa (south limit). Only springs were selected, thus results refer only to the epidermic aquifer. These springs are connected to hercynian granites and metasedimentary rocks ranging in age from the Precambrian to the Carbonic; they are composed of schists, graywackes, shales, quartzites and sandstones. The igneous rocks are of several different types: a) porphyritic biotite granite (Beiras granite), where the Nisa granite is also included; b) porphyritic two-mica granites (Tondela, Seia and Castelo Branco); c) non-porphyritic muscovite or muscovite-biotite granites (Caramulo and Boa Aldeia). Each water sample was analysed using degassing techniques that promote the extraction of the dissolved radon and the transfer to an ionizing chamber or a scintillation cell where its activity is measured.

The radon concentrations disperse over a wide range of variation, between a minimum of 19 and a maximum of 8830 $Bq.l^{-1}$. The aquifers on granitic rocks have a geometric mean ranging from 373 $Bq.l^{-1}$ (Beiras granite) to 104 $Bq.l^{-1}$ (Seia granite).). The Caramulo-Boa Aldeia group has the second highest average with 281 $Bq.l^{-1}$, followed by the Castelo Branco granite (204 $Bq.l^{-1}$) and the Tondela granite (149 $Bq.l^{-1}$). Radon concentrations in waters from the metasedimentary rocks have a geometric mean ranging from 35 $Bq.l^{-1}$ to 323 $Bq.l^{-1}$. When these rocks are metamorphosed by granites, or occur inside the latter as enclaves, the concentrations of the radioactive gas in water increases sharply to values close to those measured in waters collected on springs from igneous rocks (for example, an increase in the geometric mean from 35 $Bq.l^{-1}$ to 196 $Bq.l^{-1}$ was observed for Precambrian to Cambrian metasedimentary rocks, respectively outside and inside the contact metamorphic aureole). In general, the variability in radon concentrations is high, with the highest variance detected in the Beiras granite sample set which also display the highest absolute values, often above 1000 $Bq.l^{-1}$ (16%). This value is the limit recommended by the European Union (recommendation 2001/928/Euratom) for water used for human consumption. In general, within each lithology, the highest values relate to waters that percolate U-enriched faults that intersect the igneous rocks but also the metasedimentary ones.

Keywords: Radon gas, groundwater, granites, metasediments, Central Portugal

Restoration original meanders and groundwater dependent ecosystems in the brook valley of the Koningsdiep, the Netherlands

[1]Leo van WEE, Wibe [2]ALTENBURG, [3]Theunis OSINGA

[1]P.O. Box 10095, 1301 AB Almere, The Netherlands, e-mail: t.vwee@witteveenbos.nl
[2]P.O. Box 32, 9269 ZR Veenwouden, The Netherlands, e-mail: w.altenburg@altwym.nl
[3]P.O. Box 36, 8900 AA Leeuwarden, The Netherlands, e-mail: tosinga@wetterskipfryslan.nl

ABSTRACT

The brook valley of the Koningsdiep is located in the province of Friesland, the Netherlands. A part of the valley is currently in agricultural use, the other part is nature reserve. The brook valley is about 20 kilometres long and 6 kilometres wide (a total area of about 12000 ha). The brook valley has an open landscape with areas of agriculture, woods and heathlands. The government of Friesland has allocated the brook valley as area of interest to improve the hydrological conditions for recovery of groundwater-dependent ecosystems and agriculture as well. In order to find optimal locations of the re-establishment of this groundwater-dependent ecosystems a hydroecological research was carried out. The results were carefully and regularly communicated with all stakeholders in the interested area.

The brook is now an oversized channel that was designed for agricultural purposes. The channel has a width on waterlevel of about 10 meters and a freeboard (or dewatering level) of about 1-1,5 meters below surface level. The water comes from the upper part of the brook, the brook valley itself and agricultural areas outside the brook valley. Different goals were formulated for the brook valley. The first goal for the brook is to restore the original (shallow) meanders and (small) stream pattern of the brook in combination with raising the waterlevel (rewetting). The second goal is to find suitable locations (with a maximum of 440 ha) for groundwater-dependent ecosystems near the brook. The ecosystems consist mainly of vegetations belonging to *Calthion Palustris, Magnocaricion* and *Cirsio-Molinietum.* The third goal is improving the hydrological conditions for the agriculture in the brook valley. For this goal climate change should be anticipated by creating a storage basin. An important condition for achieving the goals is the existing nature reserve inside the brook valley. No negative hydrological effects on species are allowed.

To achieve the mentioned groundwater-dependent ecosystems, abiotic conditions must be created. First it has to be determined what specific condition each species demands. Important abiotic hydrological conditions are the mean spring groundwater level, the mean lowest groundwater level, the exfiltration in the root zone, water quality (ground-or rainwater) and flooding frequency. Information about all these hydrological conditions for the above mentioned vegetation types were obtained. For example, Fig. 1 shows the relationship between the mean spring and the mean lowest groundwater level of *Calthion-Palustris* and the ecological health (100% means optimal condition).

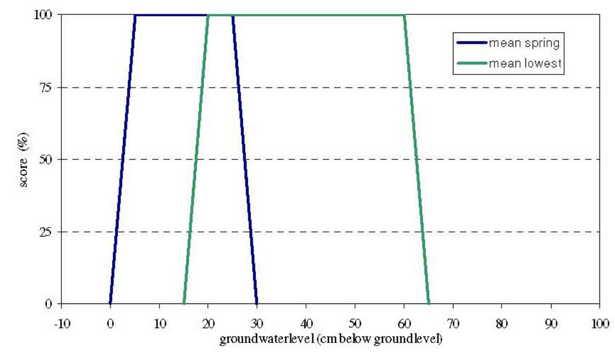


Fig. 1. Hydrological condition (score) of *Calthion-Palustris*.

Firstly, the groundwater system and the surface water system were simulated by very detailed transient models. Both models are integrated (related). The models are calibrated so that the groundwater tables and surface water levels are calculated correctly. With these models the present groundwater and surface water conditions are simulated. Secondly, several surface water management strategies were simulated (For example, the natural situation as it was around 1850). Thirdly, the abiotic conditions for the ecosystems and agriculture were used to translate the results of the numerical modelling to a more general ‘ecological and agricultural score’. Through this approach, the most suitable surface water management strategy is selected for:

- finding 440 ha area for re-establishment of groundwater dependent ecosystems (defining the border);
- optimising the yield of agriculture;
- restoring fluctuations of groundwater table and surface water
- improving the water quality of the brook;
- adaptation to climate change.

Based on the scenario modelling, an optimum design of the brook was selected that leads to the desired fluctuation of the groundwater table and surface water level. With these fluctuations the optimum score for the ecosystems and agriculture in the brook valley will be achieved.

The results are regularly discussed with the land owners, nature conservation parties, farmers and the residents in the brook valley. A special “area committee” (with two-monthly meetings) takes into account the interests of all so that everybody could understand the hydro-ecological research and its results. Due to this communication, the confidence in the outcome of the restoration of original meanders was increased. This confidence should result in a groundwater dependent ecosystem in the brook valley of the Koningsdiep for agricultural activities.

Keywords: integrated hydro-ecological modelling, restoration, communication

Risk map of high natural background of trace elements assigned for water bodies on the French territory

[1] Agnès BRENOT , [1] Laurence GOURCY, [1] Delphine ALLIER, [1] Cédric MASCRÉ , [1] Aurélien PONS, [1] Laurence CHERY, [1] Ariane BLUM

[1] BRGM, Avenue C. Guillemin, BP 6009, 45060 Orléans Cedex 02, France, e-mail: a.brenot@brgm.fr

ABSTRACT

As required by the Water Framework Directive in its Article 17, a Daughter Directive on the protection of the groundwater against pollution was issued in December 2006. It specifies that the “good chemical status” of groundwater bodies shall be partly defined by Member States themselves. But the evaluation of this “good status” requires knowledge of the natural geochemical background of water bodies in order to distinguish trace elements naturally present in the environment from those resulting from anthropogenic inputs. Commonly baselines are used interchangeably with the term backgrounds. These terms are meant to imply something about the natural trend of systems in the absence of human influences such as land use. To a larger extend it is important to decipher natural contribution of trace elements in natural water in order to further establish relevant restoration strategies and to anticipate temporal evolution of the quality of natural water. The risk map achieved by the WATER division of the BRGM for the water authorities (MEDD : Ministère de l’Ecologie et du Développement Durable and Agences de l’eau), intends to identify the different areas where water (ground- and surface water) are likely to display high natural background levels in trace elements. Elements studied include all elements considered as toxic or undesirable by the Drinking Water Directive (98/60/EC) i.e. arsenic, barium, bore, fluorine, cadmium, chromium, mercury, copper, nickel, lead, zinc, antimony, selenium, aluminium, silver, iron, manganese.

A literature search identified those areas where the geological context is likely to induce trace element mobilization from rocks to natural water. All the literature dealing with natural the occurrence of trace elements in soils, rocks and water, complemented by those handling with geochemical status of natural water (pH, redox-conditions, T°, concentration in dissolved oxygen …) were collated. Existing trace element analysis in soils and the identification of mining index, merely for crystalline area, allowed geological units to be identified in which trace elements are naturally present in rocks at high concentrations. Databases of natural water considered in this study correspond to ADES (Accès aux Données des Eaux Souterraines, French national groundwater database) database for groundwater and RNB (Réseau National de Bassin) and FOREGS (FORum of European Geological Survey) database for surface water. The risk map is based on combining information in Geographic Information Systems (GIS) format with Arcview software.

The first step towards the interpretation of trace element groundwater data in the ADES, RNB and FOREGS databases, required an assessment of the sampling location with regard to land use distribution. Some of the sampling points are highly affected by anthropogenic inputs that override the natural background trace element levels. In order to identify these sampling points, a map presenting the main anthropogenic pressures that could affect trace elements has been created with land use data from the Corine Land Cover 2000 database. Mining activities were also located as they constitute anthropogenic an amplification of natural weathering processes. Sampling points that were most affected by anthropogenic inputs were eliminated. For relevant sampling points, further investigations were done. Secondly, information from the literature and from trace element analysis in soils were summarized in order to identify areas where trace element are likely to be mobilized in the dissolved phase of natural water. Prediction of trace elements mobilisation from rocks to the dissolved phase is well documented elsewhere and allows identification of risks depending on the global geological context associated with the geochemical status of the natural water (pH, redox-conditions, T°, concentration in dissolved oxygen …). Then, this information was combined within the GIS with concentrations of trace elements (arsenic, barium, bore, fluorine, cadmium, chromium, mercury, copper, nickel, lead, zinc, antimony, selenium, aluminium, silver, iron, manganese) recorded for ground- and surface water in all the studied databases (ADES, RNB, FOREGS). If observed high concentrations are compatible with both geological context and geochemical status, an area presenting a risk of high natural background was identified.

This work leads to the precise localization on a map of areas where risks of high natural background in trace elements were identified (example Fig. 1). Risks are attributed to ground- and surface water bodies. Some

areas are well documented (soil analysis in trace element, relevant water analysis, published articles highlighting the origin of trace elements and their geological context) and this allows to clearly identify a risk of high natural background. However, some areas present scarce chemical analyses. Thus, in order to take into account these disparities, a confidence level, low, middle or high, was attributed to each area, depending on the availability abundance of information.

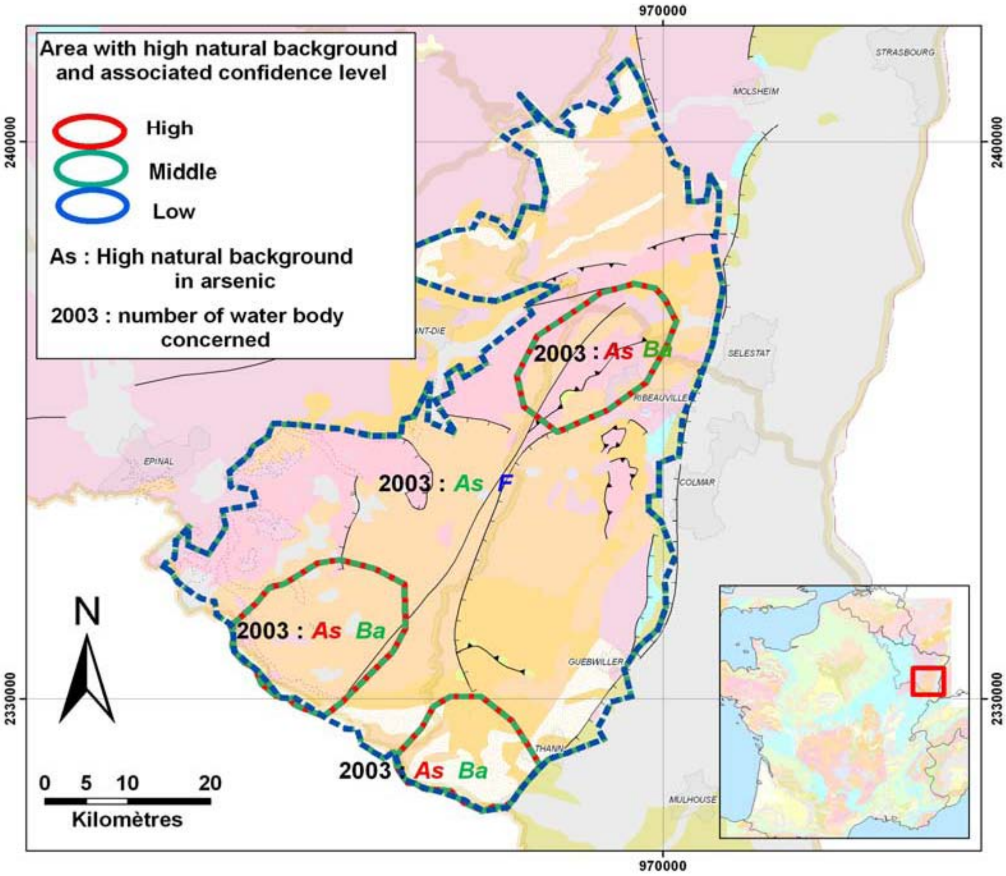


Fig. 1: Areas of high natural background of trace elements for groundwater bodies (in background: simplified geological units 1/1 000 000).

For areas where risks were identified with high confidence level and data available on natural water allows robust statistics, natural background for trace element was quantified. The percentile 90 was calculated on all trace elements analysis attributed to water bodies identified on the risk map with high confidence level. For areas where data available on natural water were not sufficient, the risk map will be used to define potential surface and groundwater data acquiring programs. Depending on the level of confidence assigned to areas presenting high trace elements background, different objectives for data acquiring program are allocated. Advice concerning data acquiring strategy (type of media to be analysed, sampling method, sampling frequency, analytical methods…) was also proposed in order to get comparable data set within the French territory. Indeed, it is important to get comparable data set in order to harmonize compliance checking throughout France and Europe in agreement with the Water Framework Directive.

Thus, such a type of study is of outstanding interest to further define values of the “good chemical status” for all European surface and groundwater bodies depending on the local particularities due to special hydrogeochemical conditions. The last step of this process is to establish the Environmental Quality Standards (EQSs and threshold values specifically for each water body.

Keywords: Water Framework Directive, natural geochemical background, groundwater, surface water, quality, trace elements.

Tectonically controlled evolution of fluvial, weathered and fractured basement aquifers in Uganda

[1,2]Callist TINDIMUGAYA*, [2]Richard G. TAYLOR, [2]Tim C. ATKINSON , [2]John BARKER

[1] Water Resources Management Department, Directorate of Water Development,
P.O. Box 19, Entebbe, Uganda
[2] Hydrogeology Group, Department of Geography, University College London, 26 Bedford Way, London, WC1H 0AP, UK

ABSTRACT

The evolution of aquifers in deeply weathered environments throughout the tropics is closely related to the long-term development of the landscape via tectonically controlled cycles of deep weathering and stripping. Deep weathering of the bedrock yields a thick weathered regolith and induces sub-horizontal fissures through isostatic uplift. Cycles of stripping partially erode the unconsolidated weathered overburden, producing a discontinuous regolith, and deposit coarse-grained clasts in river channels. We present evidence for the evolution of weathered regolith, fissued-bedrock and fluvial aquifers by tectonically controlled stripping and weathering based on historical observations and detailed studies in Uganda. Critically, field investigations identify, for the first time, a highly productive fluvial aquifer in addition to the primarily in situ weathered regolith and fissured bedrock aquifers that have commonly been described and exploited in deeply weathered terrain. The fluvial aquifer consists of well rounded, coarse sands and gravels with well yields of over 5 m^3 per hour that significantly exceed well yields of < 1 m^3 per hour typically experienced in weathered regolith and fissured bedrock aquifers. Fluvial aquifers are of limited extent on stripped surfaces but can feature significant thicknesses along former river channels on deeply weathered surfaces. The revised conceptual model of the evolution of aquifers in deeply weathered environments represents a key contribution to the understanding of the hydrogeology of these terrains and provides an important new target for the development of groundwater in Uganda and similar environments where groundwater resources are limited by the low permeability and storage of weathered and fissured crystalline rock aquifers.

Keywords: Fluvial, Weathering, Stripping, Deposition, Upwarp

The occurrence of SO4-rich groundwater in sedimentary terrain, Gunwi area, Korea: Hydrochemistry and genesis

[1]So-Young HONG, [2*]Sang-Ho MOON, [1]*Seong-Tack YUN, [1]Byoung-Young CHOI, [1]Kyoung-Ho KIM, [3]Jin-Yong LEE, [4]Jong-Ho WON, [4]Gyeong-Hwan AHN

[1]Dept. of Earth & Environm. Sci. and the Environm. Geosphere Res. Lab, Korea Univ., Seoul 136-701, Korea
[2]Groundwater & Geothermal Resources Division, KIGAM(Korea Institute of Geoscience & Mineral Resources, Daejeon 305-350, Korea
[3]Dept. of Geol., Kangwon Nat'l Univ., Chooncheon, Korea
[4]K-WATER(Korea Water Resour. Co., Daejeon, Korea

* Corresponding authors: msh@kigam.re.kr, styun@korea.ac.kr

ABSTRACT

Sulfate-rich groundwater in the Gunwi area, south Korea, occurs in fluvial sedimentary rocks of Cretaceous Hayang Group. Based on hydrochemical and isotopic data of groundwater, together with aquifer geology, three main types of groundwater are observed in the study area. These are: 1) JG type groundwater in the Jeomgog Formation, which is characterized by very high TDS values with high Ca and SO_4 concentrations(Fig. 1); 2) OT type groundwater in the other sedimentary formations, which show the chemistry of a Ca-HCO_3 type with low Ca and SO_4 concentrations; and 3) AV type groundwater in alluvium, which is characteristically high in nitrate concentration, due to agricultural contamination. Major ion chemistry such as the inter-ionic relationships between Ca and HCO_3 and between Ca+Mg and HCO_3+SO_4 (Fig. 1) and Mg/Ca ratio, as well as the sulfur and oxygen isotope composition of sulfate (Fig. 2), indicates that sulfate in sulfate-rich, JG type groundwater was originated from dissolution of evaporate (gypsum or anhydrite). In addition, the increase of $\delta^{34}S_{sulfate}$ values with increasing sulfate concentration also indicates the progressive evaporate dissolution.

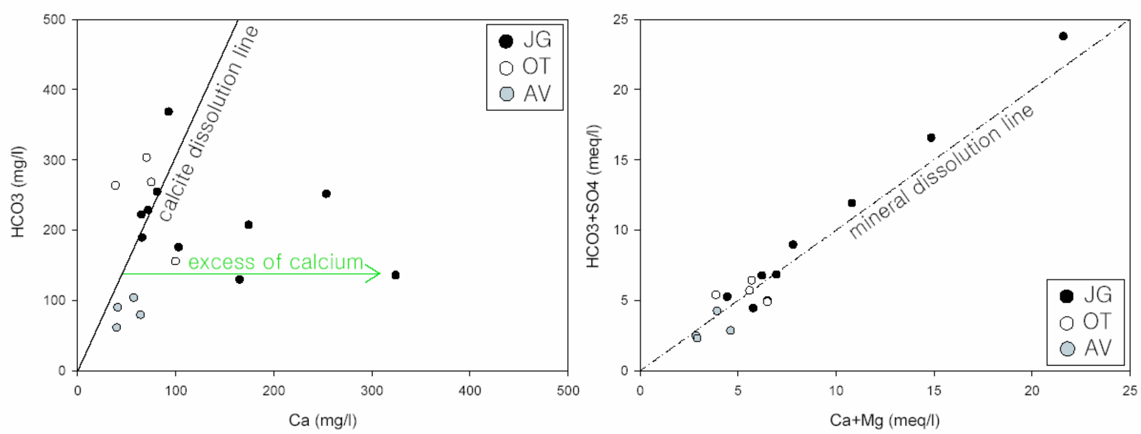


Fig. 1. Diagrams showing the excess calcium (left) and the chemistry changing along the calcite+dolomite+gypsum dissolution line for the JG type groundwater

JG type groundwater is low in $\delta^{18}O$ and δD values, suggesting that they represent a highly evolved groundwater via deep circulation in the area. Interpretation of major ion chemistry and sulfur/oxygen isotope compositions of sulfate (Fig. 2, $\delta^{34}S$ = +16.0~+19.2‰, $\delta^{18}O$ = +10.3~+12.2‰) indicates that the chemistry of JG type groundwater was mainly controlled by dissolution of calcite, dolomite and gypsum in rocks.

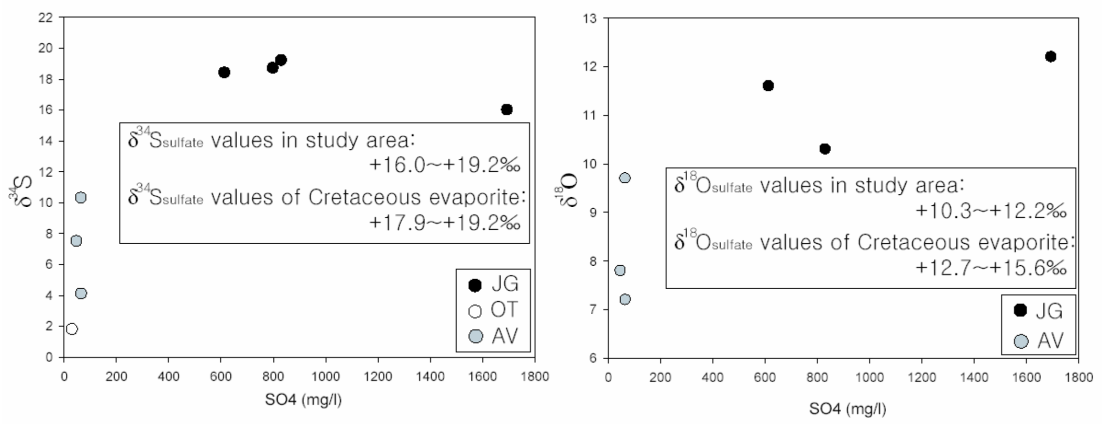


Fig. 2. The $\delta^{34}S$ and $\delta^{18}O$ values of sulfate in groundwater, Gunwi area. Data of Cretaceous evaporate are from Utrilla *et al*. (1992)

. The $\delta^{34}S$ values of sulfate increase with increasing sulfate concentrations. Together with data on Sr/Ca ratio, saturation index of calcite, and $\delta^{13}C$ values of DIC, we propose that gypsum dissolution and associated calcite precipitation was the main process controlling the evolution of JG type groundwater(Fig. 3). The results of this study indicate that playa environment was likely formed during the sedimentation of Hayang Group, resulting in the deposition of evaporate minerals.

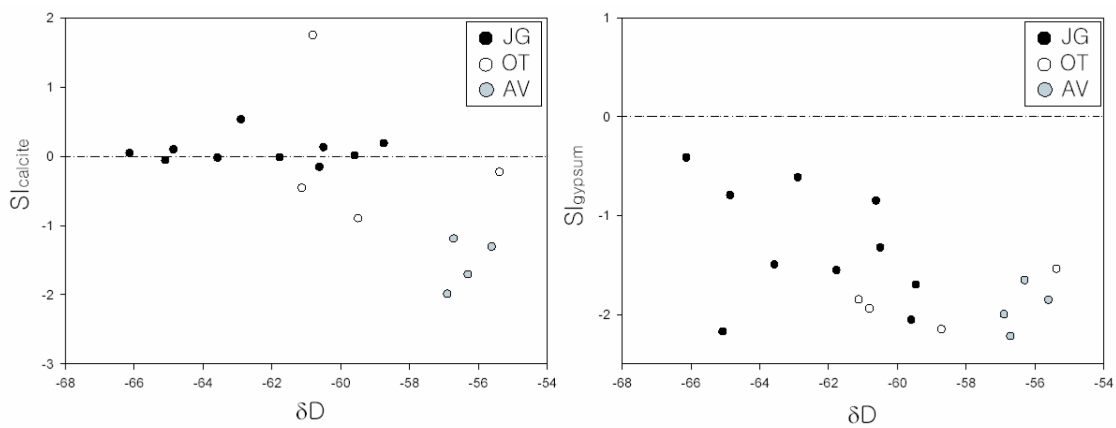


Fig. 3. Saturation index of calcite and gypsum vs hydrogen isotope composition

Key words: sulfate-rich groundwater, Gunwi area, hydrochemistry, sulfur and oxygen isotopes

Thermal waters of the Usti nad Labem area: optimalization of their use on the basis of new hydrogeological and well-logging data, Czech Republic

[1]Josef V. DATEL, [2]Miroslav KOBR

[1]Charles University in Prague, Faculty of Science, Albertov 6, Prague 2, Czech Republic,
e-mail: datel@natur.cuni.cz
[2] Charles University in Prague, Faculty of Science, Albertov 6, Prague 2, Czech Republic,
e-mail: kobr@natur.cuni.cz

ABSTRACT

Geothermal resources represent one of important alternatives of renewable energy resources. Depending on geologic and hydrogeologic conditions, two main possibilities of geothermal development occur: a) hot-dry-rock projects have been realized, based on different technological approaches, typically under specific conditions of hard/fractured rocks; b) development of thermal groundwater occurring in aquifers of various extensions with considerable groundwater flow. In both cases, energy development depends on the thermal properties of rocks and earth heat flow ascending from deep zones of the Earth crust that warms up rocks and groundwater. This general situation can be influenced considerably by local geologic and hydrogeologic conditions. The upper limit of a long-term geothermal development should be determined by thermal balance. Such an upper limit can be lowered when taking into account concrete conditions of the region under consideration and different time scales – from human to (hydro)geologic ones. Then sustainability of geothermal development and protection without causing any environmental impacts could be provided.

The aquifer system of the Benesov and Usti nad Labem area, an area of around 2000 square kilometers, is more or less a closed hydrogeological unit with a relatively easily definable boundary. Its groundwater occurs mainly in Cretaceous aquifers. In some parts it is necessary, though, to take into account the ground water in underlying and surrounding geological structures as part of the hydrological balance.

At present, the largest thermal water accumulation in the Czech Republic, with temperatures often exceeding 30 degrees centigrade and in some spots approaching 40 degrees centigrade, can be found in the voluminous and spacious Cretaceous aquifers, particularly in the basal and middle aquifers of the aquifer system of the Benesov and Usti nad Labem area. Exploitation of these thermal waters has thus far been concentrated in the Usti nad Labem and Decin regions. A crucial impetus for the research was new exploratory work done in approximately the last 10 years, and its intention was to intensify thermal water sources exploration (Datel, Krasny 2005).

Thermal waters of the Benesov-Usti aquifer system have been pumped, with generally increasing intensity, in the towns of Usti nad Labem and Decin and their surroundings for more than one hundred years. Natural hydrogeologic conditions have been severely affected by this anthropogenic impact: regional directions of groundwater flow have been changed and flow velocity has increased considerably. Thermal water of Usti nad Labem and Decin areas had not been known in the past, with the exception of some minute locally discovered thermal water instances in the Decin and Kamenice river areas. Nonetheless, these are quite insignificant from the point of view of overall hydrological and thermal balance of the aquifer system. Therefore, before deep boreholes have helped discover the thermal water resources, the whole area of thermal waters known now represented a hydrogeological structure with very slowly flowing, almost stagnating groundwater. Exploiting the resources has made the groundwater flow significantly faster. Even though the area of interest belongs to zones of increased heat flux in the deeper parts of the earth's crust, the question arises whether sufficient heating of these waters will occur with the current accelerated groundwater flow and whether in the future the temperature of the thermal water resources will not fall. It is important to bear in mind that the thermal waters have been exploited for a relatively short period of time. We can assess if destruction of thermal springs in the Decin and Kamenice river areas has an important effect on local ecosystems.

New data from 4 boreholes in the Usti nad Labem area (deep 400-500 m) were obtained – lithological data, hydrodynamic tests, chemical analyses and well-logging measurements. They were analyzed and compared with data from previous boreholes and available original groundwater regime before the starting of exploitation (at the end of 19. century). Conclusions deal with real and potential changes of groundwater piezometric level, 3D flow directions, water temperature and chemical contents. Well-logging data analyzing was very useful for detailed description of the deep aquifer (geologic, tectonic and hydrogeologic conditions).

Apart from the presence of the thermal waters, the aquifer system of the Benesov and Usti nad Labem area also represents, particularly in its eastern part, a water resource system of exceptional importance because of its great potential of fresh groundwater exploitation. The existing output estimates of the groundwater natural resources in this system have been around 10 cubic meters per second, about half of which represents water yield (Hercik *et al*. 1999). The extent of actual groundwater treatment is relatively small and does not even amount to half of the estimated water yield.

The existing knowledge implies a considerable hydraulic interconnection between thermal and other groundwaters in various areas. A typical example of this is the situation in the Usti nad Labem region. The individual extractions influence one another and reduce the utilizable yield and pressure in each well. On one hand, increasing the number of extraction spots makes the overall amount used in a specific hydraulically connected hydrogeological unit rise, on the other hand the capacity and exploitation possibilities of the water in individual extraction spots fall. Thus, the question of economically optimal number of extraction spots (wells), their placement and the mode of exploitation of the (thermal) groundwater arises.

Hydrological and thermal balance is necessary for future long-term exploitation and optimal protection not only of the exploitation areas (Usti nad Labem, Decin) but also of the whole widespread geologic structure of thermal water. The solution is drawn up through conceptual and numerical models of groundwater and heat flow in the frame of the whole hydrogeological structure unit (2000 km^2).

Acknowledgement
This research work is being supported by the research projects of the Czech Science Foundation Nr. 205/07/0691 and 205/07/0777, and the research grant of the Czech Ministry for Education Nr. 0021620855.

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Hercik, F., Herrmann, Z., Valecka, J. (1999): Hydrogeology of the Bohemian Cretaceous Basin. Czech Geological Survey Prague, Czech Republic. 91 pp. ISBN 80-7075-604-7

Keywords: thermal water, geothermal energy, groundwater, Bohemian Cretaceous basin

Use of statistical analysis to evaluate spatial and temporal variations in Gabes-South groundwater geochemistry (South-Eastern Tunisia)

[1] Mouna KETATA, [2] Fadoua HAMZAOUI, [2] Rachida BOUHLILA,
[1] Moncef GUEDDARI. [3] Luis RIBEIRO

[1]UR Géochimie et Géologie de l'Environnement-Faculté des Sciences de Tunis, Campus Universitaire, 1060 Tunis, Tunisia
[2]Laboratoire de Modélisation en Hydraulique et Environnement-Ecole Nationale d'Ingénieurs de Tunis, Bp 37, Le Belvédère, 1002 Tunis, Tunisie
[3]CVRM, Geosystems Center, Instituto Superior Técnico, Lisboa, Portugal

ABSTRACT

The aim of this study is to determine the different factors and phenomena which may control the assessment parameters of Gabes-Southern groundwaters quality.

To reach these objectives, spatial and temporal evolution of physical-chemical parameters (temperature, pH and salinity) and the concentrations of the major elements (Na, Mg, Ca, K, Cl, SO4 and HCO3) and fluorine, has been analysed based on data recorded in borehole samples during the period between 1994 and 2003. Results are compared between the wet and dry seasons.

In this paper, statistical techniques (Principal Component Analysis and Correspondence Analysis) coupled with hydrogeochemical methods, were applied to evaluate water chemical data of Gabes-South aquifer.

Results reveal that salinity and major elements concentrations presents small time variability, and spatial distribution of salinity and major elements concentrations shows a rather abnormal decrease, given the direction of the groundwater flow. Waters are mainly of SO4, Cl, Na and Ca type and mostly related to the aquifer's lithology, its origin and exploitation conditions. The concentrations of fluorine in groundwater of South Gabes (South-Eastern Tunisia) range from 0.85 to 2.78 $mg.L^{-1}$.

Keywords: Salinity, Major Ions, Fluorine, Multivariate analysis, Tunisia

TOPIC 03

Estimating and determining the impact of groundwater natural/ artificial recharge processes on groundwater dependent ecosystems

Artificial aquifer recharge experiments in Campina de Faro study area

Catarina DIAMANTINO

Laboratório Nacional de Engenharia Civil, Av. do Brasil, 101, 1700-066

ABSTRACT

This paper presents the preliminary results of the experimental work developed in the framework of one European Research Project for 6th Framework Programme named GABARDINE Project - *Groundwater artificial recharge based on alternative sources of water: Advanced integrated technologies and management* as well in the framework of a PhD Thesis development. The case study area is located in the Portuguese Southern Algarve region, more precisely in Campina de Faro, near Faro city, and constitutes a section of the aquifer system of Campina de Faro, with an area of approximately 9 km^2. It is bordered by the estuary of Ria Formosa in the south, two aquifer systems in the North, the river Ribeira de Marchil in the west and 2 km to east from the river Rio Seco. One of the main objectives of this research is the optimisation of groundwater rehabilitation through artificial recharge, aiming the minimization of diffuse pollution effects caused by typical Portuguese agricultural practices. Campina de Faro aquifer system is declared a vulnerability zone according to Portuguese Legislation with regard to nitrate concentration. This aquifer needs groundwater rehabilitation, to fulfill the *Water Framework Directive* goals and this artificial recharge experience aims to contribute to achieving this purpose. This task will be achieved by considering climate variability challenges, and selecting a vulnerable area in the aquifer system of Campina de Faro for real case study technology experiments. The main purpose of the artificial aquifer recharge experimental plan proposed is to store surplus surface water for subsequent groundwater recharge, while improving groundwater quality (decreasing the nitrates level). This will be done by recharging the aquifer with water of better quality. Artificial recharge systems require a good understanding of the site specific conditions. The type of artificial recharge system to be developed at Campina de Faro aquifer system was controlled to a large degree, by the geologic/hydrogeologic and hydrologic conditions. From the beginning of the Project a selection of interesting areas for the development of artificial recharge experiments in Campina de Faro was performed. The first area selected was Conceição but the geological and geophysical investigations revealed important lithologic constraints, that forced this area to be abandoned for the development of an artificial recharge experiment. The two other areas, named Carreiros and Areal Gordo were selected for the development of the artificial recharge experiments using different technologies and water sources. Three planned artificial recharge systems/experiments were done in Campina de Faro area and they are the following: (1) Two infiltration ponds located in Rio Seco river bed, at Carreiros test site, filled with clean gravels. The source of water for recharge was surface water from the river during floods and three piezometers for quality and quantity monitoring were drilled; (2) Three infiltration ponds, with different local sandy layers depths, at the Areal Gordo test site. The water for recharge was extracted from underneath the confined aquifer, and two piezometers were drilled for quality and quantity monitoring; (3) One large diameter well where it is intended to artificially recharge water, also extracted from underneath the confined aquifer. This paper describes these experiences, the work performed, some preliminary results obtained and its interpretation.

Keywords: Artificial recharge, Campina de Faro, aquifer rehabilitation, nitrates, Gabardine Project.

Complex interaction between shallow groundwater and changing woodland, surface water, grazing and other influences in partly wooded duneland in Anglesey, Wales

[1]Charlie STRATFORD,[2]John RATCLIFFE, Andrew [3]G. HUGHES,
[1]John ROBERTS,[3]Nicholas S. ROBINS

[1]Centre for Ecology and Hydrology, Maclean Building, Wallingford, Oxfordshire, OX10 8BB, UK
[2]Countryside Council for Wales, Llys y Bont, Parc Menai, Bangor, Gwynedd, LL57 4BN, UK
[3]British Geological Survey, Maclean Building, Wallingford, Oxfordshire, OX10 8BB, UK
Corresponding author: Nick Robins nsro@bgs.ac.uk

ABSTRACT

Newborough Warren, a coastal area of late-glacial blown sand dunes over weakly permeable glacial till, is situated in the island of Anglesey off the Welsh coast of the UK. It was partly forested with Pinus nigra var. laricio trees between 1948 and 1965. It is now a Special Area of Conservation designated for, amongst other things, humid dune slacks and dunes with creeping willow, as well as being a valuable recreational amenity attracting thousands of visitors to dunes and forest. The plantation has also attracted the introduction of red squirrels which now provide a powerful motive for woodland management. The total area of dunes comprises some 1300 ha of which the northern part is now managed plantation and the southern open duneland. The dune slacks regularly flooded during the winter in the period prior to planting the northern sector of the dunes. Since the mid 1950s, flooding has become increasingly rare. The perception is that the trees are overdrawing the available groundwater beneath the afforested dunes, so lowering the water table. Today there are conflicting pressures, one that would see the Warren maintained as it is, partly wooded and partly open, another that would see the restoration of the dune slacks through partial or total removal of the trees.

Proving that the trees are actually the cause of the lowered water table in this case is not easy. Many of the trees are now reaching maturity and their water demand is probably starting to reduce. In places, new stands have been planted as trees have been felled and most old stands have been thinned, so changing the overall water demand of that stand. However, re-growth, development of understorey and increased canopy roughness as age classes diverge, promise increasing water demand in future. A dammed lake has possessed various head stages over the last 60 years as the retaining structure has been modified, and effective rainfall may even have changed sufficiently over this same period to modify the prevailing piezometry. Besides, grazing patterns have also changed the vegetation on the open duneland following the dramatic decline in rabbit population in the 1950s due to myxomytosis and more recently sheep, cattle, ponies and rabbits cropping the grass. Full assessment of all these variables nevertheless suggests that the trees are the most likely cause of the observed water level change beneath the dune slacks during winter months. However, it is unlikely that removal of all or part of the woodland would cause a reversion to the pre-war land cover and ecosystems due to other changes in the dynamics of the dunes. This study highlights the complex interaction between groundwater and vegetation and illustrates the difficulty of providing certainty when dealing with natural habitats.

Keywords: duneland, water table, vegetation, ecosystem, uncertainty

Deep aquifer regimes in the Venetian plain (NE Italy)

[1] P. FABBRI, [1] E. MARCOLONGO, [1] A. ROSIGNOLI, [1] P. ZANGHERI

[1] Dipartimento di Geoscienze, Università di Padova, Via Giotto 1, 35127 Padova, Italy

The rivers Bacchiglione, Brenta, Piave and Leogra are responsible for the deposition of much of the material, hundreds of metres thick, which forms the subsoil of the Venetian plain. Along the piedmont belt of the plain gravelly alluvial fans are laterally penetrated by fans from adjacent rivers. The result is an entirely gravelly subsoil throughout the thickness of the high Venetian plain. Since deeper fans have often invaded further areas of the high plain, from the undifferentiated gravel cover, the terminal parts of the fans extend downstream for various distances, producing an alluvial cover which is no longer uniform1y gravely, but becomes composed of alternating layers of gravel and silty-clay of swampy, lagoonal or marine origin.

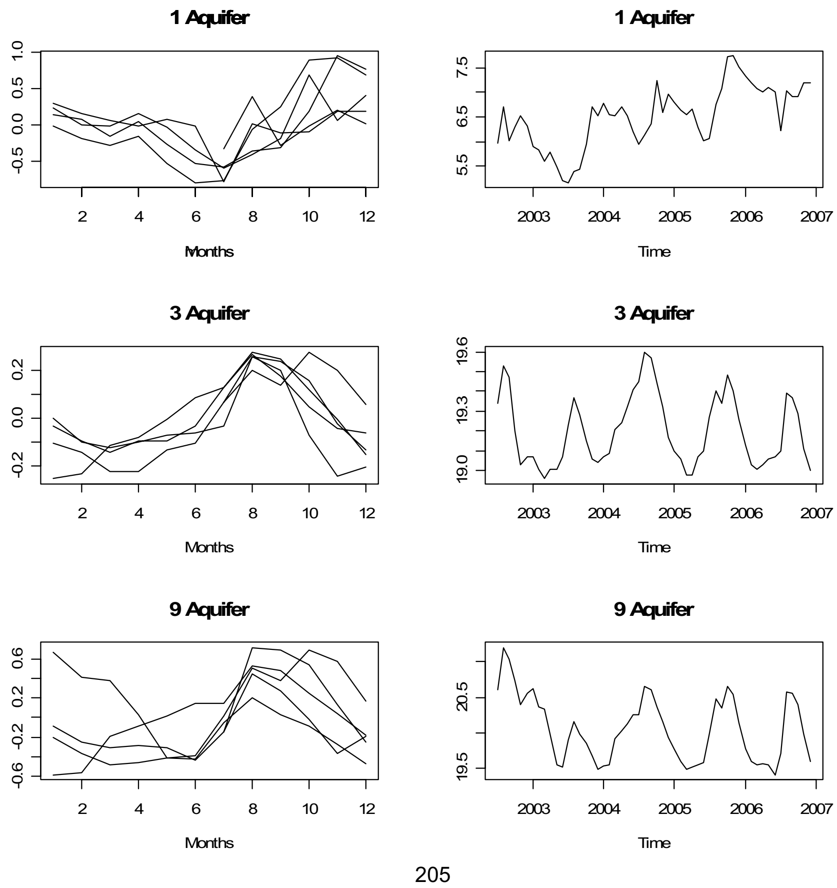
In the high Venetian plain a single unconfined aquifer is present and its water table reaches depths of 50-100 m. To the south, the water table becomes shallower until it intersects the topographic level, creating a series of plain springs called “fontanili”. These mark the passage between the high and the middle Venetian plain. Downstream from the “fontanili” line the differentiation of the cover determines a multi-layered aquifer system characterized by overlapping confined aquifers.

The recharge of the aquifers is mainly from rainfalls, dispersion of watercourses and irrigation. Their action is only effective in the high Venetian plain, where infiltration of surface waters can reach the unconfined aquifer and then the artesian aquifers linked to it.

For the first time, in such a hydrogeological situation, the potentiometric levels of some of the most important confined aquifers present in the middle Venetian plain, were monitored from 2002 to 2006. These monitoring wells are located in the Scorzè area (NE, Italy) in the ACM exploitation area, ACM being one of the public water companies present in the Veneto region (NE, Italy).

The study was focused on the aquifer regimes and potentiometric level ranges and trends.

The potentiometric data were analysed by the R code, which is a free software environment for statistical computing and graphics. The figures show visible regimes and the potentiometric level variations from 2002 to 2006.



The regime of the first confined aquifer localized at about 40 – 60 m in depth, indicates one minimum in summer, and two maximum, the most important one in autumn and the other one in spring. This regime is similar to an “alpine sublittoral” regime, which is typical of the Venetian plain. The potentiometric range is about 2 m and the trend shows one meter recovery from 2003 to 2006, probably connected to a private exploitation reduction.

The third confined aquifer at 130 – 140 m in depth shows a different regime from the first aquifer. Its regime is comparable to a “continental” one, with a March minimum and an August maximum. The potentiometric level range is 0.5 m and the trend presents very little recovery in the levels from 2002 to 2006.

The more deeply confined aquifer monitored is the ninth at 270 - 310 m in depth and its regime is a “continental” one, i.e. similar to that of the third aquifer, but its minimum is less evident. The potentiometric range is about 1 m, and the observed trend shows a definite decrease from 2002 to 2004, but from 2004 to 2007 shows very little recovery.

Keywords*:* regimes, deep confined aquifers, middle Venetian plain, Italy.

Distributed and semi-distributed hydrologic models for groundwater recharge evaluation: Application of GIS-BALAN to several basins in the Iberian Peninsula

[1]Javier SAMPER, [2]Miguel A GARCIA-VERA, [1]Bruno PISANI, [1]Diego ALVARES,
[3]Jorge ESPINHA MARQUES, [2]José A LOSADA

[1] Escuela de Caminos, Universidade da Coruña, Campus Elviña, 15192 Coruña, Spain,
e-mail: jsamper@udc.es
[2] Confederación Hidrográfica del Ebro, Ministerio de Medio Ambiente, Spain,
e-mail: mgarciave@chebro.es
[3] Dep. de Geologia (CGUP), Universidade do Porto, Portugal. e-mail: jespinha@fc.up.pt

ABSTRACT

Groundwater resources can be quantified with distributed hydrologic models. Here we present GIS-BALAN, a code which evolved from a lumped model (VISUAL BALAN V2.0), and that has been coupled to a Geographic Information System (GIS) and been completely rebuilt using object-oriented programming. GIS-BALAN solves water balance equations by evaluating hydrologic components in a sequential manner. It performs a daily balance in the upper soil, the unsaturated zone and the underlying aquifer, and deals with the surface runoff propagation. Its user-friendly interfaces for data input and post-processing of results make it a very practical tool for water resources evaluation and planning. A flexible reference table has been incorporated in order to assign model parameter values from GIS-based information such as DTM, geological and soil type and use maps. The code has been widely used as a tool for water resources evaluation, groundwater recharge estimation, and groundwater pollution studies. Here we describe its main features and illustrate its application to four different basins of the Iberian Peninsula (see Table 1).

Table 1. GIS-BALAN applications. Main basin characteristics.

Name	Area (km^2)	Mean altitude (m a.s.l.)	Climatology			Geology
			Annual rainfall (mm)	*Annual runoff (mm)*	*Annual recharge (mm)*	
Andújar	7.83	200	512 (*)	37	320	Alluvial
Serra da Estrela	28	1 430	2 336	395	422	Alluvial, quaternary glacial deposits, granites and meta sedimentary rocks
Gallocanta	404	1 086	435	2	20	Detritic
Alcanadre	505	921	744	24	99	Karstic

(*) Irrigation adds 531 mm

Key words: Groundwater recharge, GIS-BALAN, hydrologic models

Estimating recharge coefficients from groundwater vulnerability

Bruce D R MISSTEAR
Les BROWN

School of Engineering, Trinity College, Dublin 2, Ireland
bmisster@tcd.ie

ABSTRACT

Recharge to an aquifer can be estimated by first calculating the effective rainfall (total rainfall minus actual evapotranspiration) using a soil moisture budgeting technique, and then by applying a recharge coefficient to indicate the proportion of this effective rainfall that contributes to groundwater recharge. In Ireland, the recharge coefficient is determined mainly by the permeability and thickness of the superficial deposits (predominantly glacial tills) that overlie the country's bedrock aquifers. The characteristics of the subsoils also influence the groundwater vulnerability, and therefore a methodology has been developed for estimating the recharge coefficient using the groundwater vulnerability classification. The paper includes a description of three case studies where the relationship between recharge and vulnerability was quantified. One of the case study areas contains one of Ireland's most valuable groundwater-dependent ecosystems, making the assessment of recharge particularly important. Different approaches were applied to determine groundwater recharge in each study area, including catchment water balance, well hydrograph analysis, environmental tracers and river baseflow analysis. It is intended to incorporate the quantified links between recharge and vulnerability into a geographical information system (GIS).

***Keywords**:* Groundwater recharge, aquifer vulnerability, soil moisture budget, river baseflow analysis

Estimating the mean rate of annual recharge in carbonate aquifer, Alta Cadena, Southern Spain, by APLIS method.

[1]A. I. MARIN, [1] J. M. VIAS, [1]B. ANDREO, [1]M. MUDARRA

[1] Hydrogeology Group of the University of Malaga (GHUMA). Faculty of Sciences. Department of Geology. University of Malaga. E-29071, Málaga, Spain: anai.marin@gmail.com, jmvias@uma.es, andreo@uma.es, mmudarra@uma.es

ABSTRACT

Aquifer recharge can be determined by conventional methods such as hydrodynamic, hydrologic balance, or numerical, hydrochemical or isotopic models. Such methods are usually developed with respect to detritic aquifers that have undergone modification, and are then implemented on carbonate aquifers without taking into consideration the hydrogeological particularities of the latter. Moreover, such methods are not always easy to apply, sometimes requiring data that are not available. Neither do they enable us to determine the spatial distribution of the recharge.

The APLIS method estimates the mean annual recharge in carbonate aquifers, expressed as a percentage of precipitation, based on five variables: Altitude (A), Slope (P), Lithology (L), preferential Infiltration layers (I) and Soil type (S). Using a Geographic Information System, they can be superimposed to obtain the mean value and spatial distribution of the recharge.

The method has been applied to a carbonate aquifers in Southern Spain, “Alta Cadena”. This aquifer has climatic, geological and hidrogeological characteristics representative of Mediterranean carbonate aquifers moderately karstified.

The Alta Cadena aquifer extends over 70 km^2 and its topography, like of most carbonate aquifers in southern Spain, is abrupt. This massif is formed by Jurassic limestone and dolomites.

In Alta Cadena, the average rosources come exclusively from rainfall infiltration on to the surface of the aquifer. The average annual rainfall is 640 mm per year, although it is highly irregular in time.

To apply the APLIS method in the study area, the information layers (maps) corresponding to the intrinsic variables that influence recharge have been over imposed by a GIS (Arcgis). The recharge rate has been calculated and the APLIS method allows obtaining maps of its spatial distribution. We have obtained a coefficient of infiltration of 45-50% of precipitation on to the surface of the aquifer.

The recharge values obtained are similar to those previously calculated by conventional methods, balance of chloride and Thornthwaite’s method. The estimated recharge is consistent with the discharge values, which corroborates the validity of the method.

Keywords: carbonate aquifers, APLIS method, recharge, Geographic Information System

Estimation of groundwater recharge in the Metropolitan Region of São Paulo, SP, Brasil

[1]Juliana B. VIVIANI -LIMA, [1]Ricardo HIRATA, [2]Ramon ARAVENA, Veridiana T. [1]S. MARTINS

[1]LAMO – Laboratory of Physical Models, Institute of Geosciences of the University of São Paulo (IGc-USP), Rua do Lago 562, Cidade Universitária, São Paulo – SP, Brasil, CEP 05508-080,
e-mail: jviviani@usp.br; rhirata@usp.br; veridian@usp.br
[2]Department of Earth Sciences, University of Waterloo, 200 University Avenue West, N2L 3G1. Waterloo, Ontario, Canada, e-mail: roaraven@sciborg.uwaterloo.ca

ABSTRACT

The Upper Tiete Watershed (UTW) has a population of 19.5 million in an area of 5,985 km^2, which corresponds approximately to the contour of the Metropolitan Region of Sao Paulo (MRSP), Brazil. The UTW is comprised of two major aquifer systems: the Sedimentary Aquifer System (SAS) and the Crystalline Aquifer System (CAS). These aquifers consist of Paleogen and Neogen sediments of the Sao Paulo sedimentary basin (1,452 km^2) overlying the crystalline bedrock, formed by pre-Cambrian basement rocks (4,238 km^2), corresponding to the Embu Complex, Sao Roque and Serra do Itaberaba groups, and granitoids.

The importance of groundwater in the MRSP has increased substantially during the last 20 years. Several industries and condominiums are using groundwater as a complementary and often exclusive source of water supply. Data from 2000 showed that the groundwater in this region is exploited through more than 7,000 active wells (out of more than 10,000 wells that were drilled), extracting around 7.9 m^3/s of water from these aquifer systems, specially from the SAS. This volume represents 13% of the total volume of water distributed by the public supply companies. Moreover, it is estimated that if the users of the groundwater resource consume this volume from the public supply system, it would cause it to collapse.

Despite the importance of groundwater, not much is known about the quality and quantity of water that recharge these aquifer systems. Besides, in urban areas, the anthropogenic influence (presence of covered areas, pavement of surfaces, underground structures) causes changes to the natural water recharge patterns of the aquifer systems. The recharge mechanism is strongly influenced by the leakages from water mains, and sewerage and stormwater systems. Therefore, the assessment of the changes caused to the recharge by the urbanization is fundamental for better management of groundwater resources.

This study had the following objectives: i) to estimate the recharge of the SAS in two areas with different land use patterns (high and low density of paved surfaces), using different methods (water-level fluctuation, Darcyan approach, hydrochemistry, environmental isotopes); and ii) to determine the origin of the recharge water (leakage of supply water and sewerage system or natural infiltration of rainfall).

Two areas were selected based on the similarity of the geological features and difference of density of paved surfaces. The absence of active pumping wells was also considered in the selection procedure. The selected areas are located in the campus of the University of São Paulo and in a suburban neighborhood, which represents the typical land-use pattern of the city of São Paulo. Monitoring wells were installed in the shallow part of the sedimentary aquifer in both areas, which consist of four multi-level piezometer nests (at 4.5, 7.5 and 13.5m depth) and 6 single-wells (approximately 4.5m depth) in the area of low density of paved surface and 10 multi-level piezometer nests (at the water table and immediately above and below clay lenses, being 18 m the maximum depth) in the area of high density of paved surfaces. The piezometers were monitored on a daily basis during a period of 1 year and 5 months, between 2004 and 2005, and groundwater, as well as water from the public supply system and from precipitation in each area were collected for hydrochemical and isotopic analyses once a month.

The water level data show that the natural recharge for the least-paved area (university campus) starts in October, when the water levels present the lowest values, and the recharge peak occurs in January, when the water levels present the highest values. For the densely paved area (suburban neighborhood), this periods correspond respectively to September and the end of January. The rainiest and driest months for both areas were January and August, respectively, and the total precipitation for the densely paved area was 1,193 mm and 1,407 mm for the least-paved area. The water level methodology estimated that natural recharge for the poorly urbanized area is 246 mm/year and 183 mm/year for the densely urbanized area. A value of 437 mm/year was obtained through the Darcyan approach for the more densely urbanized area, and the difference between the results of the different methods can indicate the sum of the anthropogenic recharge sources (254 mm/year). The Darcyan approach applied to the less densely urbanized area provided a value of 250 mm/year for the recharge,

which is comparable to the results obtained from the water level method. It must be mentioned that this method is very sensitive to hydraulic conductivity, which varies 2 orders of magnitude in the area.

Preliminary analysis of chemical data for Na^+, Cl^-, NO_3^- and NH_4^+ showed the presence of extensive sewerage leakage in both areas. Na^+ concentration present values up to 172 mg/L, with an average value of 28 mg/L, for the densely paved / urbanized area and up to 520 mg/L and an average value of 42mg/L for the non-urbanized area. Cl^-concentration present values up to 100 mg/L, with an average value of 25 mg/L, for the urbanized area and up to 250 mg/L, with an average value of 17 mg/L, for the poorly paved area, with the highest concentrations occurring close to possible source areas. NO_3^- occurs in the urbanized area with maximum concentration of 83 mg/L (as nitrate) with an average value of 13 mg/L. Evidence collected from isotopes (enrichment of $\delta^{15}N$ and $\delta^{18}O$) and chemical data (DOC, HCO_3^-, Fe^+) indicated that denitrification is the main process attenuating the nitrate in the aquifer. In the non-urbanized area, there is very small amounts of NO_3 (up to 3 mg/L) and NH_4^+ occurs at concentrations of up to 7.7 mg/L with an average of 2.5 mg/L, which indicates that the contamination source infiltrates directly into the saturated zone of the aquifer that inhibit the conversion of this compound to NO_3^-.

Data from ^{18}O and ^{2}H collected in both areas lie on a mixing line between the fingerprints of precipitation water and water from the public supply system, indicating the contribution of these distinct sources to the recharge of the aquifers in the studied areas.

The data obtained in this study indicates that leakage of the sewage and water distribution system plays a major role in the recharge of the aquifer and groundwater quality.

Keywords : recharge, urban hydrogeology, São Paulo, isotopes, hydrochemistry

Groundwater chemical evolution in granite shallow aquifers: a case study in Vieira do Minho – NW Portugal

[1]Luís MACEDO, [2] Alberto LIMA

[1]Atrevo – Laboratório Ambiental de Estudos, Intervenções e Consultadoria Lda, 4705-581 Braga, Portugal, e-mail: luismacedo@atrevo.pt

[2] Departamento de Ciências da Terra, Universidade do Minho, 4710-057 Braga, Portugal, e-mail: aslima@dct.uminho.pt

ABSTRACT

In the past years, the rapidly expanding water requirements and the threat of a global water crisis as a result of the pollution from untreated and uncontrolled industrial and domestic activities has stimulated the development of works regarding the role of groundwater resources in supplying potable water. One of the main challenges is that of sustainability or availability in time and space as well as the issue of quality. In Portugal, several examples demonstrate the good adaptation of groundwater resources in reducing the needs of urban areas where the accentuated relief makes it difficult to implement conventional distribution systems that are based on surface water sources. The present work comprises a geochemical characterization of the groundwater resources of a selected area in the region of Vieira do Minho (Northwestern Portugal). It also aids in the understanding of the processes that contribute to the definition of the water "chemical signature", from the rain water that actually recharges the aquifer to the water-rock interaction that takes place in the geological medium and is, therefore, influenced by its mineralogical composition. A particularly interesting feature of the selected area, considering the fact that there is no human activity or presence, emphasizes the importance of natural processes in the evolution of the groundwater chemical composition. This work inscribes itself in a larger project aimed at the evaluation of groundwater resources potential of Vieira do Minho in suppressing the water requirements of isolated urban areas. The geological setting of the work area is characterized by the occurrence of a biotit-rich coarse-grained granite with oligoclase-andesine plagioclase. The rainwater collected during the monitoring period manifests a slightly acidic character and a strong dispersion of its main chemical constituents. The major cation is Na, followed by Mg and K. Of the anions, Cl is the most abundant, followed by HCO3, SO4 and NO3. Na, Mg and Cl. Note the importance of sea salts in the rainwater salinity, certainly a reflection of the reduced distance to the shore line (58 Km).

As for the groundwater, the study of its main constituents depicts an extraordinary chemical stability compared to the rain water samples. The average cationic values reveal that Na is the dominant element (2,81 mg/l) followed by K (more than ten times less abundant 0,27 mg/l), Mg (0,21 mg/l), Fe and Sr. HCO3 is the most abundant anion (4,82 mg/l), followed by Cl (2,48 mg/l), NO3 (1,10 mg/l) and SO4 (0,18 mg/l). SiO2 has an average value of 9,17 mg/l with an medium participation of about 49% in the TDS value. It is a slightly acidic water with an average pH value of 5,8, belonging to the bicarbonate-chlorine sodium facies. The electrical conductivity and TDS present average values of 16,5 μS/cm and 18,6 mg/l, respectively. The study of the trace elements demonstrates that Al is the most abundant, followed by Br, Zn, I, Ba, Mn and Rb. The Al seems to be related to the mobilization from clay minerals given the acidic nature of the solution. As for the other trace elements, they appear to result from the dissolution of the granite primary minerals, in which they commonly occur.

Another interesting observation derives from the analysis of the evolution of some of the groundwater trace elements that depict an important reduction compared to those in rain water: V (100%), Sb (95%), Cd (93%), Cu (72%), Pb (61%) e Co (50%). It is shown that the granite weathering layer should play an important role in the occurrence of ionic exchange processes and mobility that condition the evolution of highly toxic components, thus conveying groundwater important low vulnerability advantages. Despite its incipient mineral content, a closer look of the groundwater evolution reflects, nonetheless, an enrichment that seems to be related to two main processes:

(i) concentration, by evaporation, of the rainfall and

(ii) water-rock interaction. The study of the relation between constituents reveals that the water-rock interaction contribution is witnessed by the variation of SiO2, Na, Mg and also K values. It is shown that the hydrolysis of the granite primary minerals such as plagioclases (oligoclase-andesine), alkali feldspars (microcline), biotites and eventually other iron magnesium silicates, materialize the process by which the geologic medium participates in the groundwater chemical evolution that, in the case of Na, is estimated to achieve a value around 41%.

The study of the spring discharge behavior, where the groundwater samples were collected, demonstrates the importance of reduced flows under small precipitation periods on the extent of the dissolution process and consequent mineral enrichment. Na, Mg and Cl attest to the importance of sea salts introduced by precipitation in the groundwater chemical composition. Nevertheless, the water undersaturation state with respect to most of the mineral phases considered in the water-rock equilibrium study suggests that the silicates dissolution process is discrete. It also shows caulinite to be the favored mineral phase as a result. The fact that the spring is located on the surface of an accentuated relief, draining the superficial portion of a fractured shallow aquifer where the convergence of two factors – fast flow pathways and high recharge values – is the determinant in the comprehension of the groundwater chemical evolution and its incipient mineral content.

Keywords: Groundwater, granite aquifers, geochemical evolution, mineralization processes

Groundwater resources in granitic terrains: a quantitative approach to Vieira do Minho Region (NW Portugal)

[1]Luís MACEDO, [2]Alberto LIMA

[1] Atrevo – Laboratório Ambiental de Estudos, Intervenções e Consultadoria Lda, 4705-581 Braga, Portugal, e-mail: luismacedo@atrevo.pt
[2] Departamento de Ciências da Terra, Universidade do Minho, 4710-057 Braga, Portugal, e-mail: aslima@dct.uminho.pt

ABSTRACT

The recent concerns about the quality and sustainability of groundwater resources role on rapidly expanding water requirements have stimulated the development of works regarding the estimation and quantification of groundwater recharge. The North of Portugal, particularly the Minho region is characterized by the predominance of granitic rocks associated to the Vigo-Régua shear zone. The hydrogeological behaviour of these hard rock terrains is conditioned by the state of alteration and the density of the fracture network affecting these formations. The productivity of these rocks is, generally speaking, considered low, with values that only exceptionally go to 5 l/s and more frequently are about 1-2 l/s. The widespread use of groundwater in domestic supplies is witnessed by the recent development of the drill industry around this resource. However, its use in public supply systems is still under suspicion for several reasons, namely the issue regarding the availability in time and space. There are, nonetheless, several examples that demonstrate an excellent, cost and quality effective, adaptation of this resource to the supply of a small urban nucleus, although the lack of studies capable of enabling its adequate exploration is also well-known.

The evaluation of groundwater resources on a regional scale is a complex task. In Portugal, it has harnessed the efforts of several investigators. The results are usually expressed in terms of infiltration rates and generally are about 1-30%. The present work comprises a hydrogeological study aiming of the estimation of the renewable groundwater resources in a selected region, following the interest shown by the local municipal entity – Câmara Municipal of Vieira do Minho – on its potential to supply isolated urban areas where the accentuated relief makes it very difficult to implement conventional distribution systems.

The study area selected for this work is located in Louredo, Vieira do Minho – Northwestern Portugal. The geological framework is characterized by the occurrence of a biotite-rich coarse-grained granite crossed by quartz veins and some pegmatitic rock dikes with abundant quartz and tourmaline. Several sets of fractures break up the granite massif yielding a chaotic relief constituted by the individual rock blocks.

Several methodological approaches were selected in order to fulfill the abovementioned objective, including electromagnetic surveys of the geological medium, hydrograph analysis of a spring, determination of the aquifer hydraulic parameters, hydrometeorologic techniques such as daily and monthly soil water budgets, and chloride tracer mass balance.

The analysis of the spring discharge indicates its seasonal but good productive character, varying from 0,08 l/s to 2,11 l/s with an average value of 0,93 l/s. The analysis of the precipitation together with the spring discharge registered during the 323 days monitoring period reveals the rapid response of the spring to precipitation, suggesting the participation of highly permeable structures such as faults and/or fractures in the infiltration process. These, however, should have a modest order of magnitude since they had not been identified by VLF surveys. The recession values determined, n.10^{-2}/day, attest the shallow character of the underground pathway and the analysis of its variation appears to reflect the vertical variation of the permeability of the saturated geological materials, probably the result of the simultaneous existence of two aquifer systems: *a*) the underlaying fractured rock and *b*) the granite weathered layer. A tansmissivity value of 2,1 m^2/day was estimated and is compatible with the values generally admitted for the region. The aquifer recharge is estimated to be about 50% of the yearly rainfall, a value relatively superior to those commonly admitted for the region. However, given the importance of local hydrogeological specificities in the definition of this important hydrologic component and the similarity of the estimations produced by the several approaches conducted, this recharge value does not seem to be overestimated. Also noted is the importance of the distribution of the precipitation events in the occurrence of recharge. The analysis of the recharge distribution estimated by daily water budget depicts the importance of the prevalence and also intensity of precipitation events capable of maintaining the soil moisture, thus favoring the occurrence of recharge. Another interesting observation is the notable chloride concentration stability in the groundwater during the monitoring period, compared to the variations manifested by the rainwater samples collected. This, on its own, gives an impression on the aquifer dimension that are capable of assimilating the differences introduced by the precipitation.

Considering an average yearly rainfall value of 2300 mm in the spring recharge area, the available groundwater resources are estimated to be capable of supplying about 945 people/year, consuming an average 200 l/person/day, thus demonstrating the potential of this sort of resource in suppressing the needs of isolated urban areas and complementing the conventional municipal distribution systems which essentially base themselves on surface water sources.

***Keywords*:** Hydrogeology, recharge, infiltration, groundwater resources

Incorporating snowmelt in the surface flow hydrograph separation method to estimate groundwater recharge

[1]Matthew YARROW, [2]Manuel M OLIVEIRA

[1] Laboratorio de Modelación Ecológica, Departamento de Ciencias Ecológicas, Facultad de Ciencias – Universidad de Chile, Casilla 653, Las Palmeras 3425 – Ñuñoa, Santiago – Chile, e-mail: matiasyarrow@yahoo.com
[2] Laboratório Nacional de Engenharia Civil, Av. do Brasil, 1700-066 Lisboa, Portugal, e-mail: moliveira@lnec.pt

ABSTRACT

In the framework of the ECOManage project, the Aysén Fjord is one of the three physical-ecological-social systems being analyzed and modelled. The fjord receives freshwater mainly from the Aysén river watershed (Q > 600 m3s^{-1}). For two sub-watersheds, groundwater recharge is analyzed using the hydrograph separation method. Because of the high latitude and mountainous terrain of the Aysén Basin, it is important to consider the impact of snowfall and snowmelt on hydrographs and on groundwater recharge.

In the surface flow hydrograph separation method, base flow and direct runoff are separated. Base flow is an estimate of recharge that occurs in the area defined by a watershed. Between the occurrence of the recharge process and the subsequent base flow, the process of discharge from the saturated groundwater medium to the surface medium must be considered.

Base flow is a measure of the groundwater medium discharge to the surface medium if: (1) there is no storage of surface water; (2) there is no evaporation of surface water; and (3) there is no abstraction of surface water. On the other hand, groundwater discharge may translate the groundwater recharge of a watershed if: (1) recharge is the only water source of the saturated medium; (2) there is no abstraction of groundwater; (3) all the water that leaves the saturated zone flows to the surface medium; and (4) there is no evapo(transpi)ration from groundwater.

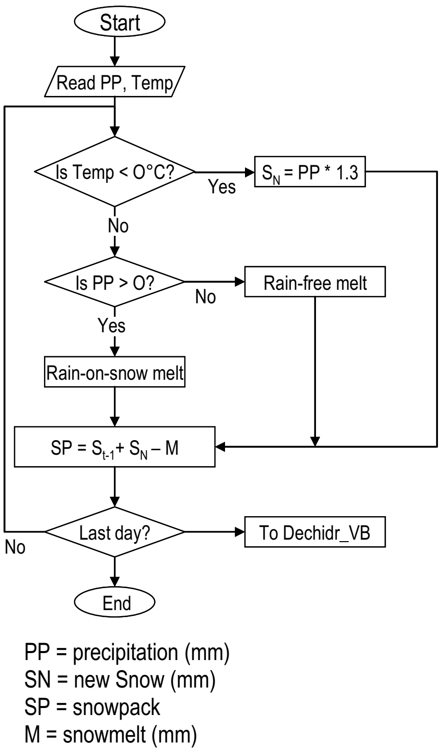


Fig. 1. Flow chart for Snowmelt model.

The surface flow hydrograph separation method is probably the easiest recharge calculation method to use, as it does not require medium characteristic parameters, and only requires knowledge of daily precipitation and flow series. This method is able to provide valuable information about the importance of base flow versus runoff in a watershed and was programmed in the DECHIDR_VB.VBP code.

The snowmelt model calculates precipitation as rain, new snow, snowpack, and ultimately meltwater. The water available for movement as base flow or surface flow (meltwater plus precipitation as rain) is calculated on a daily basis and imported into DECHIDR_VB in order to obtain values for base flow.

The snowmelt model was built in Microsoft Excel according to the flowchart in Fig. 1. It is important to note that snow was measured in units of water equivalent (mm) so as not to introduce further uncertainty as to snow depths and snowpack dynamics. Using information about temperature and precipitation for each zone, new snow was calculated daily. A daily snow balance equation was used to calculate the evolution of the snowpack over time. The snowmelt calculated for either rain-on-snow or rain-free conditions was weighted by the area of snow coverage per elevation zone.

The daily snowmelt and the precipitation as rain were summed across each watershed to get the daily water available for infiltration (eventually baseflow) and direct runoff. This output was then formatted for use with the DECHIDR_VB model.

In basins where snow represents an important percentage of the annual precipitation, the unmodified use of the hydrograph separation method could lead to erroneous conclusions. Thus, it is important to consider how snowmelt might influence the hydrographs of the associated river and how to account for this process in the hydrograph separation method. Fig. 2 indicates the two snowmelt scenarios considered in the snow model and their effect on the associated hydrograph. In Fig. 2A, a rain-on-snow event causes a large peak in the observed hydrograph. Although, DECHIDR_VB accepts one field for precipitation (or available water: snowmelt + precipitation as rain), the snowmelt model can give the proportion of snowmelt to rain on a daily basis and thus the results of DECHIDR_VB can be decomposed into components originating from snowmelt and from rain. During the spring snowmelt season, one could expect hydrograph peaks solely due to snowmelt (Fig. 2B). Without accounting for snowmelt, baseflow would be overestimated.

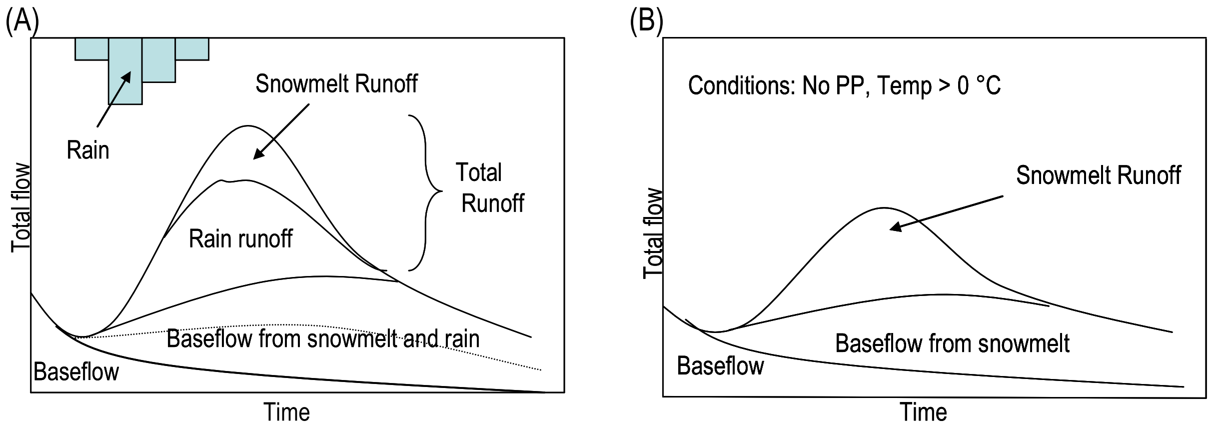


Fig. 2 – Hydrograph separation with snowmelt, (A) rain on snow event, (B) rain-free event.

In order to allow a comparison between dynamics with and without snowmelt, two runs of the model DECHIDR_VB were made. A visual comparison of Fig. 3A and Fig. 3B indicates that with the calculation of snow melt, the interpretation of the hydrograph changes. In Fig. 3A there is a steady contribution of snowmelt, with peaks of precipitation. It is likely that the daily snowmelt is not so constant. However, the snowmelt model uses monthly instead of daily radiation and thus differences between daily melt rates are probably less than what would be observed in the field. Nonetheless, the presence of this snowmelt water informs the hydrograph separation model that new runoff-recharge episodes should begin. Without this snowmelt signal (Fig. 3B), the peaks in the hydrograph are considered to be due to baseflow – due to the fact that there is no precipitation as rain. Thus, the inclusion of snowmelt can (1) help explain the high streamflows and hydrograph peaks that occur in the absence of rain events and (2) help avoid the over estimation of baseflow when using the hydrograph separation method.

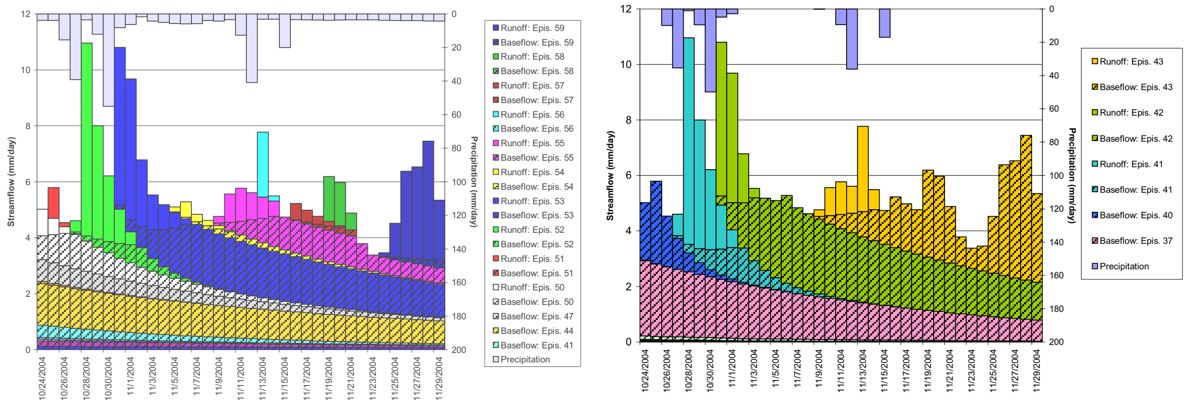


Fig 3 – Hydrograph separation detail, Rio Claro watershed, (A) considering snowmelt, (B) not considering snowmelt

The results show that groundwater recharge is relatively high in both watersheds and that snowmelt can be the major component of streamflow during the spring months.

ECOMANAGE is the acronym for the study "Integrated Ecological Coastal Zone Management System", developed for the European Commission DG Research INCO-CT Programme under contract number INCO-CT-2004-003715 and developed within the framework of the study "Optimised management of coastal aquifers and interaction between ground and surface waters" of the LNEC Research Plan for 2005-2008.

Keywords: Baseflow, snowmelt, hydrograph separation, groundwater recharge, Chile.

Quantifying impacts of a well field on an SPA/Ramsar wetland – Hardham Basin, UK.

[1]Don ROSS, [1]Sal WATSON, [1]James DUGGLEBY, [1]David GASCA-TUCKER, Will MINCHIN[2], Rob SOLEY[2], Mike PACKMAN[3].

[1] Atkins Ltd, Woodcote Grove, Ashley Road, Epsom, Surrey, KT18 5BW, UK
[2] Entec UK Ltd, 17 Angel Gate, City Road, London EC1V 2SH, UK
[3] Southern Water, Southern House, Yeoman Road, Worthing, West Sussex, BN13 3NX

Purpose and scope of the study

The purpose of the Arun Valley SPA Sustainability Study (AVSSS) has been to develop understanding of the potential impacts of public water supply groundwater abstraction at Hardham on wetlands within the Arun Valley SPA. The study, carried out over two years has included the following main elements:

- Hydrogeological and hydrological field investigations: Augering/window sampling of the shallow deposits; water level monitoring in shallow deposits, ditches and the main aquifer; topographic surveys.
- Development and application of three complementary models: a rainfall-runoff-recharge model, a groundwater model and a wetland water budget model.

Public Water Supply Abstraction at Hardham

The public water supply source at Hardham comprises a surface water river abstraction and, since 1964, abstraction from a well field in a Cretaceous sandstone aquifer (the Folkestone Beds). The well field –is licensed for a maximum abstraction of 36.5 Ml/d, though most parties accept that recharge to the basin could not sustain this rate year round. However, being able to draw upon the groundwater reserve at high rates to meet peak demands is of strategic importance to Southern Water and provides a means of supplementing abstraction from the river when river flows are low.

Wetland designations

The Arun Valley SPA qualifies as an SPA of European importance under article 4.1 and 4.2 of the Birds Directive (79/409/EEC) and as a Ramsar site for birds as well as rare invertebrates and plants.

Conceptual understanding of the Hardham Basin

The Hardham Basin has complex geology comprising a paired anticline/syncline structure of Cretaceous aquifers and aquicludes, overlain by post glacial sands and alluvial clays. Abstraction from Folkestone Beds in the core of the basin causes a regional cone of depression which responds to varying rates of groundwater abstraction (Fig. 1).

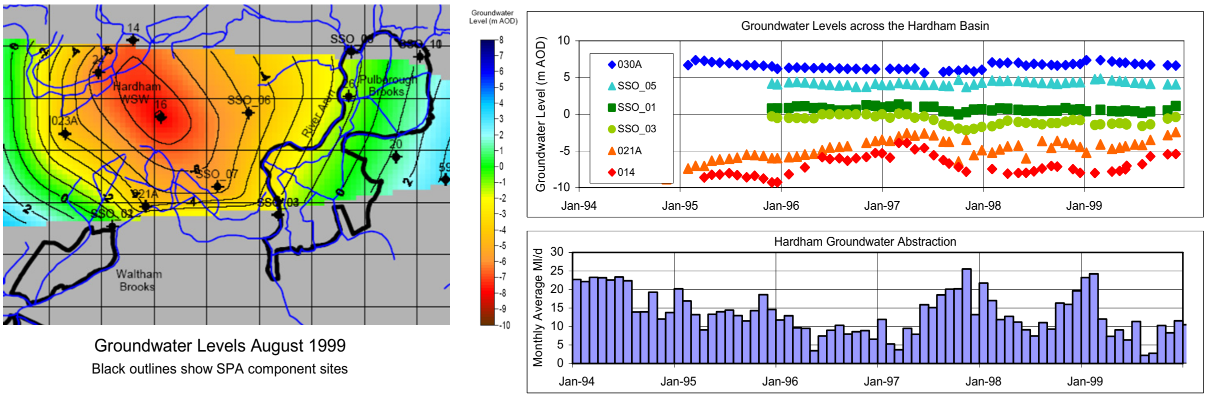


Fig. 1. Hardham Basin response to groundwater abstraction

Although regional responses are clear, it is much more difficult to understand and quantify:

a) the interactions of abstraction with the wetland and potential effects on integrity of the sites; and
b) the recharge to the basin and, as a consequence, a sustainable abstraction regime.

These issues have been investigated in this two year study.

Field investigations
Although good regional monitoring data were available from the 1990s, there was only limited understanding of the shallow geology and of groundwater-surface water interactions at the wetland sites. This has been addressed through intensive local field investigations and hydrometric monitoring, information that has greatly improved understanding of groundwater interactions within the wetlands.

Quantitative assessment of interactions has been carried out using 3 complementary models:

The Recharge-Runoff Model: This model utilises data on topography, geology, soils, land use, rainfall and potential evapotranspiration to produce spatially-distributed, time-varying datasets. These datasets are then integrated in the Entec "4R" model to produce estimates for a number of runoff and recharge components for the basin at a 100m grid resolution. Routing of runoff and interflow from sub-catchments to the wetlands are produced and the model provides recharge and streamflow input files for the groundwater model.

The Groundwater Model: The groundwater model is developed in MODFLOW. It includes a 7 layer representation of the complex hydrogeology of the basin (Fig. 2) and utilises the evapotranspiration (EVT) package which is designed for wetland/riparian areas and allows for watertable-dependent evapotranspiration.

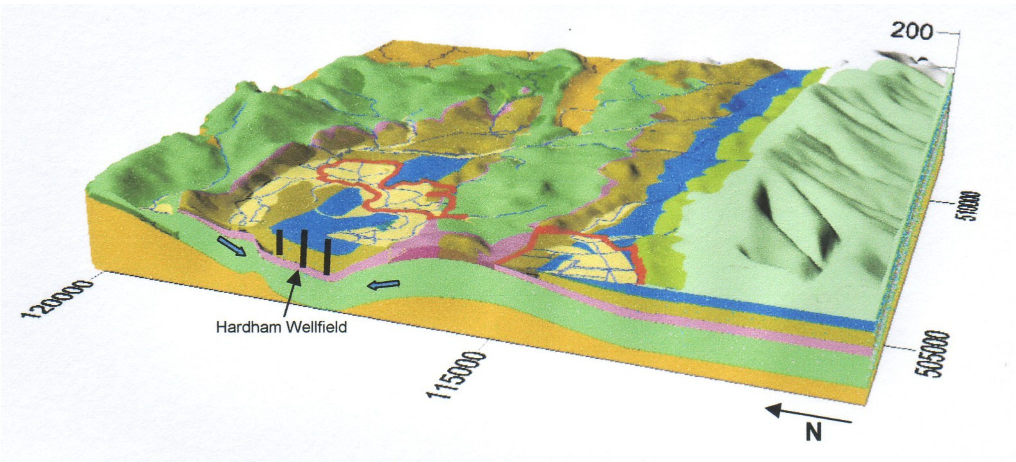


Fig. 2. Groundwater model representation of Hardham Basin

The Wetland Model: This spreadsheet-based model takes outputs from the recharge and groundwater models along with detailed topographic data from the wetlands and their ditches to estimate areas of open water and ditch water levels – the key hydrological parameters supporting the ecological communities in the SPA/Ramsar. In addition to the hydrometric monitoring data, aerial photographs collected by the local gliding club provide valuable information with which to calibrate the model.

Sustainability Assessment: The sustainability assessment is nearing completion. Various abstraction scenarios will be run with the groundwater model. The output is then interrogated with the wetland model to assess potential impacts on the designated ecological communities. At the regional scale, a sustainable groundwater abstraction regime will be designed that takes full account of the recharge to the groundwater basin.

Acknowledgements: The project is funded by Southern Water and has an active steering group with representatives from the Environment Agency, Natural England, Royal Society for the Protection of Birds and local Wildlife Trusts. The input of the steering group is gratefully acknowledged.

Keywords: Wetland, Groundwater, Modelling, Impact, Sustainability

Recharge by rainfall to Spanish aquifers through chloride mass balance in soil

[1,2 *]Francisco J. ALCALÁ and [1]Emilio CUSTODIO

[1] Department of Geotechnical Engineering, Technical University of Catalonia (UPC), 08034 Barcelona, Spain
[2] Present address: Department of Applied Physics, University of Almería, 04120 Almería, Spain

* Corresponding author. Tel/Fax: +34-950-015-477. *E-mail address*: francisco.alcala@upc.edu

ABSTRACT

The water budget evaluation in groundwater-dependent ecosystems normally requires an accurate estimation of recharge by rainfall over time. The recharge usually constitutes water difficult to estimate budget term. Classically, the recharge has been estimated in Spain by applying soil water balance methods based on meteorological variables.

This work presents a methodological synthesis for estimating rainfall recharge to the aquifers in continental Spain through the ion chloride mass balance method (BCS). It is necessary to characterize the variables of the BCS: atmospheric bulk deposition of Cl, flux of Cl in direct runoff and content of Cl in phreatic water, provided there are no other sources than atmospheric deposition and turnover time in the unsaturated zone is not sensible to recent climate and land use changes.

The calculated yearly recharge rate (potential recharge, not necessarily real) varies between 1 and 800 mm·yr^{-1}, with a typical range between 50 and 250 mm·yr^{-1} (Fig. 1a). The higher calculated percentages of recharge are ~ 60 % of local rainfall and takes place in some peninsular carbonate areas. The lowest percentages are determined in sedimentary formations, southeast coastal semi-arid areas, and certain inland areas, mainly in crystalline materials. Occasional minimum values of ~ 1 % of rainfall are calculated. The variation of yearly recharge rate over time, expressed in relative terms through the coefficient of variation, varies between 0.15 and 1.7 (Fig. 1b).

The estimation of recharge to the land through BCS can be considered something deficient in inland areas of high topographical variation and coastal zones with scarce data. It is quite accurate in areas with little topographical control, far from the coast and where initial data is available. The comparison between recharge obtained by means of BCS method and soil water balance methods in some places, where both type of data are available, presents relative differences between 0.5 and 2.

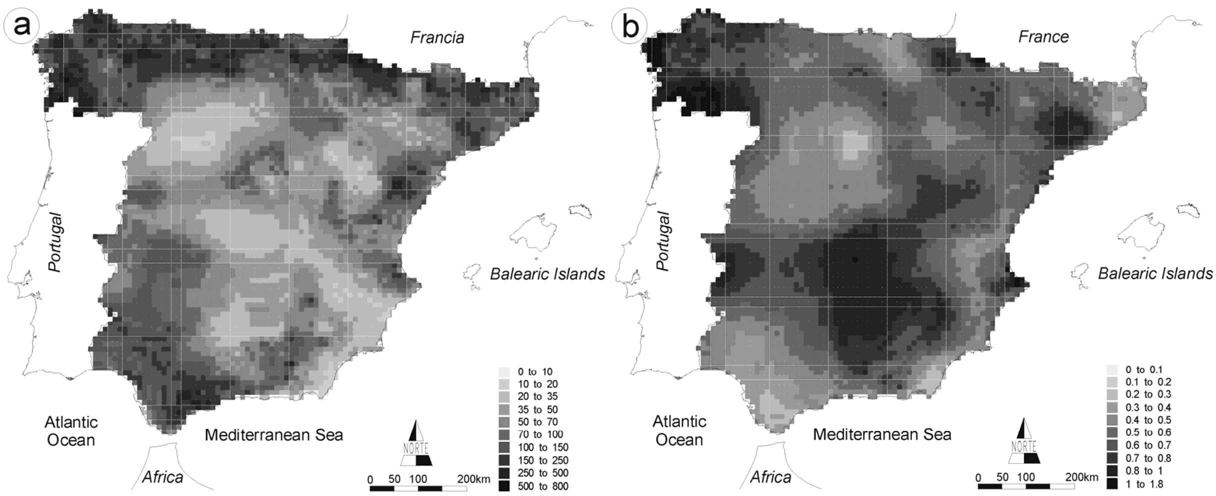


Fig. 1. (a): yearly rate of potential recharge by rainfall to the land in continental Spain (in mm·yr^{-1}).
(b): yearly recharge coefficient of variation in continental Spain (dimensionless)

***Key words**:* recharge, chloride balance, Spain

Recharge Estimation and Groundwater Resources Assessment in Granitic Terrains of Galicia-Costa Hydrographical District (NW Spain)

[1]Jorge MOLINERO, [1]Juan RAPOSO

[1]Escola Politécnica Superior. Universidade de Santiago de Compostela. Campus universitário s/n. 27002, Lugo. Spain. e-mail: molinero@lugo.usc.es; jraposo@lugo.usc.es

ABSTRACT

The Hydrographical District of Galicia-Costa extends to more than 13,000 km^2 and contains the hydrologic basins which lie exclusively within the Autonomous Region of Galicia (NW Spain). It constitutes 45% of the whole extension of Galicia but contains 75% of Galician population. Almost 40% of outcrops in Galicia-Costa consist in old crystalline igneous rocks (i.e. "granitic bedrocks") showing different alteration degrees at the surface. Regolith depths may range between 0 and near 100 m. The hydrogeological potential of these granitic terrains has always been neglected from the point of view of water resources management. Official Hydrologic Planning does not take into account the occurrence of groundwater in such igneous rock units.

5 small pilot basins have been monitored and studied during the last 3 years in order to develop and calibrate quantitative hydrologic models by means of VISUAL-BALAN tool (Samper et al., 1999). Hydrologic models have been calibrated against both piezometric heads in wells and flow rates in streams. Fig. 1 shows an example of the calibration of hydrologic models in some of the 5 pilot basins studied.

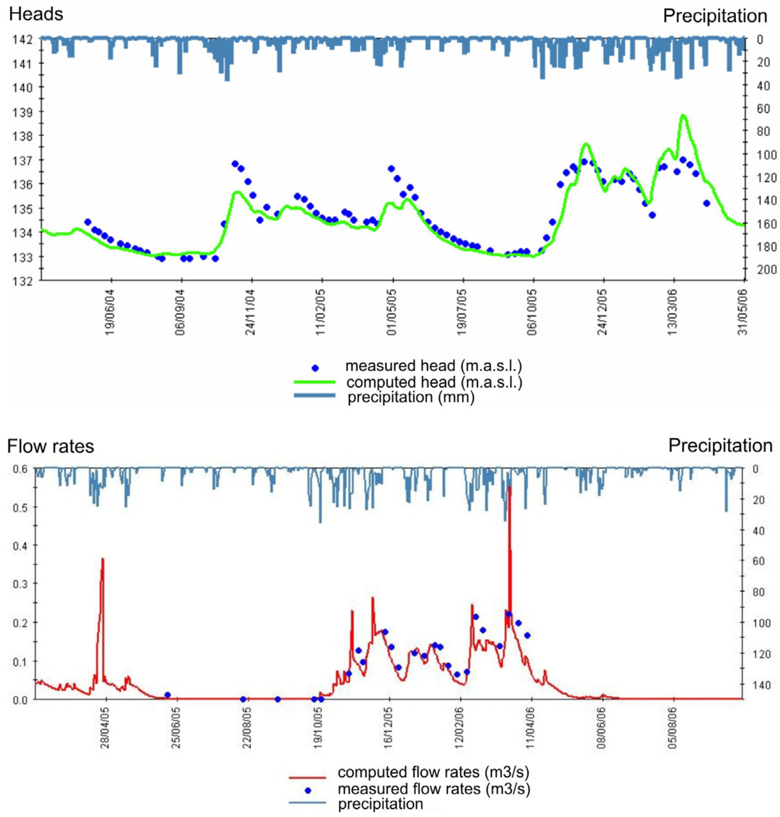
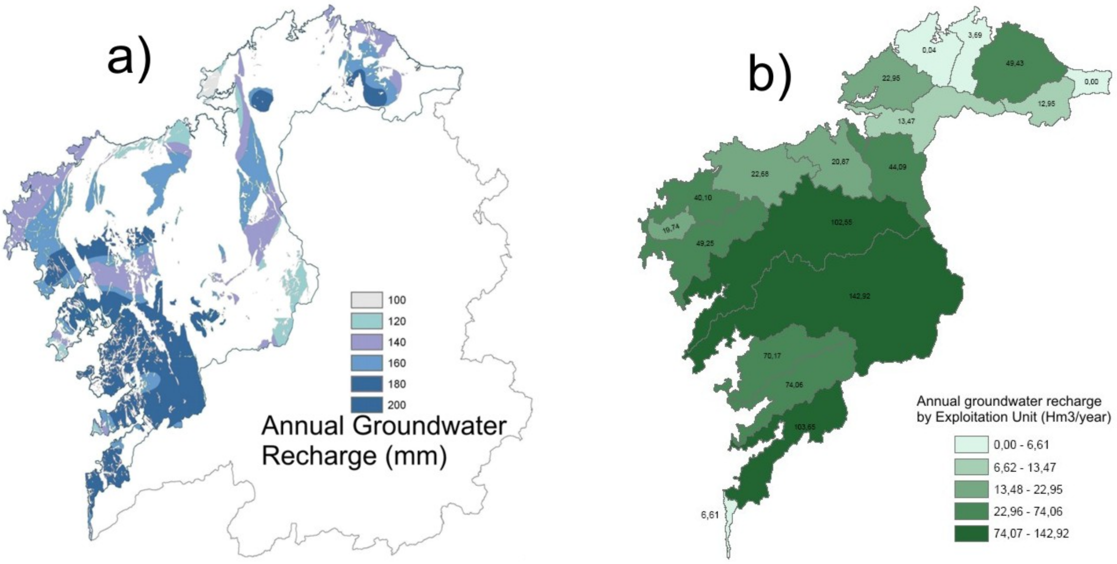


Fig. 1. Calibration of hydrologic models in pilot basins. Comparison of measured and computed groundwater head evolution (top) and flow rates in streams (down).

In the present work it is shown that granitic rocks in Galicia-Costa contain large amounts of groundwater resources. Model results indicate that most of the net rain (precipitation minus evapotranspiration) runs as hypodermic subsurface flow. Direct surface runoff usually amounts less than 5% of total precipitation, and annual groundwater recharge into the granitic aquifers give values between 9% and 16% of total precipitation. Model results are highly consistent with independent chemically-based mass balance estimations of groundwater recharge. Chloride mass balance gives a range between 10% - 20% of total precipitation as groundwater recharge into the granitic aquifers.

According to these results obtained in the pilot basins, it is estimated that annual groundwater flow through the granitic bedrocks of the whole area of Galicia-Costa would amount almost 800 millions of m^3. Such calculation has been done by means of a GIS-based tool accounting for available distributed topographic, geologic and climatic information. Fig. 2 shows the annual renewable groundwater resources in Galicia-Costa both distributed on the terrain and grouped by each Exploitation Unit (i.e. official administrative water domain).



Our results indicate that accounting for groundwater resources will dramatically change the outcomes of current official Hydrologic Plans in Galicia, which traditionally neglect such an enormous amount of groundwater actually available in the shallow subsurface. Annually renewable groundwater resources in granitic terrains of Galicia play a crucial role in both for rural water supply and ecosystems. Thus, these water resources should be taken into account in future Hydrologic Plans by Water Management Agencies.

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Keywords: Groundwater resources assessment, recharge estimation, granite, Galicia, NW Spain

The importance of groundwater recharge quantification for the sustainability of ecosystems in plains of Argentina.

[1]Mónica P D´ELIA, [1,2] Ofelia C TUJCHNEIDER, [1] Marta del C PARIS & [1] Marcela A PEREZ

[1] Facultad de Ingeniería y Ciencias Hídricas - Universidad Nacional del Litoral. Ciudad Universitaria CC 217 (3000) Santa Fe, Argentina. e-mail: mdelia@fich.unl.edu.ar
[2]Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina. e-mail: pichy@fich.unl.edu.ar

ABSTRACT

Groundwater recharge is balanced by discharge from the aquifer to the springs, rivers, etc. under natural conditions. This equilibrium is affected by the pumping of groundwater for human activities but even though this extraction is equal to recharge, it may cause important losses in discharge areas where wetlands and riparian ecosystems are developed. Thus, a correct and integrated management of groundwater resources have to take into account the recharge and discharge of aquifer systems and the groundwater users' requirements of a region (not only human beings but the environment requirements also).

In flat areas of the center of Santa Fe province, Argentina, groundwater system is formed by an unconfined aquifer that is locally recharged from precipitation, and a semiconfined one where recharge is both local (coming from the unconfined aquifer) and regional. Specifically for this area, local and regional groundwater flows were distinguished in previous studies based on hydrogeological behavior of the groundwater system, and corroborated by isotopic investigations. Discharge areas are mainly little streams and wetlands for the first one and the alluvial valley of Salado and Paraná rivers for the second one. These areas constitute very important ecosystems in which a great biodiversity has developed. On the other hand, although several important populations of the region are near to these rivers, human activities are strongly dependent on groundwater.

The objective of this work is to quantify local groundwater recharge and to give a first estimation of the amount of regional groundwater recharge in a central sector of the Santa Fe province, Argentina. The levels fluctuation method was used to estimate the first one and a chloride mass balance was done to estimate both local and regional groundwater recharge. The period of time analyzed included an important flood event of the Salado river that affected groundwater systems of the region and caused great economical losses in productive activities and a disturbance of the ecosystems of the area.

The results of this work are very important and contribute to the better knowledge of the groundwater system and provide quantitative criteria to base management and protection of ecosystems related to groundwater.

Keywords: groundwater recharge, plains, integrated management of groundwater resources

The influence of geologic structure on the recharging of the karstic chalk aquifer of Upper Normandy (France)

Smail SLIMANI*, Jean-Paul DUPONT, Nicolas MASSEI, Danièle VALDES and Benoît LAIGNEL

Contact : smail.slimani@etu.univ-rouen.fr*

Laboratory of Geology, UMR 6143 M2C « Morphodynamique Continentale et Côtière »,
IRESE A, 76821 Mont-Saint-Aignan Cedex.

ABSTRACT

The effect of climatic conditions on the rate of recharge of the karstic chalk aquifer in the Upper Normandy region, France, is of great interest because this aquifer is the sole source of drinking water for the region. The chalk plateaus are covered with clay-with-flints (resulting from weathering of the chalk) and Quaternary loess, which together constitute 5 to 50 m of fairly impervious cover; the thickness of the underlying chalk aquifer varies from 50 to 300 m. To better understand the relation between climatic conditions, piezometric levels, and geologic structure, pluriannual time series for four piezometers were analyzed by cross-correlation analysis and eigendecomposition filtering (also referred to as singular spectrum analysis). Two of the piezometers are located on the uplifted side of a major fault (either the Fécamp-Lillebonne fault or the Rouen fault), while the other two are on the downthrown side. The analyses indicate that the water table behaves differently in those compartments that are downthrown as opposed to those that are uplifted. In downthrown compartments a substantial (14 – 22 m) thickness of clay-with-flints acts as a low-pass filter with respect to recharge processes, implying a strong filtering of annual variability in water table variations, while pluriannual variability (typically 6-7 years) is clearly expressed. These compartments usually display a high amount of reserve. Conversely, in the uplifted compartments, which as the result of erosion have a thin layer (7 - 12 meters) of clay-with-flints, water table variations display obvious annual fluctuations as well as a reduction in the contribution of the long-term climatic oscillations. In these uplifted compartment areas there is a greater tendency for a rapid decrease in the piezometric level during dryer climatic periods, owing to a lower amount of reserve in the aquifer. The geologic structure thus aids in evaluation of this water resource in relation to location relative to major faults.

Keywords: geologic structure, karstic chalk aquifer, Upper Normandy, cross-correlation analysis, eigendecomposition filtering, annual and multiannual variability

The Role of Groundwater Recharge in Regional Scale Integrated Groundwater Flow Modelling

[1]Roland BARTHEL, [1]Johanna JAGELKE, [1]Jens WOLF, [1]Vlad ROJANSCHI, Marco [1]BORCHERS, [1]Jens GÖTZINGER, [1]Andras BARDOSSY, [2]Ralf LUDWIG, [3]Wolfram MAUSER

[1]Universitaet Stuttgart, Institute of Hydraulic Engineering, Pfaffenwaldring 7a, 70569 Stuttgart, Germany, Tel. +49- 711 685 66601, Fax +49 711 685 66600, e-mail: roland.barthel@iws.uni-stuttgart.de
[2]Institute for Geography, University of Kiel, Germany,
[3]Faculty for Geosciences, Ludwig-Maximilians University (LMU), Luisenstr. 37, D-80333,

ABSTRACT

This contribution deals with the discussion of groundwater recharge as a process and its meaning for groundwater flow modelling on the regional scale with a special focus on integrated management models. Integrated water resources management (IWRM) is often concerned with problems on the river catchment scale (> 10,000km^2) where the impacts of climate change or human intervention usually affect all components of the hydrological cycle. Various interactions and interdependencies between different components exist and have to be considered in the attempt to meaningfully describe processes and to evaluate the consequences of human intervention. Groundwater plays a very important role as a resource in many parts of the world and therefore deserves special attention in integrated management. Thus far groundwater flow models are the only means to meaningfully describe the effects of hydrological changes on the groundwater system. In contrast to (conceptual) hydrological models or water balance based modelling approaches, numerical 3D groundwater flow models can consider multiple aquifers, can describe horizontal as well as vertical flow, calculate flow direction and velocity, can quantitatively simulate groundwater discharge to surface waters at a specific location and above all, provide hydraulic heads in different aquifers as a result. For all kinds of groundwater related management questions, but in particular with respect to ecological issues, the mentioned capabilities of groundwater flow models are essential.

However, the application of groundwater flow models on the regional scale in heterogeneous areas poses severe problems due to insufficient data availability, discretisation problems and numerical instability etc. Therefore regional scale groundwater flow models are still rare. A particularly significant issue we identified in two regional scale integrated modelling projects (RIVERTWIN, Neckar catchment, Germany, 14,000 km^2, financed by the European Commission, www.rivertwin.org and GLOWA-Danube, Upper Danube catchment 77,000 km^2, financed by the German Ministry of Research and Education, www.glowa-danube.de) is the question of how to determine and apply groundwater recharge as a boundary condition for a groundwater model. In both catchments, recharge is the most important boundary condition. In the integrated systems, it is calculated by coupled soil water balance or hydrological models. It proves that the recharge calculated by a distributed conceptual model (HBV) or a physically based SVAT scheme respectively cannot be applied to the groundwater flow model unmodified without changing the hydraulic properties of model cells to values outside the reasonable ranges. The reason is that the underlying hydrological concepts of recharge determination and the conceptual setup of the groundwater flow model do not match. Whereas the groundwater flow model considers mainly regional scale aquifers, the hydrological models are partly based on *soil* parameters which are determined on a 'local' scale (1*1 km grids). The soil parameters determine percolation through the soil or root zone (often 0 to 5 m) whereas regional aquifers can be located at a depth of even more than 100 m.

A more detailed analysis of the encountered problems reveals that groundwater recharge, as a process and as a quantity, is something that always needs to be defined in a scale and context specific way. Groundwater recharge is an apparently well defined process and commonly defined as 'water entering the saturated zone'. However, groundwater recharge remains a quantity that cannot be measured directly and, in particular, not on a large scale. The large number of methods to estimate or calculate groundwater recharge indicates that its quantification is not an easy task. At the same time it is widely believed amongst groundwater modellers that groundwater recharge is one of the least uncertain 'physical' input values for groundwater flow models. It is therefore very often used as a 'fixed' input (meaning no calibration takes place) whereas other values (hydraulic conductivity, leakage coefficients etc.) are changed and used for model calibration over wide ranges. This assumption forms a good basis for many groundwater flow models and is usually valid in all cases where recharge is aggregated over longer periods and larger areas.

However, in regional groundwater flow modelling and in integrated (coupled) systems the situation is different. Here recharge needs to be defined specifically for the regional aquifers that are considered in the numerical groundwater model. As on larger scales, small (shallow) aquifers of small vertical and horizontal extent can usually not be included in the models. It must be discussed how the actual natural recharge to those smaller scale aquifers can be treated in the numerical model. Depending on the relief and the geological setting of a region it is very often the case that groundwater recharge entering such small aquifers does not reach the deeper regional aquifers because it leaves the saturated system as springs or groundwater discharge to smaller surface water bodies. For the regional groundwater flow model, such local recharge must, therefore, be subtracted from the actual recharge applied. It is obvious that it is a question of how groundwater recharge is defined or, in other words, on which conceptual approach the recharge determination is based. Here a distinction between physical approaches based on soil water budgets and unsaturated flow processes (e.g. Richards Equation), and more conceptual water balance and storage cascade based approaches, can be made. The physically based approaches tend to provide a groundwater recharge that can be called ‘root zone percolation’. The recharge values in that case are often far larger than the actual recharge to regional aquifers and can therefore not be directly used, in particular if thick unsaturated zones exist. The conceptual approaches, which often rely on a calibration to river discharge, provide better results with respect to the total volume because they integrate over larger areas - catchments or sub-catchments – and can distinguish to a certain extent between slow, regional groundwater discharge (baseflow) and faster, local groundwater discharge (interflow). On the other hand, conceptual methods provide results that are spatially less accurate due to their integrative approaches.

With respect to integration, problems occur because in coupled modelling systems of the hydrological cycle the input to groundwater flow models is usually determined by other models (hydrological models, soil water balance models) and the output of groundwater flow models is used as input to other models (hydraulic surface water models). That means the groundwater modeller has to accept an input (groundwater recharge) that was not necessarily calculated to suit the groundwater model’s specific set up and at the same time to provide an output that is usually not important in groundwater flow modelling.

In this contribution we will demonstrate the problems mentioned so far using the practical examples from the Neckar and Upper Danube Catchment groundwater flow models. The models and their conceptual and numerical set-up are presented briefly as well as the different coupling strategies to hydrological and hydraulic models. Modelling results of the stand alone groundwater models for steady state and transient conditions are presented and discussed. It is shown that an individual calibration of the models yields relatively good results with respect to measured discharge in the case of the hydrological/hydraulic models and to measured groundwater levels for the groundwater flow models (MODFLOW) respectively. However, if coupled together the results get worse. The joint, coupled calibration of all parameters involved, that is required here, is an extremely tedious and conceptually difficult task on the regional scale. However, we think that even if coupled model results might, from a strictly disciplinary view point of view, be worse than results of stand alone models, model coupling is beneficial. Here we will show that an integrated approach provides more information than the single models alone; not only does it provide more than one measurable quantity for model calibration, it also gives us the chance for an indirect check on usually internal state variables, the model structure and the conceptual base of the model. This can help to better understand process representation in individual models and might thereby be a means to reduce uncertainty. Coupled modelling is a valuable exercise because it forces us to describe the water cycle in a holistic, scale and context specific, consistent way that acknowledges both the groundwater and the surface water system. Integration provides a means to better understand and quantify linking processes such as groundwater recharge.

Keywords: Groundwater Recharge, Groundwater Model, Hydrological Model, Coupling, Neckar

Using inverse modelling to reduce uncertainty on the recharge to aquifers. The case of Petrignano d'Assisi (Italy)

Emanuele ROMANO and Elisabetta PREZIOSI

Water Research Institute, C.N.R., via Reno 1, 00198 Rome (Italy). Email: romano@irsa.cnr.it

ABSTRACT.

Estimating the recharge and, in general terms, the global water budget is one of the main aspects to be faced in order to characterize the hydraulic behaviour of an aquifer. Its correct estimation is a key point in the sustainable groundwater management (e.g. safe yield establishment) and in the implementation of regional flow models. The information needed for good calibration of such models includes the piezometric surface, the hydrodynamics parameters distribution and the water balance, both on a global and at a local scale.

Unfortunately, while it is usually possible to correctly define the piezometric field when a sufficient number of measuring points are available, the errors on the experimental determination of *k* and the unsolved problem of its correct upscaling at the aquifer scale, together with uncertainties on the water balance make it difficult to have a unambiguous assessment of the hydrodynamic behaviour of the system.

In order to define the water budget terms of an aquifer both recharge or discharge can be assessed by means of field measurements; under particular situations (i.e. steady state conditions and no flow boundaries) a direct measure of discharge allows for a complete assessment of the global balance. When this is not feasible, it is common practice to attempt to assess the recharge by means of estimates of vertical flow from lysimeters or from soil moisture data. However, these kind of measures are strongly influenced by the accuracy of the instruments and by local conditions (such as soil texture, land use, exposition, etc.) so that global estimates based on those data are affected by large uncertainties.

In this paper we propose to reduce the uncertainty on the recharge of a porous regional aquifer, integrating its estimation with the results of the numerical simulation of different flow situations (both in stationary and transient conditions) using several sets of piezometric head data as targets for inverse problems.

The methodology has been applied to the case study of Petrignano d'Assisi (Umbria, Italy). The aquifer of the Petrignano plain, whose surface is approximately 75 km^2, is a porous, alluvial aquifer, bounded by lacustrine and fluvio-lacustrine sediments that act as impervious boundaries (Fig. 1). The total recharge to the aquifer is composed of rain infiltration (effective infiltration, I_{eff}), losses from the Chiascio River and infiltration from lateral boundaries; discharge occurs along the Chiascio in its lower course. Under undisturbed conditions, (piezometric field of 1974, Fig. 2 left), groundwater flow was approximately directed from North to South. Since the beginning of the '80, when a pumping station for human consumption started to operate, a large depression cone has developed in the middle of the plain. Moreover withdrawals for agricultural purpose are widespread on the plain. At present (piezometric field of 2004, Fig. 2 right), drawdown has reached approximately 15 m depth at the pumping station area. The excessive deepening and widening of the depression cone determined a significant changing in the capture zone causing problems in quantity (because of an excessive drawdown) and in quality (related to the transport of contaminants from a much wider area).

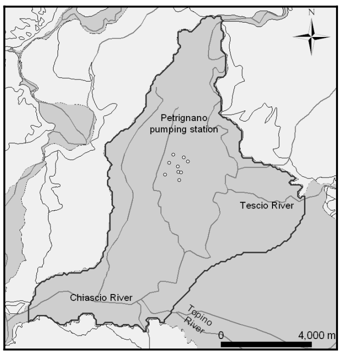

Fig.1. Study site: quaternary alluvial sediments (dark grey area). Dots show the position of the Petrignano pumping station wells.

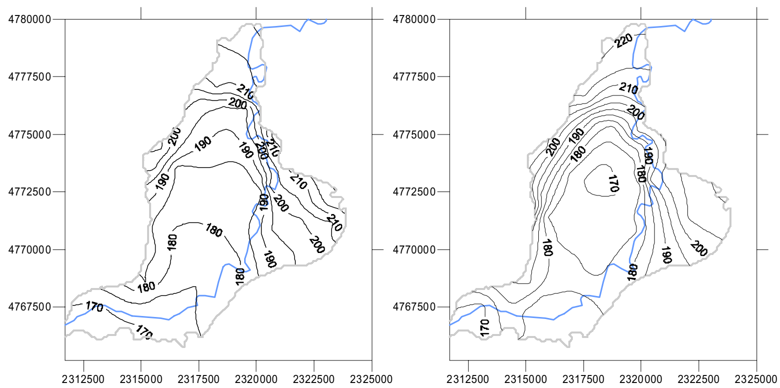

Fig. 2. Piezometric map referred to undisturbed conditions in 1974 (left side) and after exploitation in 2003 (right side). Reference coordinates on the axis are in Gauss-Boaga 32 E system, values in metres Same scale than Fig.1.

As an answer to this, a finite difference flow model was developed by means of the well-known code MODFLOW (McDonald and Harbough, 1988). For the calibration, the piezometric data concerning the undisturbed condition (1974) and the water table evolution from 1998 to 2004 have been provided by Arpa Umbria (the agency for the protection of the environment in the Umbria Region), which permitted a reliable reconstruction of the hydrodynamic situation prior to and subsequent the aquifer development. Conversely, data on conductivity and storage coefficients were limited to a few points and the recharge estimates arising from previous studies were not enough to allow to a reliable assessment of the global water budget. In other words, uncertainties in the model calibration arise from two different terms: the hydrodynamics parameters and the water budget. However the fact that these two terms are related via the diffusivity equation gives the possibility of reducing the uncertainty on both of them calibrating the model on to two different flow situations: the 1974 undisturbed condition and the present situation strongly modified both by exploitation and by climatic variations of the effective infiltration.

A first calibration was performed considering the undisturbed condition as target. Once the losses from Chiascio (180 l/s) and the recharge from lateral boundaries (50 l/s) have been assigned, the conductivity field that reproduces the target piezometric heads better has been calculated under three different reasonable hypothesis of I_{eff}: 150 mm/y (MOD1), 200 mm/y (MOD2) and 250 mm/y (MOD3). The calibration of the k distribution of the model has been performed in steady-state conditions by means of the inversion technique known as “comparison method” (Ponzini and Lozej, 1982; Guo and Zhang, 2000), that permits the identification of a possible conductivity pattern once assigned the target piezometric field, the boundary conditions and the source terms. Hence for each value of the supposed I_{eff} a distribution of the conductivity parameter that reproduces the reference piezometric map well was assessed.

The purpose of the second step of the calibration was to identify, among the three diverse k fields computed in the first step related to different hypothesis of I_{eff}, the one that reproduces a second flow situation better. For this purpose the piezometric time series from 1998 to 2004 was considered, in particular the strong drawdown suffered by the aquifer during the period 2001-2003 as a consequence of a regional drought that determined an enhancement of the abstractions both for civil and agricultural purposes. As an example, in Fig. 3 (dots) the level variation measured in a piezometer of the Arpa monitoring network from 1998 to 2004 is shown, together with the results of the simulations computed for the three different hypothesis of conductivity field (solid and dashed lines).

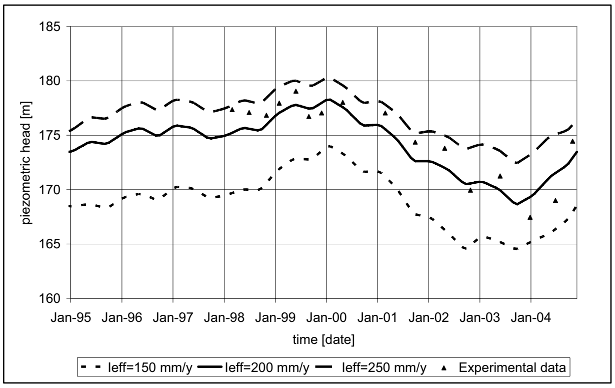

Fig. 3. Transient simulation results under three different hypothesis on mean effective infiltration compared with the piezometric experimental data

Simulations results have shown that, once assigned the storage coefficient, the conductivity field calibrated for the value of 200 mm/y for the mean effective infiltration term (MOD2) permitted to correctly reproduce the observed drawdown (Fig. 3). As a general conclusion the calibration performed using two different sets of piezometric data allowed us to reduce the uncertainty on the global water balance. However, it is important to stress that calibrations have been performed considering fixed values both of lateral infiltration from the external boundaries and of losses from Chiascio, hence all the uncertainties were ascribed to the effective infiltration term and on the related k fields Nevertheless, the assumption that all the uncertainty on the water balance is due only on the I_{eff} term does not limit the validity of our conclusions regarding the total amount of water flowing into the aquifer, even if the available data does not permit assessment of the relative percentage of each source term and its distribution throughout the study area.

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Keywords: water balance, ground water modelling, inversion techniques

Utilising Sustainable Drainage Systems to protect a sensitive groundwater dependant Eco System: The Ballyman Glen

[1] Shane HERLIHY, [2] Yvonne CANNON, [3] Wolfram SCHLUTER

RPS Group, West Pier Business Campus, Dun Laoghaire, Co. Dublin, Ireland,
e-mail: [1]shane.herlihy@rpsgroup.com; [2] yvonne.cannon@rpsgroup.com;
[3] wolfram.schluter@rpsgroup.com

ABSTRACT

A detailed hydrological and hydrogeological study was undertaken as part of an Environmental Impact Assessment (EIA) to evaluate the potential impacts from a golf course development on a down-gradient ecosystem, Ballyman Glen. The Glen is a groundwater dependant ecosystem, with an alkaline fen and protected under Irish Environmental Law. The proposed golf course development had the potential to significantly alter the local hydrological cycle and pose a threat to this protected ecosystem. A detailed integrated drainage and artificial recharge system was devised to mitigate against any impact the development may have on the local hydrogeology and Ballyman Glen.

Keywords: Artificial recharge, groundwater dependent ecosystem; sustainable drainage

TOPIC 03

Estimating and determining the impact of groundwater natural/ artificial recharge processes on groundwater dependent ecosystems

An Hydrogeologic study for optimizing the exploitation of ground water for irrigation in two agricultural enterprises. Conlara valley, Province of San Luis, Argentina.

[1] Carlos A. J. TORRES, [1] Norberto G. BUCICH, [1] Patricia LUNA.

[1] Instituto Nacional del Agua, Centro Regional de Agua Subterránea, Avda. José I. De la Roza 125 E – 5400 San Juan – Argentina. Tel. +54-264-4214826 Fax +54-264-4212415 – E-mail ctorres@ina.gov.ar - nbucich@ina.gov.ar - pluna@ina.gov.ar

ABSTRACT

The company CRESUD SACIF y A owns two agricultural farms (Santa Bárbara and La Gramilla), situated in the Conlara valley. The agricultural exploitation in both farms is carried out with complementary irrigation through central pivot systems supplied with ground water. Seven pivots have been installed in Santa Bárbara and twenty in La Gramilla, which are supplied by water produced by 32 wells drilled in their perimetral zones.

The discharges from these wells vary between 82 m^3/h and 405 m^3/h. The pivots cover different surfaces, which total 3789 hectares, of which 1234 are in Santa Bárbara and 2555 in La Gramilla.

In view of the intensive exploitation of the subterranean hydric resource, a hydrogeologic study was made in order to insure the sustainability of the water extraction and determine the interference degree, with the purpose of minimizing the development costs.

The Conlara valley, which is situated in the Pampean Ranges geologic province, is a North-South elongated tectonic depression limited both in East and West by mountain chains. These chains are made up by igneous and metamorphic rocks Precambrian-Early Paleozoic in age, usually known as Crystalline Basement. These rocks constitute the hydrogeologic basement of the ground water basin and make up the original valley bottom. The valley has been filled with fluviatile and aeolian clastic materials during Quaternary and Prequaternary times. This fill shows variable grain sizes, from gravel to silt and clay. An important ground water basin was formed in these sediments which contains the aquifer currently being exploited for irrigation in the agricultural farms existing in the valley.

In this material filling the valley two geologic units have been determined: The Fine Clastic Formation below and the Coarse Clastic Formation above.

The geophysic information obtained and the data from available wells made it possible to determine not only the distribution and thickness of both units in the subsurface of the agricultural establishments, but also the geometry of the ground water basin.

The region has a continental type pluviometric regime, with maximum monthly rainfalls during the summer months and minimum precipitations in the winter season. This rainfall regime is the one prevalent in the Pampean Ranges region and in Northwestern Argentina. The annual rainfall average is about 680 mm.

The recharge of the aquifers derives mainly from the infiltration of water of temporary streams that drain the mountainous area and takes place where these streams enter the sedimentary fill area of the valley. The direct recharge by rainfall in the modeled areas is considered to be very low or even null in relation to the main recharge and, for this reason, has been ruled out in the present study. Moreover, the depth of the ground water surface does not let the pluviometric events satisfy the field capacity of the aeration zone, except where the ground water level is very near the surface.

The pump tests carried out in wells of Santa Bárbara and La Gramilla allowed the determination of the hydrodynamic characteristics of the aquifer used in the application of the simulation mathematical model used for the effects of the production of ground water in fields submitted to pumping. With this model different scenarios were simulated, including one with maximum exploitation.

The mathematical flow model of the aquifer system made before the present study was used to calculate the water volumes entering the area of interest and their relations with the extraction volumes and natural runoff, in order to determine the sustainability of the current and the planned exploitation.

To optimize the use of groundwater on both agricultural farms, the results of the present study were used to specify recommendations for adjusting programmes in the different sectors of each farm in order to diminish interference with dynamic levels in the wells.

Concomitantly, comparative analyses of the historic information of the level variations were made, from which it could be concluded that the water exploitation will not produce any hydric environmental impact in the area.

Keywords: Hydrogeology, ecosystem, groundwater

Application of the water balance model GROWA for specifying the boundary condition groundwater recharge in a spacious groundwater model

[1]Frank HERRMANN, [1]Christoph JAHNKE, [2]Ralf KUNKEL, [1]Hans-Jürgen VOIGT, [3]Jens VOIGT, [2]Frank WENDLAND

[1]BTU Cottbus, Chair of Environmental Geology, Erich-Weinert Str. 1, 03046 Cottbus, Germany, e-mail: herrmanf@tu-cottbus.de, voigt@tu-cottbus.de, jahnke_christoph@yahoo.de
[2]Research Centre Jülich, Institute of Chemistry and Dynamics of the Geosphere, 52425 Jülich, Germany, e-mail: r.kunkel@fz-juelich.de, f.wendland@fz-juelich.de
[3]RWE Power AG, Stüttgenweg 2, 50935 Köln, Germany, e-mail: jens.voigt@rwe.com

ABSTRACT

Groundwater recharge is one of the most important boundary conditions for modelling and simulating the groundwater dynamics in a model. In practice, the accurate representation of that variable which shows considerably fluctuation in space and time, is challenging. This also applies to the groundwater model which is operated for the Lower Rhine lignite mining area by RWE Power AG (PEUKERT & HELMBOLD, 2000). This groundwater model is used for the simulation of groundwater dynamics in the context of dewatering the open pit mining area and also for the evaluation of the implication of groundwater subsidence on the ecosystems influenced by the mining activities.

In a case study for the entire Federal State of North Rhine Westphalia in which the lignite mining area is located, the yearly groundwater recharge was determined with the empirical grid based water balance model GROWA (KUNKEL & WENDLAND, 2002; BOGENA et al., 2005). Within the framework of the presented study, the possibility of transferring the GROWA results into the groundwater model of RWE Power AG has been investigated. An additional intention was to analyse the options for a qualitative and quantitative enhancement of the RWE model performance in the river plain areas. In the study this has been implemented by coupling the two models.

In this contribution, first the calculated area-specific groundwater recharge values will be presented and analyzed. In this context, special attention is paid to the movement of the open pits during the time period from 1971 until 2000, as this has made a synchronisation of parameters of both models necessary. Finally, the results of transferring the yearly GROWA values into the groundwater model will be analysed and discussed in its regional context.

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Keywords: groundwater, recharge, dynamics, model

Contribution for the estimation of groundwater recharge in the Serra da Estrela crystalline-rock groundwater bodies (Portugal)

[1]Eric MENDES, [1]Luís M. FERREIRA GOMES & [2,3]M. T. CONDESSO DE MELO

[1]Universidade da Beira Interior, Covilhã, Portugal;
[2] *ELMAS*, Departamento de Geociências da Universidade de Aveiro, Aveiro, Portugal;
[3] Instituto Superior Técnico, Lisboa, Portugal.

ABSTRACT

In highland areas such as the Serra da Estrela Natural Park formed by predominantly low permeability igneous and metamorphic rocks, the bedrock itself may be a potential source of groundwater. The importance of these groundwater resources for public water supply relies on the groundwater recharge and storage capacity of the main crystalline-rock formations, as well as on the different factors that may affect the groundwater quality.

Detailed hydrogeological studies have been carried out in the Serra da Estrela Natural Park in order to estimate the natural recharge rate of crystalline bedrock formations and their capacity to supply water to the city of Covilhã, where most of the population of the region lives. Although Serra da Estrela Natural Park has abundant rainfall, most of it falls from October through March, summer precipitation is scarce and it does not meet water demands. Therefore, groundwater is an important resource available to satisfy the growing water demand.

Part of the rainfall in the region rapidly flows downhill towards the drainage areas of the principal rivers and streams. The rest infiltrates in the bedrock, moving mainly through secondary openings, such as joints, fractures and faults. Traditionally, water mines and springs are used to utilise these groundwater resources.

The methods used to estimate groundwater recharge include the analysis of daily data of spring baseflow and its comparison with data provided by the chloride mass balance method. Chemical data from rainfall and groundwater were also collected.

The results contributed for the development of the hydrogeological conceptual model of the region and show that about 15% of the rainfall recharges shallow groundwater resources. This recharge values may not be of significance at regional level, but certainly constitute an important local source of water for the drinking supply.

Acknowledgements
The authors would like to thank the Águas da Covilhã Empresa Municipal for supplying all the required data, and the Portuguese Science Foundation (FCT) for funding a Post-Doc grant to Teresa Melo (SFRH/BPD/30775/2006).

Keywords: Groundwater recharge, Serra da Estrela, fractured rocks

Ecologic-hydrogeological systems in arid areas

Vladimir N. OSTROVSKY

All-Russian Research Institute for Hydrogeology & Engineering Geology (VSEGINGEO),
142452 Zeleny-Village, Noginsk District, Moscow Region, Russia
Phone: (07)(495) 521-20-00, Fax: (07)(495) 913-51-26, E-mail: vseginge@rol.ru

ABSTRACT

The paper describes the ecosystems in arid areas that have a number of specific features determined by dry climate. In spite of low biological productivity, the vegetative cover exerts a considerable influence on groundwater formation: to a greater degree on its discharge and less on the recharge. The infiltration recharge of groundwater is regulated by zonal distribution of vegetation. In turn the biological productivity of vegetation depends on hydrogeological features. A special class of ecosystems is distinguished - ecologic-hydrogeological (phytohydrogeological) systems that are formed and function due to an interaction between plants and groundwater. The ecologic-hydrogeological systems are dynamic formations that can be transformed in time and mainly due to changes in hydrogeological conditions. Depending on the structure of shallow groundwater balance, the ecologic-hydrogeological systems can evolve towards xerophytization or halophytization. All these features of the ecologic-hydrogeological systems development should be taken into consideration in predictions of desertification of territories.

Keywords: arid areas, phreatophytes, ombrophytes, groundwater-vegetation interaction, ecologic-hydrogeological systems, daily eurhythmy of groundwater.

Ecosystems of arid areas have a number of specific features, namely: a low biological productivity, with underground vegetation mass is considerably larger than on-ground one; a wide variety of life forms of plants: xerophytes (i.e. plants of dry habitats), halophytes (i.e. plants of salted soils); distinctive differentiation of plants into two ecological groups: phreatophytes that are fed with participation of groundwater, and ombrophytes existing at the expense of atmospheric moisture. Of predominant spread in the arid zone are communities of ombrophytes; less spread are phreatophytes which, unlike communities of ombrophytes, possess a high biological productivity. Ecosystems, the structure, state and dynamic of which are determined chiefly by hydrogeological factors, are proposed to be named phytohydrogeological. Functioning of such ecosystems depends mainly on two factors: groundwater and vegetation, to a considerable degree represented by phreatophytes. By data of E.A.Vostokova (1980), the root depth of the latter can reach 30-40 m, but, on the average, not deeper than 5-10 m. Phytohydrogeological ecosystems are widely found in valleys and deltas of the rivers Volga, Terek, Amu-Darya, Ili and others, in the areas of groundwater discharge on piedmont and intermontane plains, and in drainless depressions of the arid zone. The phytohydrogeological systems are associated often with zones of faults. But if to take into consideration that the hydrographic network adapts also to tectonic disturbances, then one can consider that the areal spreading of the given ecosystems is considerably controlled by tectonics. Transpiration of phreatophytic vegetation is the basic consumer of groundwater in arid areas. These systems can be both natural and anthropogenic. The phytohydrogeological systems play the basic role in groundwater discharge. Transpiration consumption of the phreatophytes can reach 1000-1500 mm and larger and exceed the maximum values of evaporation that is possible at the expense of solar radiation. This is explained by the advective income of heat in the area of groundwater discharge from the surrounding desert areas warmed by the sun. Variations in groundwater levels in the phytohydrogeological systems depend on the type of vegetation. The phytohydrogeological systems are characterized also by daily eurhythmy of shallow groundwater levels, revealed first in 1932 by W.N.White in the valley Escalant in California. The phytohydrogeological systems are transformed during desertification of territories, which happens presently in a number of arid regions. Evolutionary tendency of the phytohydrogeological systems is determined by hydrogeodynamic conditions – i.e. filtration parameters of water-bearing rocks and velocity (outflow) of groundwater movement. At active outflow, the phytohydrogeological systems are replaced by communities of xerophytic ombrophytes, at weak one – by halophytic communities, in which evaporative concentration of salts takes place, turning soils into solonchak. It is impossible to assess unambiguously practical importance of the phytohydrogeological systems. On the one hand, they adversely influence groundwater resources, namely decreasing their amount. But on the other hand, one should not forget that the phytohydrogeological systems represent nice pastures and hayfields, which are widely used by local population as a fodder resource for cattle. Besides, implementation of recommendations to remove phreatophytes as proposed by some authors, will lead to activization of salinization and a decrease in comfortability of landscapes as a human habitat. The problem should be solved on the basis of integrated hydrogeological and landscape investigations. .

Effect of Discharge and Recharge Events in some Wells in the Port Harcourt Area of Niger Delta, Nigeria.

[1]Promise A. AMADI E-mail: amadipee@yahoo.com & [2]Boniface C. E. EGBOKA

[1] Hydrogeology Section, Department of Geology, University of Port Harcourt, P. M. B. 5323, Port Harcourt, Rivers State, NIGERIA.

[2] Department of Geological Sciences, Nnamdi Azikiwe University, P. M. B. 5025, Awka, Anambra State, NIGERIA.

ABSTRACT

From 2000 to 2002, depths from ground surface to watertables in three hand-dug wells in certain parts of the Niger Delta were measured monthly, specifically to monitor the effect of rainfall discharge and recharge events on the ground water level in the area. A 30-meter water level sensor, model No. CPR6 that reads to the 1000th of a meter was used. Data generated showed that, during these years, and at all stations, two discharge periods and one recharge event occurred. In 2000, the first discharge event (January to April) lowered watertables from 8.765m to 10.091m in one well; 8.561m to 9.075m in another and from 8.460m to 9.735m in a third; while the respective figures for the second discharge event (October to December) are from 6.645m to 8.346m, 7.545m to 8.435m and from 6.505m to 8.307m. During the recharge event (May to September) watertables were elevated from 9.945m to 5.631m; 9.032m to 6.890m and from 9.657m to 5.451m respectively. In 2001, the first discharge event caused watertables to fluctuate between 9.065m and 10.115m again in the first well, 8.705m and 9.061m in the second and between 8.905 and 9.902m in the third. The fluctuations during the second discharge event were between 6.895m and 8.936m and 7.632m and 8.678mm respectively. During the recharge segment, the respective watertables were raised from 9.895m to 5.115m; 8.944m to 6.665m and from 9.525m to 7.930m. The 2002 measurements showed that during the first discharge event, watertables changed from 9.462m to 10.086m and from 8.853m to 9.871m; and during the second, the changes were from 6.441m to 6.515m and 7.774m to 7.961m respectively. Again these trends were reversed by the recharge event and watertables changed from 9.630m to 4.998m and from 9.587m to 7.407m respectively. During the years, 2000 to 2002, recharge reaching the groundwater system was maximum in the month of September, this being reckoned as the month when the groundwater body received all the infiltration available from the unsaturated zone. Maximum discharge occurred in April, again when the groundwater body may have lost all the infiltration available from the unsaturated zone. Average watertable fluctuation was 4.824m in the first well and 2.409m in the second, and these are interpreted as being influenced by fluctuations of the discharge and recharge events and these are nature-induced and seasonal.

Keywords: Wells, discharge, recharge, nature-induced, seasonal

Effects of land use changes on the groundwater recharge at Tecocomulco sub basin, Central Mexico.

[1] Rafael HUIZAR-ALVAREZ, [2] Guillermo HERNÁNDEZ-GARCÍA

[1] Instituto de Geología, Universidad Nacional Autónoma de México, 04510, México,
e-mail: huizar@servidor.unam.mx
[2] Instituto de Geofísica, Universidad Nacional Autónoma de México, 04510, México,
e-mail: ghdez@geofisica.unam.mx

ABSTRACT

From the regional perspective, the study of subbasin is a recharge area for the neighboring surrounding area such as the Apan and Singuilucan sub-basins, and the Mexico basin. Despite the fact that the Tecocomulco plain corresponds to a discharge area, the unplanned groundwater extraction and changes in land use cause the drying of the lagoon. The alteration of the vegetation layer affects the groundwater reserve, since the surface runoff has been increased and the infiltration diminishes. Applying the flow model, we observed that of the additional surface water contribution that arrives at the lagoon, the greater percentage evaporates. In the areas with erosion, the recharge drops to 30 %; the maximum increase in groundwater extraction from 2000 to 2020 totals $0.1 m^3/s^{-1}$. The cartography of the water level shows that, due to the extraction increase and decrease in recharge, the lagoon will became a wetland.

It is necessary that strict surveillance be kept on land use and reforestation practices in the sub-basin to avoid the lagoon becoming a wetland or possibly, even disappearing.

Keywords: Tecocomulco Lagoon, recharge zone, wetland, recharge

Flow Dynamics, Drawdown and Renewable Groundwater Reserves in the Metropolitan Area of Fortaleza, Ceará State, Brazil

[1] Rinaldo Afrânio FERNANDES & [2] Celso de Oliveira LOUREIRO

[1]Rua Albita, 131, s306 – Cruzeiro – Belo Horizonte/MG – 30.310-160, Brasil, e-mail: rinaldo@hidrovia.com.br
[2]Av. Contorno, 742, s710 – Centro – Belo Horizonte/MG – 30.110-060, Brasil, e-mail: celso@desa.ufmg.br

ABSTRACT

This work describes the flow dynamics, the condition of the drawdown and the groundwater renewable reserves in the Metropolitan Area of Fortaleza, Ceará State/Brazil (Fig. 1) based on the natural hydrogeologic conditions and the great amount of groundwater pumping from existent wells in the area.

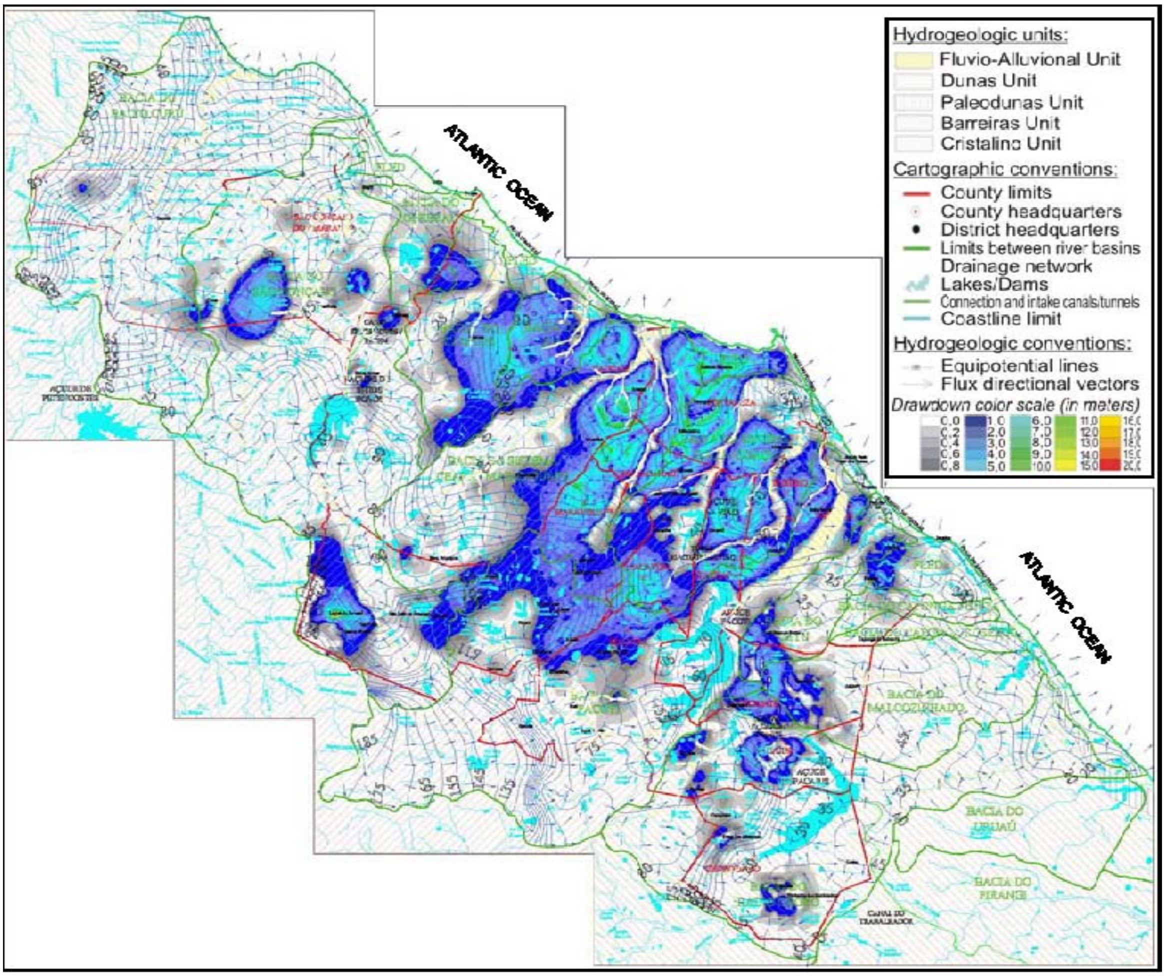

Fig. 1. Schematic map showing the results of study in Metropolitan Area of Fortaleza.

For this, a hydrogeologic conceptual model was conceived and implemented in a computational code, which showed the following main results: the groundwater flows, preferentially, towards the beds of the main courses of superficial water and towards the sea; the average drawdown can be up to 20 meters, being less in the districts located in the domains of crystalline rocks, where the density of wells is lower; the operation of the wells is capable of producing about 95,67 million m^3/y, of which, 79,79 million m^3/y of fresh water and 15,88 million m^3/y of groundwater comes from the intrusion of the saline waters. The total renewable reserves, calculated by the model, correspond to approximately 350,82 million m^3/y.

Keywords: flow dynamics, drawdown, renewable reserves.

Hydrogeological specificities regarding slope instabilities: a case study in Rio Caldo – Terras de Bouro (NW Portugal)

[1]Luís FERREIRA, [2]Alberto LIMA

[1]Atrevo – Laboratório Ambiental de Estudos, Intervenções e Consultadoria, Lda., 4705-581 Braga, Portugal,
e-mail: luisferreira@atrevo.pt
[2]Departamento de Ciências da Terra, Universidade do Minho, 4710-057 Braga, Portugal,
e-mail: aslima@dct.uminho.pt

ABSTRACT

The present study aims to understand the relation between precipitation, infiltration and evolution of the groundwater level in Rio Caldo – Terras de Bouro region (NW of Portugal) in order to understand the influence of the hydrogeological factors on slope instability observed in that zone in the 2000 – 2001 winter, which was particularly pluviometric. The geological setting is characterised by the presence of a two mica (with predominance of biotite), calco-alkaline, porphyritic of coarse or medium-coarse grain granite (Terras de Bouro granite). The granite is abundantly intruded by basic rocks bodies and aplite-pegmatitic dikes and is cut by several faults. Globally, in this zone, the rock is very weathered (W3 – W5). The slopes are considerably steep and differentially occupied by forest, farming fields and edifications.

The hydrogeological study was conducted during the last months of 2003 and the first semester of 2004 in order to build a conceptual model to be applied to the hydrogeological year of 2000 – 2001. The methodological approach selected involved the collection of precipitation data, the monitoring of piezometric levels, the estimation of infiltration by daily water budget and the comparative analysis of piezometric levels variation versus estimated infiltration.

Based on the precipitation data collected in the Penedo station for the hydrological year of 2003 – 2004, the precipitation for the S. Bento da Porta Aberta station for the same period was estimated, which gave a more adequate station to the study zone. These values were then used to automatically calculate a daily water budget with specific software. The evolution of the precipitation and infiltration estimated for the hydrological year of 2003 – 2004 in the region of Rio Caldo – Terras de Bouro is shown in the Fig. 1.

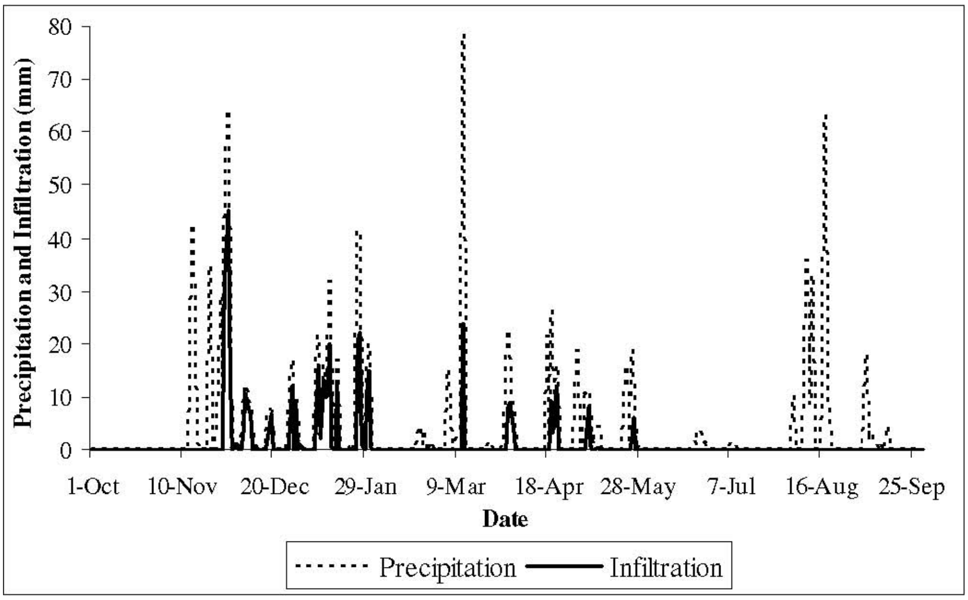

Fig. 1. – Evolution of the precipitation and the infiltration during the hydrological year of 2003-2004

Globally, during this hydrological year, 1194,73 mm of precipitation were estimated over the study zone of which approximately 402,79 mm had infiltrated. Regarding these values, the aquifer recharge was estimated to be about 34% of the yearly rainfall. This is slightly higher than the usual rates commonly admitted for the region, and these are between 1 and 30%. The observation of the evolution of six piezometers between

December of 2003 and June of 2004 added to the understanding of the local behaviour of the piezometric level during the same period. This behaviour was contrasted with the aquifer recharge in order to determinate local characteristics that are related to it, namely the equations that rule the groundwater level decrease in recession periods and the effective porosity. The equations of groundwater level decrease were calculated for the zone of each piezometer by linear regression of the piezometric levels measured during a period without aquifer recharge and can be seen in Table 1.

Table 1. – Equations of groundwater level decrease calculated for each piezometer (x – time in days; y – piezometric level in meters; z – piezometric level of “day 0” in the time period considered)

Piezometer	Equation
1	y = -0,0201x + z
2	y = -0,0329x + z
3	y = -0,0326x + z
4	y = -0,0136x + z
5	y = -0,015x + z
6	y = -0,0106x + z

The effective porosity was calculated for the zone of each piezometer for a period of aquifer recharge and based on the following expression:

$$PE = [RA / (SN + D * t)] * 100 \qquad (1)$$

where PE is the effective porosity (%); RA is the aquifer recharge (mm); SN is the increase of the piezometric level (m); D is the daily groundwater level decrease (m) and t is the period considered (in days). The results are expressed in Table 2.

Table 2. – Effective porosity values calculated for the zone of each piezometer

	Piezometer 1	Piezometer 2	Piezometer 3	Piezometer 4	Piezometer 5	Piezometer 6
Effective Porosity	7%	9%	12%	13%	15%	27%

This approach allowed the simulation of the groundwater level in the 2001 – 2002 winter, based on the precipitation data for that period. Once the hydrogeological aspects have weight in slope instability, those results are then used to calculate safety factors for the slopes in question. These factors decreased with the increment of the piezometric level which increases with the increment of precipitation.

Keywords: Infiltration, precipitation, piezometric level, effective porosity

Identification recharge and discharge process by temperature gradient profile in Jakarta Groundwater Basin, Indonesia

[1]Rachmat Fajar Lubis, [2]Yasuo Sakura, [3]Robert Delinom.

[1] Graduate School of Science and Technology, Chiba University 1-33 Yayoi-Cho, Inage-Ku Chiba 263-0043 Japan, e-mail: fajarlubis@graduate.chiba-u.jp
[2]Faculty of Science Chiba University 1-33 Yayoi-Cho, Inage-Ku Chiba 263-0043 Japan, e-mail: ysakura@faculty.chiba-u.jp
[3] Research Center for Geotechnology Indonesian Institute of Sciences Jln Cisitu Sangkuriang Bandung 40135 Indonesia, e-mail: rm.delinom@geotek.or.id

ABSTRACT

Many quantities of water resources for life and social needs often depend on groundwater. However, the management of groundwater resources is not enough and many problems related to groundwater resources such as decline of water table and contamination of groundwater have occurred in the world in recent years. Indonesia is no exception.

Proper management of groundwater resources requires knowledge of the recharge and discharge processes to the groundwater basin. This paper describes the process in Jakarta groundwater basin, Indonesia, using a theory of simultaneous transfer of heat and fluid in a porous medium. Temperature-depth profiles in monitoring wells are used to determine gradient geothermal. To examine the rule of hydraulic flow in the distortion of the isotherms in this area, some methods are compared.

As a result, subsurface temperature distribution is strongly affected by heat advection due to groundwater flow. It was shown that subsurface temperature data yielded useful information of the recharge and discharge processes in groundwater basin.

Keywords: Recharge discharge process, subsurface temperature

Quantifying groundwater recharge by using the simplified monthly sequential water balance

[1]Maria do Rosário JESUS

[1]Groundwater Division, Water Resource Department, Instituto da Água (INAG), Av. Almirante Gago Coutinho, nº. 30, 1049-066 Lisboa, Portugal, e-mail: rosario.jesus@inag.pt

ABSTRACT

Recharge is one of the most important parameters for planning groundwater resources. The Water Framework Directive (WFD), in its 4th article, requires the knowledge of the annual recharge rate. The Portuguese Institute for Water (INAG) developed a useful framework by using the simplified monthly sequential water balance to estimate the recharge.

In this model (Fig. 1), we assume that there are two distinct water reservoirs: a sub-surface one, and a deeper one for the groundwater. If the superficial reservoir is full, the excess water will split between surface runoff and percolation to the groundwater reservoir, which in turn will be depleted at a rate **d**; the soil (sub-surface reservoir) is a preferential reservoir; if the water in soil is below the limit of water storage in soil, then the real evapotranspiration is lower than the potential one.

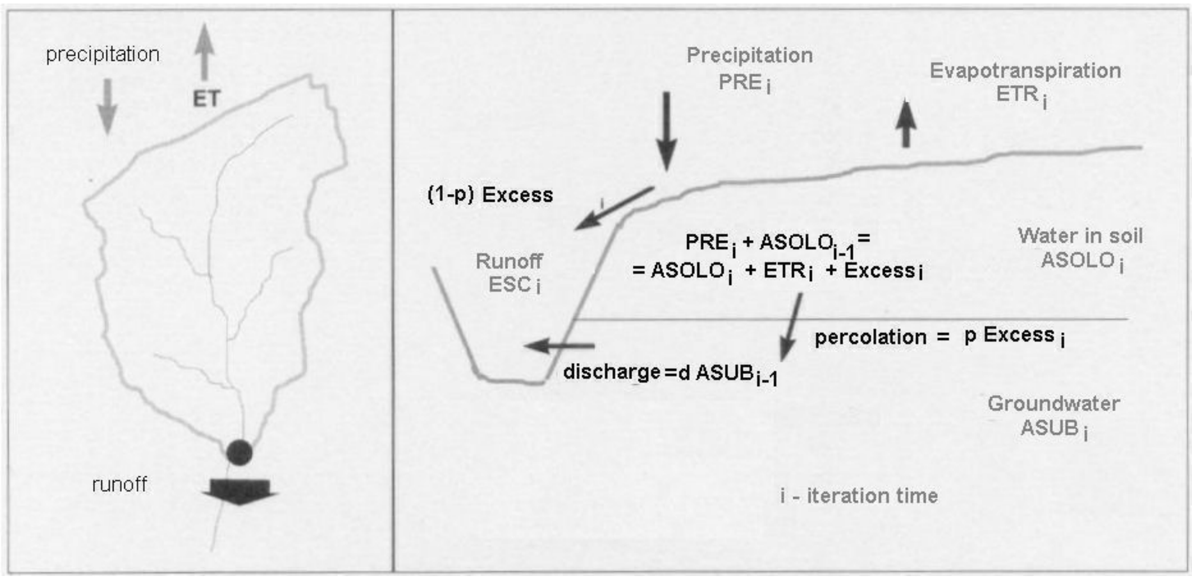

Fig. 1. Water balance in the basin (adapted from Pimenta *et al.* 1998).

The basin is defined, using a GIS framework, for each flow station where the soil is considered to be homogeneous and the runoff occurs in natural conditions. The parameters of the monthly sequential water balance are determined by using the average monthly precipitation and the runoff.

In order to calibrate and validate the model, the runoff coming from the estimates must be cross checked with real flow data, in order to obtain the best fit. The monthly average recharge is estimated by using the parameters of the model: the monthly average precipitation, and the potential monthly average evapotranspiration. The former is obtained from climatic stations, and the latter is calculated by using the Thornthwaite methodology.

The average recharge rates reached with this simple method are compared with values in literature and good approximations were obtained.

Keywords: recharge, runoff, precipitation, evapotranspiration, discharge.

Studies on subsurface thermal environment and groundwater flow around Tokyo Bay

[1]Vuthy MONYRATH, [2]Yasuo SAKURA, [3] Akinobu MIYAKOSHI

[1]Graduate School of Science and Technology, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba-shi 263-0043, Japan, e-mail: monyrath@gmail.com
[2]Faculty of Science, Chiba University Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba-shi 263-0043, Japan, e-mail: ysakura@faculty.chiba-u.jp
[3]National Institute of Advanced Industrial and Technology, Tsukuba, Japan, e-mail: miyakoshi-a@aist.go.jp

ABSTRACT

In Tokyo Bay groundwater basin, subsurface thermal environment formation is an important process that is basically controlled by the groundwater flow and heat transport, and biological activity. In order to understand the characteristics of the distribution of the subsurface temperature and thermal environment around Tokyo Bay, subsurface temperature was measured using observation wells around the bay in a vertical profile. A cross section which cuts across the bay from east to west was made and vertical distribution of subsurface temperature at the depth of minus 50m and 100m on both sides of the bay were made using the borehole temperature data. Preliminary 2D simulations of the groundwater flow and subsurface temperature distribution were also done to confirm the field observation. The results show that the subsurface temperature in the western side of Tokyo area is higher than in the eastern side, Chiba. This fact suggests that groundwater discharges into Tokyo Bay. However, the different distance of recharge areas results in the variability of the topographical driving force. Therefore, the intensity of the recharge is also different. Human activities such as urbanization and groundwater pumping also affect the subsurface temperature and groundwater flow in the study area. The result of the numerical simulation confirms the subsurface temperature variation along Tokyo Bay.

Keywords: Subsurface temperature, Subsurface thermal environment, Tokyo bay, groundwater flow, observation well

Temperature logs: an aid in groundwater studies

[1]Elsa Cristina RAMALHO and [2]António CORREIA

[1] INETI, Apartado 7586, 2721-866 Amadora, Portugal, e-mail: elsa.ramalho@ineti.pt
[2] Department of Physics and Geophysical Centre of the University of Évora, Rua Romão Ramalho 59, 7000-671 Évora, Portugal, e-mail: correia@uevora.pt

ABSTRACT

Temperature logs have been used in geosciences with several goals; one of them is the study and estimation of the terrestrial heat flux. In these studies, boreholes that are in thermal equilibrium are chosen to measure the temperature as a function of depth to calculate the geothermal gradient. This is then multiplied by the thermal conductivity of the geological formations crossed by the borehole to produce an estimate of the heat flow density or terrestrial heat flux. Boreholes in thermal equilibrium are boreholes where there is no heat transfer by convection of water or other fluids driven by an existent thermal gradient or by other forcing means.

It is obvious then that boreholes that are not in thermal equilibrium are of no use for terrestrial heat flux studies. However, water flowing in a borehole produces a heat transfer that may change with time and can be detected as a change in the temperature inside the borehole. A detailed temperature log, or a set of temperature logs obtained at different times, can, therefore, be of great use for detecting patterns of water circulation inside a borehole. As a matter of fact, groundwater flow is a very effective way of heat transfer and in this work we use temperature logs to study the hydrodynamics inside a well, in an aquifer or several aquifers crossed by a well. Groundwater flows through the formations according to geological conditions. Therefore, it can flow in the permeable formations of an aquifer, can flow between two aquifers crossed by a borehole, can flow in a fracture system or fracture systems, can go up or down a borehole depending on the pressures of the aquifers, and so on.

Temperature logging is a simple, cost-effective way of characterizing the geological formations where a borehole has been drilled and can be used as a tool to delineate, or to help delineate the borehole casing and assess its performance in terms of water production. Precise continuous or discrete temperature logs can then provide useful information about the permeable formations where the water flows and about the very water flow as a result of pressure differences in the aquifers inside a borehole.

In this work, examples on the use of temperature logs for water well construction and water well hydrodynamics will be shown and analysed with the objective of demonstrating their usefulness in groundwater studies.

***Keywords*:** Temperature logs, heat transfer, groundwater flow, hydrodynamics.

The Effect of Vegetation (Prosopis Sp.) on Groundwater levels in Rugseer River, Kenhardt, South Africa

[1]Fanus FOURIE, [2]Khumbalani MBATHA, [3]Heyns VERSTER, [4]Gawie Van DYK

[1]Department of Water Affairs and Forestry, Private Bag X313, Pretoria, 0001, South Africa,
e-mail: fouries@dwaf.gov.za
[2] Department of Water Affairs and Forestry, Private Bag X2015, Dundee, 3000, South Africa,
e-mail: mbathak@dwaf.gov.za
[3] Department of Water Affairs and Forestry, Private Bag X5912, Upington, 8800, South Africa,
e-mail: versteh@dwaf.gov.za
[4]Department of Water Affairs and Forestry, Private Bag X6101, Kimberley, 8300, South Africa,
e-mail: vandykg@dwaf.gov.za

ABSTRACT

The objective of the study was to qualify if invading Sp Prosopis is utilizing groundwater and if, to quantify the volume utilized. To reach this objective the Rugseer River, Kenhardt was identified and the groundwater levels, rainfall and groundwater quality were monitored to investigate the effect of clearing of the Prosopis sp. on the groundwater levels and to quantify the volume. This report consists of the evaluation of data before and after the Prosopis was cleared.

Prosopis trees increase the natural canopy cover of the study area from 7 percent to 28 percent. Prosopis trees constituted about 96 percent of the trees in the study area.

The water quality indicates that fresher water occurs on the eastern side of the Rugseer River. The current main surface drainage is also on the eastern side. It can then be postulated that the current surface drainage is reflected by the groundwater quality.

The continuous water levels data was used in tracing the water levels trends. From the water levels declines measured during summer (October to March) it was deduced that evapotranspiration is taking place at a rate. Declines of between 0.97m and 1.57m were measured and the trend was visible at all stations. Water levels rise immediately after surface runoff and quickly after non-surface runoff rainfall events. Water from the bedrock lets the water level rise in the winter months when no rainfall occurs. There are 4 superimposed water level trend cycles.

Clearing of 49ha of the 98ha of the study area started in July 2002. The effect of the Prosopis Sp. having been cleared from the study area was measured for the next 3 and half years, until Feb 2006. The water levels followed the declining trend in the summer months but the decline was between 30% and 60% less.

Keywords: groundwater, water level, rainfall, Prosopis, vegetation-groundwater interaction

Thermal Use of Groundwater and Source Water Protection

[1]Grant FERGUSON and [2]Allan D. WOODBURY

[1]Department of Earth Sciences, St. Francis Xavier University, Antigonish, NS, CANADA,
e-mail: gferguso@stfx.ca
[2]Department of Civil Engineering, University of Manitoba, Winnipeg, MB, CANADA,
e-mail: woodbur@cc.umanitoba.ca

ABSTRACT

The use of groundwater for thermal applications is currently growing due to increased concern for the environment and rising fuel costs. In many cases, such applications inject water back into the source aquifer to maintain hydraulic head. The injection of water at a different temperature has implications to the operation of the individual system and also to a larger area of the aquifer. Changes in temperature may cause chemical reactions or promote microbiological activity but perhaps of larger concern is the effect on the hydraulic head field. In many jurisdictions, permitting non-consumptive groundwater use has not been scrutinized to the same degree as consumptive use because there is little, if any, effect on the water budget of the aquifer. However, significant changes in groundwater flow can result even when net withdrawals are zero. This is issue is particularly challenging in areas where significant interaction between groundwater and surface water. In this study, we examine the implications of non-consumptive use of groundwater for thermal applications on capture zones for source water protection studies through a series of numerical simulations.

Keywords: non-consumptive use, heat flow, geothermal energy, capture zone analysis, groundwater-surface water interaction

Transboundary Aquifers in Argentina (South America), cooperation for protection and governability.

[1,2] Ofelia C TUJCHNEIDER, [1] Marta del C PARIS, [1] Marcela A PEREZ & [1] Mónica P D´ELIA

[1] Facultad de Ingeniería y Ciencias Hídricas - Universidad Nacional del Litoral. Ciudad Universitaria CC 217 (3000) Santa Fe, Argentina. e-mail: pichy@fich.unl.edu.ar

[2] Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina.

ABSTRACT

South America is a very large continent with a great amount of water resources. However, these resources have an irregular distribution and the continent also shows arid regions in need of water for development.

This territory has very important superficial basins, most of them shared by several countries. South America also has very big transboundary aquifers. Historically, it has been the norm that more intense interest and efforts were dedicated to studying and understanding the superficial basins, and therefore, less efforts were dedicated to groundwater. Unfortunately, both kinds of resources have been affected by pollution or intensive exploitation. Therefore, its contamination and quantity diminution represents a major risk and requires future protection.

In the particular case of Argentina, in the early 80's some research defined the possibility this occurring in the Guarani Aquifer System, shared by Brazil, Uruguay, Paraguay and Argentina, and at the moment further investigations are being carried out by international organizations in cooperation with this country's government.

Between 2002 and 2006, as a result of the UNESCO Programme ISARM Americas, six other transboundary aquifers were preliminary defined and research efforts continue. Most of them were defined by the experts of the countries involved, while others have to be studied in order to better define its geometry and boundaries.

Even though there is experience on treaties and other legal tools developed by the riparian countries for superficial waters, to date this aspect has not yet been well developed for groundwater.

The great challenge for all the South American countries is the selection of appropriate models of institutional organization for the management and protection of transboundary water.

Independent of the diversity of the possible institutional models, they must take into account the real richness in water resources of the whole territory and the effective need for understanding and cooperation between each country.

This involves a great responsibility as well as a big opportunity for the future: on the basis of local hydrological knowledge developing adequate legal instruments for managing and protecting transboundary groundwater resources, to avoid conflicts and reduce poverty.

In this contribution, the principal aspects of these transboundary aquifers are exposed, and their importance for water supply, for human use and for the sustainability of the groundwater dependent ecosystems.

Keywords: transboundary aquifers, management and protection, cooperation

TOPIC 04

Impact of groundwater contamination on ecological systems and processes

Arsenic in groundwater from W-Sn abandoned mine sites in NE Portugal

[1]M. Rosário PEREIRA, [2]Hugo NOVAIS, [3]Adelaide FERREIRA, [4]Paula F. ÁVILA

[1]Dep. Geologia UTAD, Ap.1013, 5001-801 VILA REAL, Portugal, e-mail: rpereira@utad.pt
[2]E. Sec. Lousada, 4620-655 Lousada, Portugal, e-mail: hnovais@gmail.com
[3]INETI, R. da Amieira, Ap.1089, 4466-956 S. Mamede de Infesta, Portugal, e-mail: adelaide.ferreira@ineti.pt
[4]INETI, R. da Amieira, Ap.1089, 4466-956 S. Mamede de Infesta, Portugal, e-mail: paula.avila@ineti.pt

ABSTRACT

Arsenic occurs in bedrock mainly associated with sulphide minerals and through weathering it is released and accumulates in soils, sediments, surface and groundwaters, depending on geochemical conditions.
The aqueous chemistry of arsenic differs significantly from most true metals. Arsenic is soluble across a wide pH range and that means that contamination of waters by arsenic is not a hazard exclusively associated with the generation of acid mine drainage. Several aspects of water composition promote high solubility of arsenic in surface and ground waters that include reducing conditions and high concentrations of phosphate, carbonate/bicarbonate, dissolved organic carbon and high pH (Smedley and Kinniburgh, 2002; Nordstrom, 2000; Nordstrom, 2002).

Portugal has a long tradition in mining and that activity has left a millennial legacy of abandoned mines with tailing piles and waste rock. Some studies are being developed in order to characterize arsenic pathway in areas where, from a geological point of view, release of trace metals and arsenic species to the environment could happen from enriched sulphide minerals associated with Au and with Sn-W mineralization and where the use of contaminated land and water could represent a threat to human health. Inorganic arsenic in both of the oxidation states III and V are recognized human carcinogens causing urinary bladder, lung and skin cancers (IARC,1987).

Groundwater hydrogeochemistry at W-Sn abandoned mine sites neighbourhoods, in Portugal NE, point to the presence of low mineralised groundwater (median E.C. $\approx$ 130 µS/cm) with acid to neutral pH ($4.7 < pH < 7.1$) and low metal content (Zn+Cu+Cd+Ni+Co+Pb < 1 mg/L). Arsenic concentration in groundwater was found to be above the water drinking limit (10 µg/L) in 7 of the 22 samples. Oxidation of the primary As-bearing minerals, such as arsenopyrite and pyrite, derived from interaction between water and Sn mineralised quartz veins, associated with shear zones, are responsible for high As concentration (As 159 µg/L) in groundwater with low Fe and pH around 5. Reductive dissolution of Fe- and Mn-oxihydroxides and desorption of bounded As, associated with soils rich in organic matter, is responsible for high concentration of Fe, Mn and As (As 390 ppb) in groundwater associated with W-Sn mineralised veins. Nitrate reduction by organic matter can explain the increase of dissolved bicarbonate and of pH in reductive environment associated with Tuela river alluvial soils.

Keywords: Abandoned mines, arsenic contamination, groundwater

Development of a *Myxobolus cerebralis* free groundwater source in a hydrogeologically complex environment

[1]Alan L MAYO, [1]Stephen T NELSON, [1]Camille DURRANT, [1]David TINGEY

[1]Department of Geological Sciences, Brigham Young University, S235 ESC, Provo, Utah, USA, e-mail, alan_mayo@byu.edu

ABSTRACT

During the past fifty years *Myxobolus cerebralis*, a parasite that causes whirling disease in salmonid fish, has spread to hundreds of streams in the northeastern and western United States. The disease results in deformities and premature death. Because waters infected with whirling disease are permanently contaminated, the spread of *M. cerebralis* is a serious threat to all watersheds and fish hatcheries. There is now evidence that the parasite can contaminate shallow groundwater systems.

In 2000, the Utah State fish hatchery at Midway, Utah, which relied on shallow groundwater, was closed due to *M. cerebralis* contamination. Utah sport fishing is a $500 million industry, thus, the spread of whirling disease in Utah is a great concern. Prior to closing, the hatchery supplied over 20% of Utah's rainbow trout, the predominant game fish in the state. Hatchery water was supplied from several unconfined aquifer springs. Head spring supplied about 50 % of the hatchery water and the remainder of the water discharged into fish raceways by diffuse spring discharges.

To reopen the hatchery, a non-contaminated groundwater source had to be found. Confined aquifer groundwater beneath the hatchery was identified as a possible source. However, the complex hydrostratigraphy near the facility and the potential for subsurface mixing of thermal and contaminated near surface waters present many challenges. It was also important to ensure that pumping confined aquifer water would not induce downward vertical movement of contaminated unconfined aquifer water into deeper confined aquifer water. Therefore, to develop a sustainable *M. cerebralis* free water supply for the hatchery a groundwater investigation was first undertaken.

At the hatchery shallow and deep alluvial groundwater systems discharge at the same location, the solute content and groundwater age unexpectedly decrease with depth. The down gradient end of a 14 km^2 tufa platform, located at the hatchery, has long been recognized as the discharge focus of a shallow alluvial groundwater system. Previous studies identified up gradient upwelling of thermal water as a significant contributor to the shallow system. Three alluvial aquifer systems have been identified at the hatchery: a shallow unconfined aquifer, a intermediate semi-confined aquifer, and a deep confined aquifer. The aquifers are separated by tufa layers.

In this investigation we have used multiple tools - solute, isotopic, physical, geophysical methods to evaluate flow paths and groundwater recharge histories which contribute to the inverted chemical and age relationships. Up gradient in the tufa mound the unconfined aquifer is recharged by upwelling thermal water (>6,000 ^{14}C years), which is diluted along the flow path by downward moving modern recharge in the tufa platform. Upper and lower confined alluvial systems, which flow beneath the tufa platform, are recharged up gradient with both old, but not thermal, (> 2,000 ^{14}C years) and modern stream waters. At the base of the tufa platform much of the unconfined aquifer water discharges, but down gradient of tufa platform appreciable confined aquifer waters mix with the unconfined aquifer. Thus at the down gradient end of the tufa platform most of the discharge is from the unconfined aquifer and down gradient of the platform most of the unconfined aquifer discharge is from the underlying confined systems (Fig. 1).

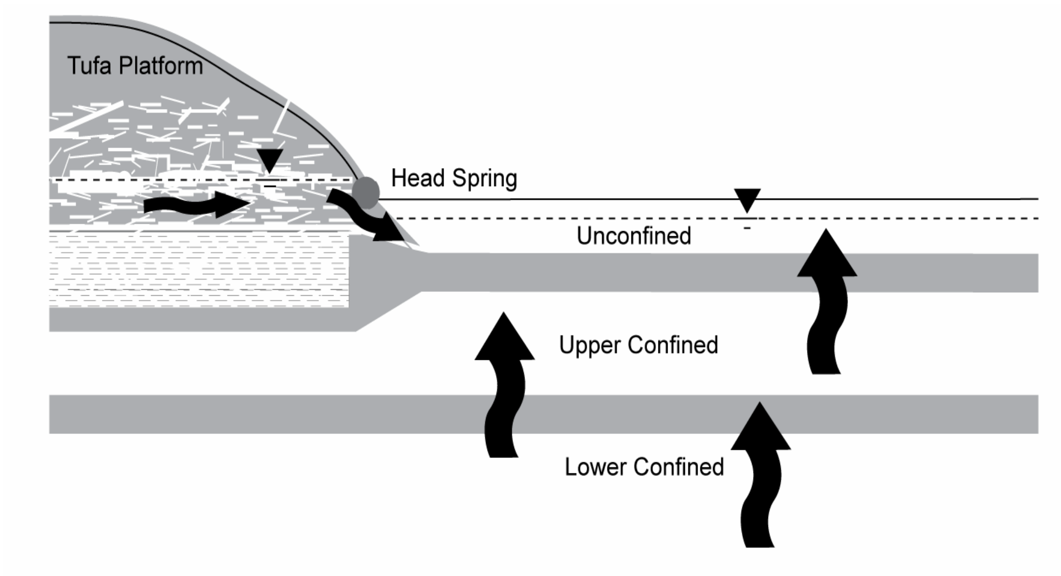

Fig. 1. Conceptual model of the unconfined aquifer illustrates the water table is north of the fractured tufa of the upland tufa platform.

Once the lower confined aquifer system (≈ 60 m below ground surface) was identified as a potential *M. cerebralis* free aquifer, a series of pump test were performed to evaluate the aquifer potential and pumping rates which would prevent downward migration of *M. cerebralis* contaminated unconfined aquifer water from mixing with the upper and lower confined aquifer water. At the conclusion of the aquifer testing, aquifer production rates were determined and test fish raised in lower confined aquifer water were free of *M. cerebralis*. Based on these results a new hatchery design has been completed and full fish production is anticipated in 2009.

Keywords: Hydrogeology, *Myxobolus cerebralis***,** contamination, groundwater mixing, isotopes

Distribution and source identification of heavy metals in soils and groundwater in the Loures region (N-Lisbon, Portugal)

[1]Catarina SILVA, [2]M. Rosário CARVALHO

[1]Universidade de Lisboa, Faculdade Ciências, Centro de Geologia, Ed. C6, 3ºP, Campo Grande, 1749-016 Lisboa, Portugal, csilva@fc.ul.pt
[2]Universidade de Lisboa, Faculdade Ciências, Ed. C6, 3ºP, Campo Grande, 1749-016 Lisboa, Portugal, mdrcarvalho@fc.ul.pt

ABSTRACT

Agricultural soil has both a direct and indirect influence on public health via food production. It is therefore of great importance to protect this resource and ensure its sustainability. The Loures region is located N of Lisbon and, despite the rapid development of urbanization, remains one of the most important areas for vegetable production for the Lisbon market. The increasing industry and the use of agrochemicals has become a serious problem for agricultural soil and groundwater contamination.

The Loures alluvial plain is formed by deposits associated with the catchment's area of the Trancão River. These alluviums are mainly formed by fine sediments originated in the surrounding "Complexo de Benfica" and "Complexo Vulcânico de Lisboa" formations. The "Complexo de Benfica" is a continental sedimentary formation composed mainly of conglomerates, sandstones, siltstones, and mudstones. The "Complexo Vulcânico de Lisboa" is a volcanic complex characterized by very weathered basaltic flows and pyroclastic deposits. The alluviums form a continuous unconfined aquifer that is hydraulically connected with the surface waters. Seasonally the Trancão River is invaded by the estuarine brackish water of Tejo River. The aquifer is exploited for irrigation by several dug wells.

The present study examines the distribution and the source of heavy metals (Co, Cr, Cu, Ni, Pb, and Zn) concentration in topsoils, subsoils and groundwater of the Loures region. Physical-chemical analyses (soil pH, organic matter content (OM), and cationic exchange capacity (CEC)) were performed in 58 samples of topsoil and subsoil (approximately at 40 cm depth) of the alluvial plain. The clay component of the soil associated to basaltic rocks and the basaltic rocks from the "Complexo Vulcânico de Lisboa" have been also analyzed. In order to address the main factors that control retention/mobility of the heavy metals in soils by the groundwater 36 shallow wells were sampled. Major elements and vestigial metals have been determined in water samples.

In the topsoils: *i*) OM content range between 0.5-8 %; *ii*) values of pH fall in a narrow range, 7-8.3, indicating subalkaline conditions; *iii*) the CEC varies between 8.3-29 meq/100g. In the subsoils : *i*) OM content range between 0.2 and 5.7 %; *ii*) the soil pH varies from 6.6 to 8.1; *iii*) the CEC varies between 6-28 meq/100g. Zn is the only element whose content has the same distribution function in the soils and in the basalt samples. It can be originated in the weathering of parent material and subsequent pedogenesis. The Co, Cr, Cu and Ni have lower content in the soils, compared to the basaltic samples, as the result of rock leaching during the process of soil formation. The topsoils show concentrations of heavy metals slightly higher than that of subsoils.

The waters from the alluvial aquifer are characterised by a pH that ranges between 6.8 and 8.7, and by a very large range of conductivity, from 660 to 4640 μS/cm. The water chemical *facies* varies from the bicarbonate type to Na-chlorate in the more saline waters. Considering natural groundwater, the Cr and Cu show anomalous concentration values for almost all samples. Few water samples have high concentration values for Co, Ni, Pb and Zn.

A multivariate statistical analysis was used to identify geochemical associations within the topsoils, subsoils, and water samples. In the soils Ni, Co, and Cr have the same behaviour and are in close association with the amount of smectites in the soil. The spatial distributions of these elements show the same association (Fig. 1(a), (b), (c)), and higher concentrations in the western area, which is an urban and industrialized area. Statistically, Zn and Cu show great affinity with the OM content and have the same spatial distribution (Fig. 1 (e), (f)), in most of the samples of agricultural land. This suggests that the agricultural soil has been exposed to high input of anthropogenic metals, most likely related to the application of agrochemicals. In the topsoils Pb concentrations have no relation to any other heavy metal or soil parameter, but in the subsoils samples Pb is associated with the OM content. Pb values are higher in soils close to main roads, in the southern part of the area and in a small place in the north (Fig. 1 (d)).

The partitioning between rock or soil and solution depends on the chemical behaviour of the elements and on the redox conditions that affect the mobility of redox-sensitive elements. The multivariate statistical analysis of water samples allow to distinguish two main groups: 1) bicarbonate waters rich in Cu, Zn, Pb, Ni and Co; 2) slightly basic chlorate waters enriched in Cr. The heavy metals present in the first waters' group have

high mobility because they are strongly complexed by carbonate or bicarbonate, as a result of the high total carbonate species in groundwater. The Cr is a mobile element in basic solutions, where it forms soluble complexes as $CrOH_4^{2+}$.

The spatial distribution of the heavy metals in groundwater and soils (Fig. 1) show that Cr is the only element that present an inverse relation between the dissolved concentration in the groundwater and the remaining Cr in the topsoil. This can be explained by the Cr affinity to insoluble oxides and hydroxides that limit its mobility.

Although the heavy metal concentrations measured in this study are not excessively high they can affect the quality of agricultural products.

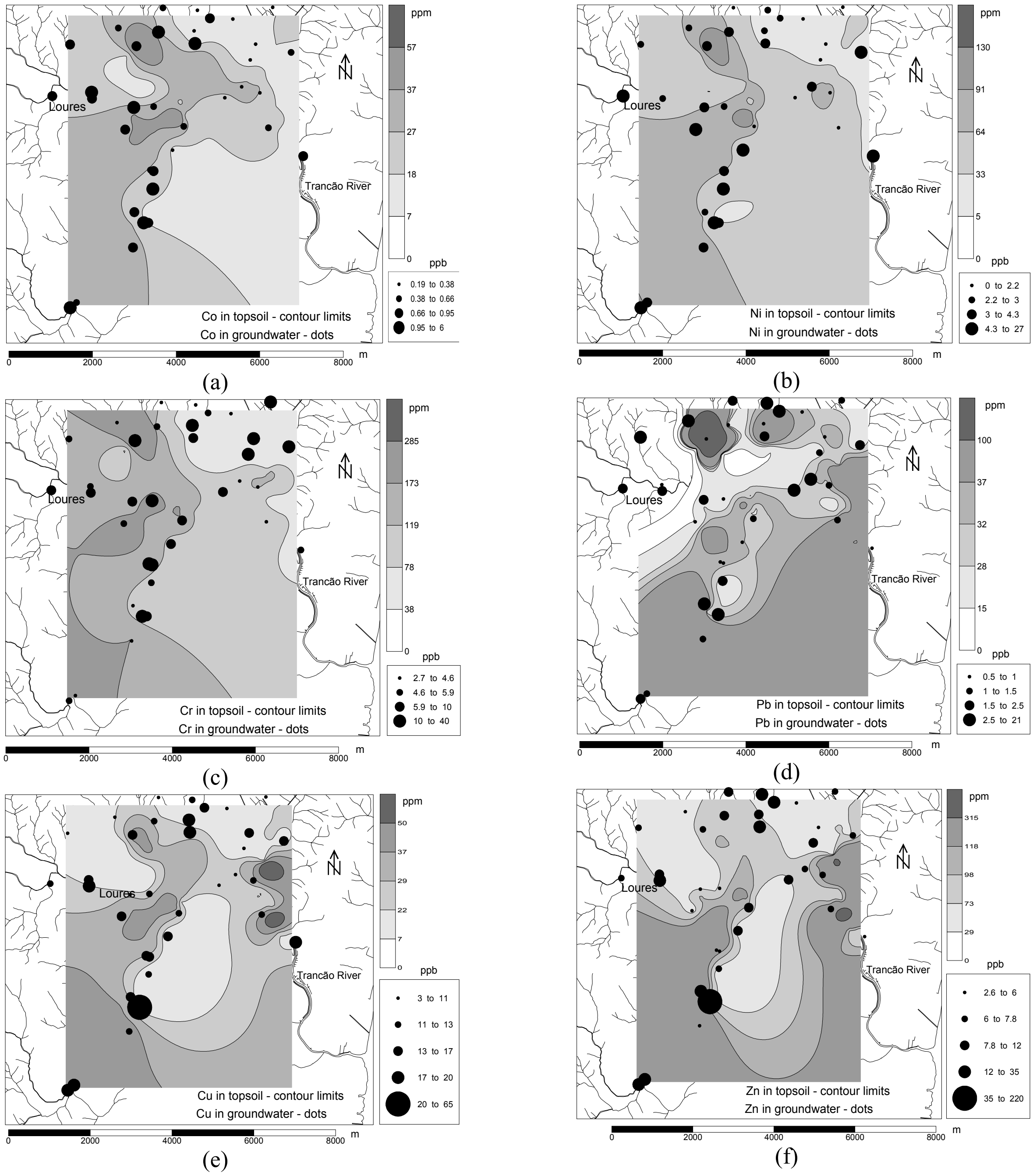

Fig. 1 - Spatial distribution of the analysed heavy metal in topsoils (contour limits) and groundwaters (dots) for: (a) Co; (b) Ni; (c) Cr; (d) Pb; (e) Cu; (f) Zn.

Keywords: Heavy metals, soil, groundwater, source, Loures.

Environmental characterisation of a nuclear site

[1]Massimo Vincenzo CIVITA, [1]Marina DE MAIO, Adriano [1]FIORUCCI

[1]Chair of Applied Geology – Turin Polytechnic – Head of Research Line 4 "Evaluation of aquifer vulnerability" – GNDCI – CNR (*National Group for Defence against Hydrogeologic Catastrophes - National Research Council)*
[2] Associate Professor in Applied Geology – DITAG - Turin Polytechnic
[3] Research Fellow in Applied Geology – DITAG - Turin Polytechnic

ABSTRACT

This study, carried out in collaboration with SOGIN (Nuclear Treatment Plant Management Company), is an integral part of environmental characterisation activity in the area where the EUREX treatment plant is situated, near Saluggia. With the aim of depicting the base conditions for the environment, which will then be used to develop decommissioning activities for the plant itself, a series of criteria were defined to enable identification of the status of reference for the environment, i.e. geologic, hydrogeologic and chemical structure, intrinsic and integrated vulnerability, land use.

The site in question is situated over an unconfined aquifer with matrix permeability in sediments of alluvial origin in the plain on the left bank of the Dora Baltea river. The whole area is strongly affected by human input, with industrial activity, extensive areas dedicated to agricultural use, quarries and numerous modestly sized centres of population. In addition, it was seriously affected by the floods of November 1994.

Keywords: environmental characterisation, intrinsic vulnerability, integrated vulnerability, hazard points

Groundwater – surface water interactions in the Pateira de Fermentelos region (Portugal) – implications on water quality

[1]Clara SENA & [1,2]M.T. CONDESSO DE MELO

[1] *ELMAS*, Departamento de Geociências da Universidade de Aveiro, Aveiro, Portugal;
[2[Instituto Superior Técnico, Lisboa, Portugal

ABSTRACT

Pateira de Fermentelos is a natural lagoon in the Cértima river mouth which supports important aquatic ecosystems. This lagoon is related to a topographically low area of the Cértima river watershed and is surrounded by outcropping Meso-Cenozoic formations, which support important phreatic to semi-confined aquifers.

The phreatic and the semi-confined aquifers present in the vicinity of the Pateira de Fermentelos lagoon can be divided into two main types regarding the aquifer matrix: quartz and feldspar rich cretaceous to quaternary sandstones and iron oxyhydroxide rich triasic sandstones. Jurassic carbonate rocks crop out few kilometres upstream the lagoon, in the Cértima river watershed, and are intersected by boreholes, at approximately 100 m depth, in the studied area.

The cretaceous sandstones that crop out around Pateira de Fermentelos lagoon are part of the Aveiro Cretaceous Groundwater Body (ACGWB) recharge area. The ACGWB represents a strategic water resource for the Aveiro region, which is characterized by high industrial, agricultural and urban water demand.

The distinct aquifer formations present in the Pateira de Fermentelos region show distinct water compositions, mainly due to water-rock interaction processes, which also influence the water hydrochemistry of the lagoon. Nevertheless, the urban, industrial and agricultural activities developed over the aquifer formations and along the Cértima river watershed are capable of modifying the natural hydrochemical pattern of both surface and groundwaters.

The main human activities developed in the Cértima river watershed that may contribute to the degradation of the surface and groundwater quality of the Pateira de Fermentelos region are: (1) agriculture; (2) metallurgic and ceramic industries; and, (3) domestic and livestock sewage. These human activities represent a major pressure to the water quality preservation of Pateira de Fermentelos lagoon and associated wetlands, and also to the infiltrating water that contributes to the recharge of the ACGWB.

With the objective of studying surface-groundwater interactions around the Pateira de Fermentelos lagoon, it was decided to monitor the water table and surface water levels monthly, as well as surface and groundwater quality, during the hydrologic year of 2005/06. The monitoring of water levels permitted the generation of monthly piezometric maps and to compare surface and groundwater bodies' levels, while the water quality monitoring permitted the study of monthly evolution of temperature, pH, redox potential (Eh), dissolved oxygen (DO), electrical conductivity (EC) and the chloride, sulphate, bicarbonate, nitrate, nitrite and ammonium content of surface and groundwater bodies.

The analysis of the water levels monitored monthly both in the lagoon and in the groundwater bodies, led to the conclusion that the Pateira de Fermentelos and its hydrographical network drain the phreatic aquifers along most of the year, generating water table depressions adjacent to the main surface water bodies. Inversion of the flux transfer may occur only in lowland areas adjacent to the lagoon during rainy periods. Nevertheless, this surface water loss to the surrounding lowland marginal phreatic aquifers may be transferred back to the lagoon after some days, due to the high hydraulic potential between the elevated areas of the phreatic aquifers and the lowland areas that surround the lagoon. The semi-confined aquifers which show some degree of isolation between shallow and deeper parts seem to be hydraulically connected to the shallow phreatic aquifers in a heterogeneous way, while connection with the surface water bodies is unknown.

The results obtained in the present study permits the statement that Pateira de Fermentelos water composition reflects its major contributor – the Cértima river, and to a lesser extent, the contributions of the drained phreatic aquifers and of the Pano and other surrounding streams. The biogeochemical processes prevailing in the lagoon and adjacent wetlands affect elements speciation, which contributes to mitigate pollution impacts on the surface water bodies.

There seem to be three main types of natural waters flowing to the Pateira de Fermentelos lagoon: (1) the Cértima river with a Ca-HCO_3 water facies, EC around 550 µS/cm and circum neutral pH, mainly due to jurassic carbonate rocks and iron oxyhydroxide rich triasic sandstones that crop out in the terminal area of the Cértima river watershed; (2) the cretaceous phreatic aquifer with a Na-Cl water facies, a relatively low EC around

115 µS/cm and frankly acid water (average pH of 5), reflect the low chemical kinetics of the dominant siliciclastic aquifer matrix; and, (3) the triasic phreatic aquifer with a Ca-Na-HCO_3 to Ca-Mg-SO_4 water facies, a relatively high EC of about 650 µS/cm and neutral to slightly alkaline waters, reflect the sulphates and iron oxyhydroxides that are present in the aquifer matrix. Semi-confined aquifers that include jurassic carbonate rocks may present high EC (reaching 4070 µS/cm in one sampled borehole) and high sulphate, calcium and sodium content, possibly due to sulphate minerals like gypsum.

During the 2005/06 studied year, the aquifers showed distinct nitrate contents depending on the sample point and on the time of the year, while the lagoon and Cértima river nitrate content seem to depend mainly on the season of the year. The phreatic cretaceous to quaternary aquifer show, in urban to agricultural areas, nitrate content varying between 78 and 133 mg/L (observed in January and September 2006, respectively), and in forested areas between 2 and 13 mg/L (observed in October 2006 and November 2005, respectively). The semi-confined aquifer shows the less variable nitrate content, between 6 and 8 mg/L (observed in February and September 2006, respectively). The surface water bodies show a variation of nitrate content between less than 1 mg/L (between May and August of 2006) and 209 mg/L (reached in November 2005).

High nitrate concentrations observed in the phreatic to semi-confined aquifers seem to be related to agriculture and sewage losses, occurring in higher concentrations at the end of the summer, while high nitrate concentrations observed in the surface water bodies seem to be related with the mobilization of retained contaminants in the soils and aquifers, immediately after the first rains at the beginning of the rainy season, before the dilution effect of rain water starts to act. During almost the whole studied year (between March and October 2006) , the lagoon and Cértima river show a nitrate concentration inferior to 10 mg/L, while the marginal drained phreatic aquifers, underlying agriculture areas, show nitrate concentration above 70 mg/L along the studied year. This accentuated nitrate content difference between the two water bodies seems to reveal an important attenuating capacity of the wetlands related with Pateira de Fermentelos lagoon and the Cértima river.

The naturally high concentrations of carbonates, sulphates, iron oxyhydroxides found in the Pateira de Fermentelos lagoon and Cértima river, conjugated with high amounts of clay minerals and organic matter content, and an important aquatic ecosystem including species known for their nutrient absorbing and metal retain capacity, like water hyacinth (*Eichhornia crassipes*), common reed (*Phragmites australis*) and water milfoil (*Myriophyllum sp.*), induce biogeochemical processes that contribute for an important contaminant attenuation capacity of the Pateira de Fermentelos wetlands, preventing its eutrophization and favouring the ecosystem's sustainability.

The phreatic aquifers are more vulnerable to contamination by the distinct human activities developed in the studied region, mainly due to the lack of attenuating biogeochemical processes like the ones that occur in Pateira de Fermentelos wetlands. The semi-confined aquifer seems to be protected from contamination impacts due to the relatively slow hydraulic connection with the overlying phreatic aquifer.

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Keywords: Pateira de Fermentelos; groundwater bodies; Aveiro Cretaceous Groundwater Body (ACGWB); human pressure; biogeochemical processes.

Hydrodynamic conditions of ground and surface water as a principal parameter to the solid wastes disposal sites selection. The case of Polidentri village in Attica, Greece.

[1]Ioannis KOUMANTAKIS, [2]Dimitris ROZOS, [3]Kostas MARKANTONIS, [4]Paraskevas TSAGARATOS, [5]Helen VASILEIOU, [6]Helen GRIGORAKOU

[1] School of Mining and Metallurgical Engineering, National Technical University of Athens, 9 Heroon Polytechniou str, 15780 Athens, Greece, e-mail: markantonis@metal.ntua.gr
[2] School of Mining and Metallurgical Engineering, National Technical University of Athens, 9 Heroon Polytechniou str, 15780 Athens, Greece, e-mail: rozos@metal.ntua.gr
[3] School of Mining and Metallurgical Engineering, National Technical University of Athens, 9 Heroon Polytechniou str, 15780 Athens, Greece, e-mail: markantonis@metal.ntua.gr
[4] School of Mining and Metallurgical Engineering, National Technical University of Athens, 9 Heroon Polytechniou str, 15780 Athens, Greece, e-mail: ptsag@metal.ntua.gr
[5] School of Mining and Metallurgical Engineering, National Technical University of Athens, 9 Heroon Polytechniou str, 15780 Athens, Greece, e-mail: elvas@metal.ntua.gr
[6] School of Mining and Metallurgical Engineering, National Technical University of Athens, 9 Heroon Polytechniou str, 15780 Athens, Greece

ABSTRACT

Parameters that are related to surface and undergroundwater resources should be considered among the most significant ones, to be examined as critical factors for the exclusion or the acceptance of a site, under certain conditions, as a place for land disposal and management of domestic and industrial solid wastes.
Beyond the value of water as a physical source that is of vital importance for life and development, the environmental value of water ecosystems and the necessity of their conservation, should not be disregarded.

In addition, regarding the suitability of sites for disposal and management of solid wastes, the particular importance of surface and groundwater, either in the concept of the transportation contaminants or in soil and rocky formations susceptibility to failure manifesting as creepings, landslides, subsidences, settlements, etc is obvious.

Based on the above, the water parameters were thoroughly and systematically examined for the influence of factors, like the distance from water supply sites (like wells springs, lakes etc), active faults, seismicity, distance from urban areas, etc. The selection of the proper sites for the complete management of domestic wastes from Eastern suburbs of Athens was studied and certain conclusions reached. This study was submitted to the community authorities of Polidentri village in NW Attica, a site at which was pre-selected for the establishment of a complete solid wastes disposal system.

The data with regard to surface and groundwater revealed that the final selection of the site in question would cause serious reductions in quality to the groundwater of a karstic aquifer but also to the waters of Marathon artificial reservoir, which are required to cover water supply necessities of Athens agglomeration.

Keywords: water ecosystems, contamination, land disposal and management of solid waste, karstic aquifer, artificial reservoir.

Investigating the Feasibility of Implementing Heating Rods in Fe^0-PRBs to Enhance their Performance: A modeling approach

[1]Farshid FATEMI, [2]Omid KHAJEH-MAHABADI, [3]Lei LIU

[1]Department of Civil and Resource Engineering, Dalhousie University, Halifax, NS B3J 1Z1, Canada, e-mail: Farshid.Fatemi@dal.ca

[2]GuD Geotechnik und Dynamik Consult GmbH, Dudenstrasse 78, D-10965, Berlin, Germany
e-mail: Omid@bauinf.tu-cottbus.de

[3] Department of Civil and Resource Engineering, Dalhousie University, Halifax, NS B3J 1Z1, Canada,
e-mail: Lei.Liu@dal.ca

ABSTRACT

This presentation presents a study performed to evaluate the feasibility of implementing a series of heating rods within a zero-valent iron permeable reactive barrier (ZVI-PRB) to improve the barrier's removal efficiency, enhance the conventional design of PRBs, and reduce construction and reactive material costs. A numerical modeling approach is undertaken where a hypothetical case is introduced and typical site values are assigned to it. The amount of electrical energy required to heat the barrier from an initial temperature, T_1, to a final temperature, T_2 is assessed. Through different simulation cases, the effect of (1) initial temperature of the groundwater entering the PRB, (2) different amounts of total heat injected, (3) distribution of the heating rods, and (4) different types of porous media, on the temperature increase within the PRB are evaluated. Results show that the amount of energy required to increase the temperature of our hypothetical case by $10\,°C$ is approximately 935 *W*, which could be provided by renewable energies such as solar. It is explained that there are multiple benefits for increasing the temperature within the PRB. Apart from boosting reaction rates, temperature increase can reduce water viscosity and increase flow within the barrier, which broadens a barrier's catch area. It can enhance solubility of gases to reduce blockage caused by gas generation. An upward flow is formed inside the wall which can also help reduce gas blockage. By implementing heating rods, design widths are reduced, which could potentially reduce the materials (thus cost) used and/or justify the use of more expensive reactive material in PRBs. Heating the PRB was found to generate a heat plume of 20 *m* length downstream of the PRB after one year, which would increase biodegradation of the residual contaminants leaving the PRB within this zone.

Overall, it is concluded that heating rods may be used in the initial design of the ZVI-PRB, to reduce the dimensions, and hence the initial costs, of the PRB. They may also be implemented in an existing field ZVI-PRB, where the removal rates aren't as expected, to improve efficiency of removal. In either case, they are found to be beneficial in many ways. It is indicated that any approach which can make existing remediation methods more efficient and less costly is of significance from the standpoint of the overwhelming costs of groundwater remediation practices.

Keywords: Groundwater contamination, remediation, permeable reactive barriers, modelling, heating rods.

Natural contamination in groundwater and its impact on environment: a case study in Eskisehir and Kutahya Regions, Turkey

[1]Galip YUCE, [2]Mesut SAYIN, [1]Didem UGURLUOGLU, [1]Mert DONMEZ, [3]Turgay ESER, [2]Alime T. DILAVER, [2]Funda AYDIN, [3]Sakir OZCELIK

[1] Eskisehir Osmangazi University, Department of Geological Engineering, Meselik, Eskisehir,Turkey, gyuce@ogu.edu.tr; dugurlu@ogu.edu.tr; mertos26@hotmail.com.
[2] General Directorate of State Hydraulic Works, Department of Quality Control and Technical Research (TAKK), Esenboga, Ankara, Turkey mesutsayin@ttnet.net.tr; alimetd@yahoo.com; fundaarmagan@yahoo.com.
[3] 3rd Regional Directorate of State Hydraulic Works, Division of Geotechnical Survey and Groundwater Research, Eskisehir, Turkey. turgayeser@mynet.com; dsi3@dsi.gov.tr

ABSTRACT

The aim of this study is to investigate the natural contamination of groundwater resources in the Eskisehir and Kutahya regions and to understand the impacts of contamination on the environment. The study region covers residential areas where domestic and potable water demands are mainly provided from groundwater. The area includes settlements of Kutahya-Gunyuzu-Sivrihisar-Mihaliccik-Bozuyuk with a total of 20,000 km^2, where igneous, metamorphic, and sedimentary rocks are exposed.

Major ions, heavy metals, environmental isotopes, gross-alpha, and gross-beta analyses of 208 water samples (including thermal water samples from 10 locations) collected from 84 locations were performed during wet and dry seasons. The trace element concentrations in the 49 fresh water samples taken from 74 locations are over the limits of Code TS 266, 1997 (Turkish Drinking Water Standards) and WHO, 1993 standards. Particularly, Fe, Mn, Al, As, Ba, Zn, Cr, Cu and B ion concentrations exceed the limits. The gross alpha values in 18 locations and gross beta in 3 locations also exceed the limits of aforementioned standards given for radioactivity (gross alpha: 0.1 Bq/l; gross beta: 1 Bq/l). In addition, radioactivity values are critical in 33 locations in view of either gross alpha or gross beta or both; the gross alpha values in 20 locations and gross beta values in 13 locations are close to the limit. On the other hand, gross alpha and gross beta contents of thermal waters in the studied area are within the limits given by Turkish Natural & Mineralized Waters Regulations. Nitrate values of samples were over the allowable limits for drinking water (50 mg/l) in 4 locations and more than 10 mg/L in 36 locations in the study area.

It was found that natural contamination in groundwater of the study area is mainly sourced from geological formations. Accordingly, the high value of Fe ion concentration in groundwater samples originates from ophiolitic and granitic rocks, Mn and As ion concentrations are sourced from volcanic rocks (tuff and andesite), and high values of Al, Ba, Fe, Mn in water are related to thorium ore deposits and hydrothermal alterated areas. The ophiolitic rocks are the source of excess Cr, Mn, Fe, Al in the water. On the other hand, the waters in contact with old mined areas and waste disposal areas have very high Mn, Fe, Cu, Cr, As and Al contents due to the acidic conditions increasing the mobility of heavy metal ions in water. The Mn, Fe, Ni, Al, As, Ba, Si, B contents of the thermal water is high, as is expected.

The high natural radioactivity (gross-alpha and gross-beta) of groundwater in the area is mainly observed in the waters related with igneous rocks (granite, granodiorite), volcanic rocks (tuff, riolitic tuff, andesite, dacite, and basalt), metamorphic rocks (marbles), and the hydrothermal alteration zone around thrusted fault zone (mainly consisting of fluorite, barite and REE rich Kizilcaoren ore complex, phonolite and pegmatite rocks) (Orgun *et al.*, 2005). The highest gross-alpha values are observed in groundwaters around Phrygian Valley (at the south of Eskisehir) where andesite and tuff are widespread. The highest gross-beta anomalies are observed in waters near thorium (second largest ore deposit of the world), uranium, barite and fluorite ores around Beylikova (at northeast of Eskisehir). The high values of gross-alpha anomalies observed in groundwaters related with limestone and marble rocks which can be explained by an increase in uranium solubility under oxidizing conditions due to high dissolved oxygen levels (Yuce *et al.*, 2007).

According to previous literature (Fidanci *et al.*, 1998; Atabey, 2005), excess fluoride is present in the water samples taken from vicinity of Kizilcaoren village. Obviously, this is the reason of fluorosis disease which is a common problem in the area. High thorium concentration was also detected in plants around Kizilcaoren due to dust contamination by the mine itself (Zararsiz *et al.,* 1997).

All these results clearly show that there is a close relationship between hydro-geochemistry and environment, i.e. lithology and water chemistry. However, further studies are needed to enlarge our knowledge of this problem and for a better understanding of human health protection.

Keywords: Eskisehir, groundwater, natural contamination, geological formations, environment.

Nitrates and phosphates mobility in different agricultural soils after sewage sludge application

Jose M. SORIANO-DISLA; Ignacio GÓMEZ; Cesar GUERRERO; Jorge MATAIX-BENEYTO; Manuel M. JORDAN; Jose NAVARRO-PEDREÑO; Ernesto GARCIA

Department of Agrochemistry and Environment, University Miguel Hernández. Avenida de la Universidad S/N, 03202 Elche, España, jsoriano@umh.es; ignacio.gomez@umh.es; cesar.guerrero@umh.es; j.mataix@umh.es; manuel.jordan@umh.es; jonavar@umh.es; ernesto.garcia@umh.es

ABSTRACT

The aim of this work is to know how some edaphic properties influence the leached quantity of nitrate, phosphate and COD (organic content), following a single sewage sludge application. It is also an objective of this study to investigate if the different sewage sludge mineralization grade affects the concentrations of the mentioned leachates. Finally, the pollutants temporal evolution will be studied as well.

A column study was carried out applying sewage sludge to 20 agricultural soils. 20 columns remained without application, acting as controls. Leachates were taken after 2, 4 and 6 months, analyzing the parameters mentioned above.

Significant differences were observed as a consequence of the treatment, the irrigation (except nitrates) and the interaction of both. Moreover, the higher quantities were obtained in the first leachate for COD and phosphates, showing similar quantities for nitrate along the three leachates.

Table 1. Significance levels of the repeated mesures ANOVA test

	Nitrates	**Phosphates**	**COD**
Treatment (T)	<0,001	<0,001	<0,001
Irrigation (I)	no significance	<0,001	<0,001
T x I	<0,01	<0,001	<0,001

Texture and oxidable organic matter were found to be the most important properties for COD. In the case of phosphates, the higher values were obtained with low pH. Finally, nitrates do not show correlation with any of the studied properties.

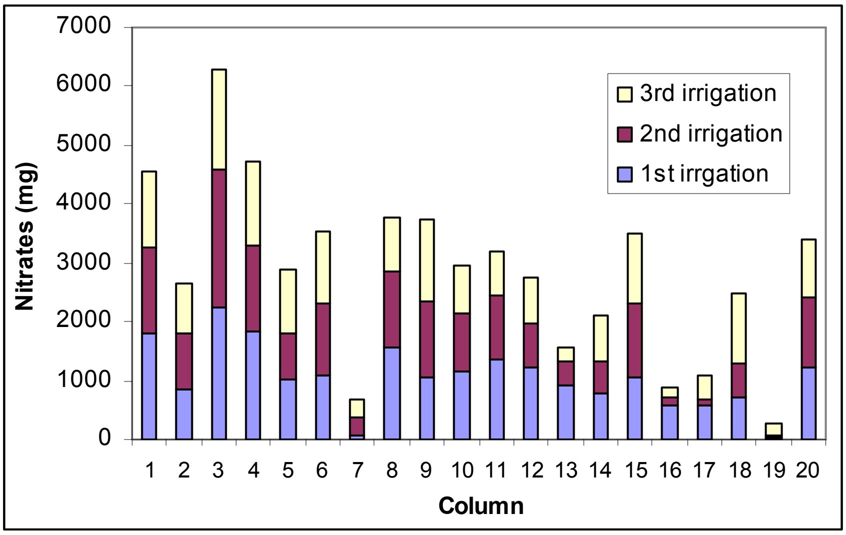

Fig.1. Nitrate values (mg) for each leachate

The present work proves the role of different soil and sewage sludge properties in the analyzed pollutants content, the necessity of multivariate approaches as well as the need for further studies on new types of soil and sewage sludge.

***Acknowledgements*:** The authors gratefully acknowledge the financial support of the research to the Spanish Ministry of Environment (Number of expedient: 021/2006/2-4.2).

Keywords: columns, mobility, nitrates, phosphates, sewage sludge

Nitrogen cycle in gravel bed rivers: The effect of the hyporheic zone.

[1] Alessandra MARZADRI, [2] Alberto BELLIN

Department of Civil and Environmental Engineering, University of Trento. Via Mesiano 77, 38050 Trento, Italy.
[1] E-mail: alessandra.marzadri@ing.unitn.it
[2] E-mail: alberto.bellin@unitn.it

ABSTRACT

By increasing crop growth modern agriculture is said to be responsible for the explosion of human population and for a huge human perturbation of the planet's biogeochemistry through a massive supply of reactive nitrogen to land surface. A large part of this supply is fixed by plants and soils, while the remaining part returns to the atmosphere via denitrification and is leached into rivers and groundwater. Several studies have shown the importance of microbial processes in removing nitrogen from rivers with first-order gravel bed streams playing a major role in reducing the total load. Consequently, modeling transport of nutrients and contaminant in rivers demands inclusion of temporary storage and nitrification-denitrification processes within hyporheic and riparian zones. In general, bedforms cause variations in the pressure at the bed surface, which in turn induce flow into and out of the hyporheic zone. In gravel bed rivers alternate zones of high and low pressure generated by bedforms induce a complex flow pattern within the hyporheic zone that interacts with the stream through downwelling (i.e. high pressure) and upwelling (i.e. low pressure) zones. We model nitrification of NH_4^+ and denitrification of NO_3^- by using two chained first-order kinetics. Furthermore, for simplicity, we assume that the streambed is confined, homogeneous and with a negligible lateral inflow, that streamflow is constant and that the typical time scale of subsurface flow is small with respect to the morphological time of bar development and migration. We solved the two transport equations for NH_4^+ and NO_3^-, coupled with the chained first-order kinetics modeling nitrification and denitrification processes within the hyporheic zone, by using a Lagrangian approach and assuming that dispersion is negligible. The Lagrangian approach is particularly convenient in this case because it permits formulating the transport equation in term of residence time which is the controlling parameter of both retention and nitrification/denitrificaton processes. With this simple, yet powerful, model we studied the interplay between streambed morphology and Nitrogen export from the hyporheic zone of a gravel bed river including the interplay between ammonia and nitrate.

Keywords: Hyporheic zone, Gravel bed river, Nitrification, Denitrification, First order kinetics

Radon monitoring of groundwater and streams in the uranium mining area of Urgeiriça (Central Portugal)

[1]Luis J.P.F. NEVES, [1]Alcides J. S. C. PEREIRA, [1] Cátia V.M. GONÇALVES, [1] Ana M.P. VICENTE

[1]Laboratório de Radioactividade Natural, Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia da Universidade de Coimbra, Largo Marquês de Pombal, 3000-272 Coimbra, Portugal, e-mail: luisneves@dct.uc.pt

ABSTRACT

The mining area of Urgeiriça (Central Portugal) was the most important centre of uranium exploitation in Portugal up to the year 2000; it comprises a deactivated underground mine that reaches a depth of 500 meters, and a large industrial complex that includes a chemical plant for ore treatment, several tailings, administration buildings and water treatment facilities. The water that percolates through the old mine and tailings, as well as mechanical erosion and radon exhalation from radium rich materials are the main potential sources of contamination of the environment. These processes can transfer chemical elements as well as radioisotopes to the surrounding environmental compartments.

In this paper we address the problem of radon transfer to streams and groundwater, which was evaluated through sampling of 32 locations, including holes (13), wells (9) and streams (6), as well as water from the old mine (2) and exsurgences from tailings (2). Temporal variability was also addressed, since sampling was repeated three times, between October 2004 and February 2005. The analysis were carried out in the Laboratory of Natural Radioactivity of the Faculty of Sciences and Technology of the University of Coimbra, using an Alphaguard PQ2000 Pro unit, in the 48 hours following each campaign. The radon detection limit is 60 $mBq.l^{-1}$ and the typical error is 10%.

The results obtained for the same sampling sites over the three campaigns are quite consistent, showing a scarce variability, since the meteorological conditions were stable during this period and the weather unusually dry. As expected, the highest radon concentrations results were obtained in the potential contamination sites, namely the old mine and some holes located on the largest tailings (Barragem Velha). Mine water was sampled in two access points; water levels in one case allows for a significant aeration (Santa Bárbara), which results in radon concentrations between 79 and 1.129 $Bq.l^{-1}$. This is not the case of the other sampling point (Poço 4), where radon shows much higher concentrations (2.746 to 3.649 $Bq.l^{-1}$). The three holes of the Barragem Velha tailings showed radon concentrations between 6.450 and 11.353 $Bq.l^{-1}$, with a spatial distribution well correlated with its internal structure and radiometry. Two exsurgences of water percolating this tailings occur close to a stream that crosses the mining area (Ribeira da Pantanha) and were also sampled. However, due to access difficulties, only after a short trajectory in the open air. The results show radon concentrations ranging from 33 to 667 $Bq.l^{-1}$. This can be interpreted as a partial radon loss in contact with open air, but also probably as showing a slow groundwater flux, allowing for a significant radon decay from the source.

A total of 10 control holes distributed in the mining area were also sampled. The results of the three campaigns range between 1 and 75 $Bq.l^{-1}$, with one exception (107 to 155 $Bq.l^{-1}$). Taking into consideration that several of these holes are located in the immediate proximity of the old mine and tailings, the results allow the conclusion that no contamination of groundwater is being produced, or, alternatively, that a low transmissivity of the bedrock allows for radon decay within a short distance.

The results obtained for wells show a strong variability within each campaign (1 to 694 $Bq.l^{-1}$; 4 to 449 $Bq.l^{-1}$; and 16 to 868 $Bq.l^{-1}$), and their range is identical to those observed in other areas of the Beiras region with similar geology. Moreover, the spatial distribution of the results shows no relation with the potential contamination sites (old mine and tailings).

Finally, two streams were sampled before and after crossing the mining area (Ribeira da Pantanha and Ribeira de Travassos). The results shows low radon concentrations in the surface waters (6 to 64 $Bq.l^{-1}$), with no spatial trend that can be related with contamination induced by the mining area. The highest values (55 to 64 $Bq.l^{-1}$) were observed in the Ribeira da Pantanha, before the stream interception of the mining area.

Keywords: Radon, water, Urgeiriça, uranium mines.

Relationship between natural and degraded beach ecosystems and *E. coli* levels in groundwater below beaches of the Great Lakes, Canada.

[1]Allan S. CROWE, [1]Jacqui MILNE, [1]Tom EDGE

National Water Research Institute, Environment Canada, 867 Lakeshore Road, Burlington, Ontario, Canada, L7R 4A6, e-mails: allan.crowe@ec.gc.ca; jacqui.milne@ec.gc.ca; tom.edge@ec.gc.ca

ABSTRACT

High levels of *E. coli* that frequently exceed recreational water quality guidelines are a common problem at swimming beaches throughout the world. Recent studies undertaken at beaches along the shores of the Great Lakes in Canada have focused on investigating the source of the *E. coli* found in nearshore waters adjacent to beaches and the causes of persistent and frequently high levels of *E. coli*. Our studies have found that the beach ecosystem (both physical features of the beach and the beach's plant communities) impact of *E. coli* levels in the ground water below beaches.

Beaches along the shores of the Great Lakes in Canada can be grouped into two types. The first type of beach, referred to as a "dry beach", is characterized by a sand dune on the leeward side of the beach and a surficial layer of dry sand about 20 cm thick on the beach and dunes. Vegetation is absent on this beach, but beach grass (*Ammophila breviligulata*) is present within the dunes. The second type of beach, referred to as a "wet beach", is characterized by absence of sand dunes and damp sand at the surface. Beach grass is generally absent, and replaced by phreatophytes, including sedge grass, phragmites, and cattails. Also, many wet beaches are actually degraded beaches where the natural sand dunes and beach grass have been removed by beach-front residents. The removal of sand dunes and beach sand lowers the ground surface and results in a shallow depth to the water table that roots of phreatophytes can reach. In addition, many residents remove the dunes and natural beach grass and replace this natural vegetation with lawns of turf grass, which migrates on the wet sand on the beach, thus, alternating the natural beach ecosystem.

Both types of beaches typically have extensive development of permanent and seasonal residences adjacent to the beach and at least 50 m from the shoreline. The vast majority of these residences employ septic systems for waste water disposal/treatment and these are a major reservoir of *E. coli*. Groundwater flow, and associated contaminant transport, beneath both types of beaches is towards the lake throughout the year. The hydraulic gradients below both types of beaches along the shores of the Great lakes consistently range between 0.0029 and 0.018, and hydraulic conductivity of beach sand is approximately $2x10^{-2}$ cm/s to $4x10^{-2}$ cm/s. However the depth to the water table below theses types of beaches is quite different; 0.5 - 2.5 m deep below dry beaches and 0.2 - 0.5 m deep below wet beaches.

Our studies show that *E. coli* are present at a dry beach only below the swash zone (<10 m from the shoreline); *E. coli* was not detected in groundwater below the beach or adjacent dunes. *E. coli* was also detected in the groundwater below the swash zone at wet beaches. However, *E. coli* was consistently detected below the entire wet beach at levels between 0 and 200 *E. coli*/100 mL. Although septic systems are present at both types of beaches, our studies show there is no evidence of migration of *E. coli* via groundwater flow through the dunes beach to the lake from properly functioning septic systems at these beach-front residences. Only at one location at a wet beach was there evidence of movement of *E. coli* from a septic system towards the lake, but *E. coli* migrated just several metres from the tile bed. Antibiotic resistance analysis of the *E. coli* below the wet beach provides evidence that the *E. coli* below these wet beaches have gull and geese signature rather than a human (i.e., septic system) source.

There are two primary factors that led to the consistence presence of *E. coli* in groundwater below wet beaches and the consistence absence of *E. coli* in groundwater below dry beaches. First, geese are a major source of the *E. coli* found at recreational beaches. The phreatophyte vegetation and turf grass that is present at wet beaches provide an environment and source of food that attracts geese. The lack of vegetation on the beach and the presence of beach grass within the dunes at dry beaches do not attract geese. Second, because wet beaches have both a shallow depth to the water table, and the water content of the sand near residual saturation, it is likely that *E. coli* from fecal material on the beach surface is infiltrating to the water table. At a dry beach, the greater depth to water table, and the surficial sand having a zero water-content, provides little possibility of infiltration of *E. coli* to the water table.

Unrestricted residential development at beaches and degradation of the natural beach environment may cause *E. coli* in groundwater below beaches of the Great Lakes. Our investigations of cottage septic systems as sources of *E. coli* in groundwater below beaches are largely negative. However, there seems to be a link between the destruction of the natural dune - beach grass ecosystem at a dry beach and replacement with lawns and phreatophytes at a wet beach. The latter beach provides an attractive environment for geese and a favourable groundwater setting for infiltration of their *E. coli* to the water table.

Keywords*:* groundwater, beaches, *E. coli*, beach ecosystems

Some ecological problems connected with Baku-Tbilisi-Ceyhan (BTC) pipeline (Georgian section)

[1] Ucha. I. ZVIADADZE, [2] Marina L. MARDASHOVA

[1] Ateni str. 4, Tbilisi 0179, Georgia; e-mail: u_zviadadze@gtu.ge
[2] Kostava str. 75, Tbilisi 0175, Georgia; e-mail: m_mardashova@gtu.ge

ABSTRACT

The total length of Baku-Tbilisi-Ceyhan (BTC) oil pipeline within the Georgia section from Jandari Lake (East) to Georgian-Turkey frontier (West) is 248 km.

This study looked at the effect of laying a pipeline through the southern part of Borjomi gorge, within the catchments area of river Borjomula. The Borjomula river is an affluent of the river Mtkvari. The river Mtkvari is the main water artery of the South Caucasus.

The Borjomi region is especially important for future development of Georgia's economy. The health resort, Borjomi, is world famous for its unique microclimate and curative mineral waters. The main focus of this report is the Bakuriani lava flow and the risk of it being polluted by accidental oil spills on the pipeline. A section of pipeline on the southern outskirts of village Tsikhisjvari is only a distance of 0.5 km from the outcrop of Upper Pliocene – Middle Quaternary lava formation ($N_2^3 – Q_3$) represented by intensive fractured basalts and andesites.

The gorge of the river Borjomula is drowned in lava formation. Groundwater discharge is connected with this formation in the form of a group of springs within the environs of villages Sadgeri, Daba and Tsemi. A powerful fresh spring – "Mill spring" also called "Sadgeri spring" is used for the water supply of the Borjomi resort.

Taking into consideration the fact that the main bulk of underground flow moves toward the deepening of the waterproof bed of Maikop series, the existence of Sadgeri and Daba springs with a total discharge of about 100 l / sec, is absolutely logical.

It is not difficult to follow the dynamics of groundwater contamination in case of accidental oil spills (Fig.1).

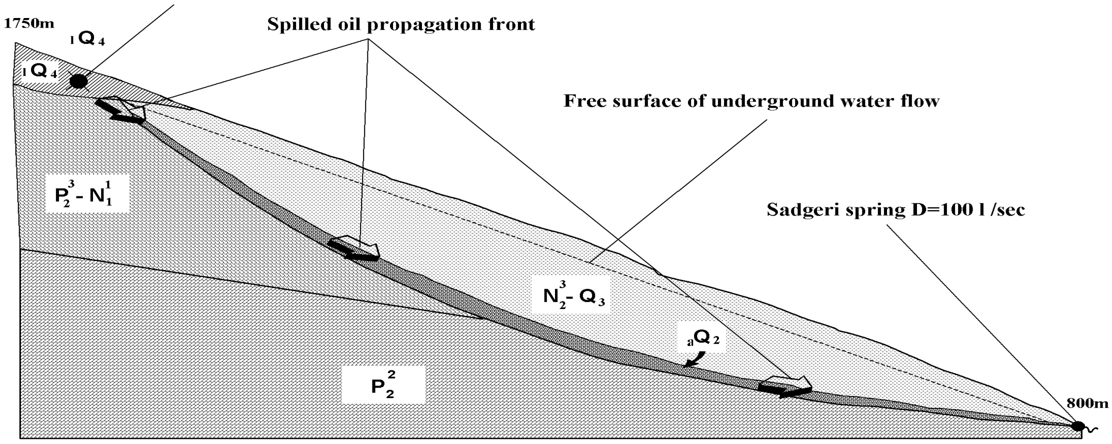

Fig.1. Scheme of groundwater pollution by spilled oil

Legend: P_2^2 - Volcanic sub aqueous series; $P_2^3 - N_1^1$ - Clayey Formation (Maikop series); $N_2^3 - Q_3$ - Lava formation; aQ_2 - Paleo riverbed of r. Borjomula; lQ_4 - lacustrine sediments.

Based on the above mentioned, it is doubtless that in case of any leakage from the pipeline the contamination by hydrocarbons of lava rocks and related groundwater is inevitable, which certainly will cause ecological disaster in the Borjomi region.

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Keywords: Groundwater, oil pipeline, contamination, water-supply

The characterization of contamination and the role of hydrogeology in the risk management of a mega brownfield site

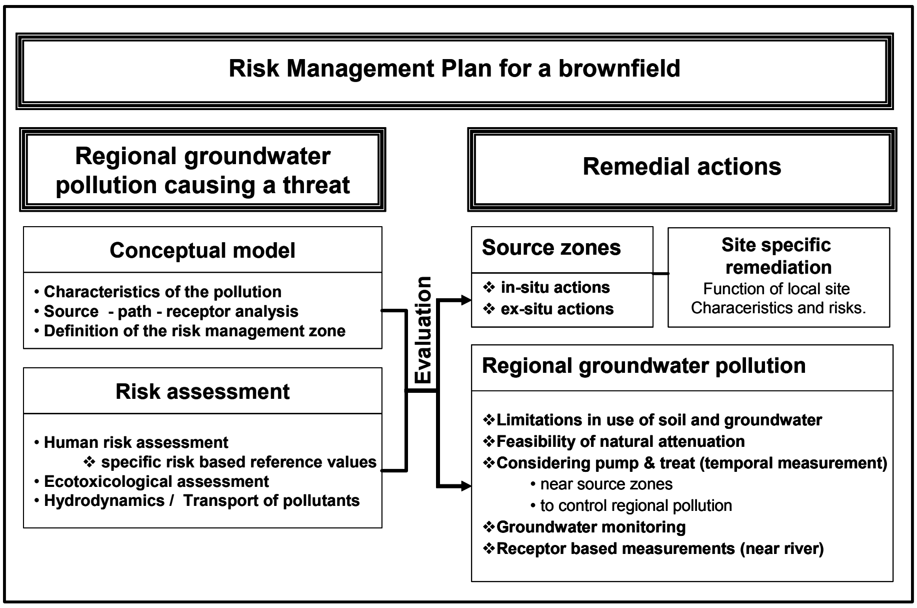
Jan BRONDERS*, Ilse VAN KEER, Kaatje TOUCHANT, Johan PATYN, Jeroen PROVOOST

VITO (Flemish Institute for Technological Research), Boeretang 200, B-2400 Mol, Belgium
* Corresponding author: e-mail: jan.bronders@vito.be

ABSTRACT

Field studies carried out on and around the brownfield of Vilvoorde – Machelen (north of Brussels, Flanders) have indicated the presence of an extensive regional groundwater pollution. A groundwater plume containing a mixture of BTEX (benzene, toluene, ethylbenzene and xylene) and chlorinated aliphatic hydrocarbons (CAH) covers an area of at least 70 ha (plume dimensions are 1.2 by 0.6 km). Although several sources in the vadose zone are still present, chemical analyses indicated that the mass of the pollutants is present in the groundwater. The semi confined aquifer, in which the pollution is present, consists of Quaternary gravels embedded in a sandy sometimes loamy matrix.

The redevelopment of this area is a complex process caused by the presence of a mixture of urban and industrial activity. This includes abandoned industrial sites as a result of more than 100 years industrial activity. The investigation and remediation of each single site in this region will not result in the effective removal of the groundwater pollutants due to economic and legal entanglements, fragmentised remediation, and the rather large time span needed to complete these actions. Therefore a risk management plan (RMP), in which hydrogeology plays an important role, was deployed. The goal of such a plan is to define a feasible action plan in order to manage groundwater pollution threatening ecosystems. The action plan defined for the mentioned brownfield included the identification of appropriate measurements to control the effects of the groundwater pollution on the hydrological ecosystem e.g. the groundwater itself and the final receptor, the nearby river Zenne. A schematic overview of the RMP is given in Fig. 1.



Fig; 1. Schematic overview of the RMP

To characterise and evaluate the migration of the pollution and to assess associated human health risks, a regional hydrogeological study was carried out. The study contained the following steps: a region wide inventory of the soil and groundwater quality, a risk evaluation including the derivation of site specific risk based quality reference values, groundwater modelling including transport calculations, isotopic analyses, measurement of groundwater-river interface contaminant fluxes and finally a proposal for a remedial action plan.

The risk evaluation for the current situation showed that, at a regional scale, human health risks were not expected to occur. However, a restriction on the use of groundwater as drinking or industrial process water was issued. The groundwater modelling confirmed that the pollution present in the Quaternary aquifer is drained towards the nearby river Zenne, indicating that the existing groundwater plume will not become much larger. Flow times to the river are in the order of decades. As a consequence, the pollutants will be present in the aquifer for many years to come. The proposed remedial actions for the region include the removal of the source zones present in the vadose zone, a series of precaution measures including a selection of groundwater pump and treat scenarios of the plumes located near the source zones. Additional monitoring of the pollutant groundwater fluxes to the river and monitoring of the natural attenuation process is advised.

***Keywords**:* hydrogeology, brownfield, contamination, risk evaluation.

TOPIC 04

Impact of groundwater contamination on ecological systems and processes

A Sustainable Use of Groundwater: Villarrica, Paraguay

[1]Ana Elizabeth Godoy ARAÑA, [2]José Joel CARRILLO-RIVERA

[1]Posgrado en Geografía Ambiental, Universidad Nacional Autónoma de México;
[2]Instituto de Geografía, Universidad Nacional Autónoma de México
Circuito de la Investigación Científica, s/n,
Coyoacán, México, DF. C.P. 04510
Tel: +(5255) 5622 4360, ext. 45467, 45509
Correos: annaliz@gmail.com
joeljcr@igiris.igg.unam.mx

ABSTRACT

The urban growth of Villarrica has developed without previous planning. In addition, other activities such as an important deforestation rate to gain land for crop or agriculture use, the dump of solid and liquid waste into rivers, and the lack of an adequate sewage system, have created conflicts that are the cause of important environmental damages that affect surface and groundwater directly, consequently the quality of life of the population and ecosystems. These negative impacts are reflected in the environment specifically in different ways: i) impact on the physicochemical and bacteriological quality of surface and groundwater, ii) loss of vegetation cover, iii) changes in discharge and recharge processes, iv) increase in soil erosion rate, v) damage of different ecosystems such as wetlands, among others. Even though many of these problems are not perceptible at first glance, they directly affect the water resource.

The area of Villarrica presents favorable conditions in terms of the amount of volumes of surface and groundwater to cover the present population needs. This is due to the climatic conditions, its geographic position with in the Tebicuary River basin, as well as with the nature of the geological units and their regional extension. These rock units are composed primarily by sandstone with variable thickness from few to hundreds of meters. The city overlies this unit. These rocks are widely exposed in the study area, which makes them vulnerable to contamination due to this high hydraulic conductivity ($k = 3.86E^{-}05$ m/s).

The present study analyses the functioning of groundwater and its relation to other components of the environment as well as some socioeconomic processes by the integration of existing information and field work on the lithology, water chemistry and bacteriological data, topography, and vegetation cover as well as on the industrial activities and waste disposal sites of the area.

Results obtained from field sampling and analyses (high values in *E. coli*, 3,026-130 UFC/100ml; Cl^-, 329 mg/l; NO_3, 11.20-18.20 mg/l; DBO, 930-5.4 mg/l; TSD, 1,471-578 mg/l) suggest the fragility of the hydrological (groundwater) system by the deterioration of its physicochemical and bacteriological quality in wells, springs, and streams. The presence of *E. coli* and NO_3 are an indicator of the lack of sewage system in the area and a threat to the health of the environment. The problem is enhanced by the industries in the urban area, which lack water treatment plants; they discharge their effluents directly into streams or infiltrate them into the ground.

There is no thermal discharge zone in the study area which suggests that groundwater belongs to local flow systems, therefore due to their short lengthy path this makes groundwater and the ecosystems that are attached to it, very vulnerable to impacts produced by man on the land surface.

Keywords: Groundwater, Contamination, Villarrica, Paraguay.

Environmental impact of sawmill by-products degradation-groundwater quality case study, Western Serbia

[1]Dejan MILENIC,[2]Petar Papic, [3]Djuro Milankovic

[1] Dept. of Hydrogeology, Fac. of Mining & Geology, Un. of Belgrade, Serbia, dmilenic@yahoo.ie
[2] Dept. of Hydrogeology, Fac. of Mining & Geology, Un. of Belgrade, Serbia,
[3] Dept. of Hydrogeology, Fac. of Mining & Geology, Un. of Belgrade, Serbia, djuro2703@yahoo.com

ABSTRACT

The forests of the Republic of Serbia cover approximately 27% of its total area, i.e. about 2.4 million hectares. It has been planned to increase the percent of afforestation to 31.5% of the total area until the year 2010. Such a rich natural resource has been exploited intensively by the wood and timber industry. Rapid industrialisation of this branch of the economy in the Republic has big development potential and opened new work places. However, to obtain a final product, a number of industrial procedures are required, and these leave behind significant by-products, mostly harmful and with enormous negative impact on the quality of the environment. In the utilization of a forest, namely timber, the percent of useful wood amounts about 58%, while the remaining 42% is waste branches, tree stumps and sawdust. This waste appears immediately felling the trees and preparing for their transport. The total of the forest potential of Serbia, this waste amounts to about 3 million m^3.

The areas especially rich in forests and timber are situated in Western Serbia along the border with the Republic of Srpska (Bosnia and Hecegovina). One of such municipalities is the municipality of Nova Varos, an area distinctly rich in natural resources. First of all it concerns forest and water resources. Zlatar Mountain, being among the most beautiful mountains in Serbia, is a big karst natural resource for forest and water resources. The forest resource is highly utilised, which is confirmed by the large number of newly opened saw mills and lumber mills in the territory of the municipality. However, a large number of saw mills are not registered and are found in so-called “grey” area. Here there are neither records nor adequate environmental protection measures to correct managing of the forest waste after processing.

The mechanisms of ground water pollution by wood and timber industry waste (first of all by sawdust) are highly complex and require a multidisciplinary approach. The solving of questions related to the protection of endangered areas namely the remediation of already polluted groundwaters, requires close cooperation of hydrogeologists, chemists, foresters, and related disciplines. It is known that the impact of fresh sawdust on the quality of the environment is correlated with the time of the decaying, wearing and degradation of incorrectly disposed sawdust. After a certain time, sawdust, in contact with the soil and in anaerobic conditions, can result in the forming of a high content of phenol, methane, iron, manganese, and other elements. When geological-hydrogeological conditions are favourable, contact with groundwaters occurs, and direct contamination takes place.

The chemical composition of sawdust depends on the kind of wood, soil conditions and external factors. Numerous organic compounds of highly complex structures make the composition of sawdust. The elementary analysis of sawdust has shown that the proportion of carbon is the highest, being 50%, and then after that oxygen with 40%, hydrogen with about 6% and nitrogen with about 1%. Among organic compounds the proportion of cellulose is the highest, about 40%, lignin about 28% and chemical cellulose of about 27%.

Sawdust, as the most common waste, endangers the water potential of Zlatar Mountain directly. Groundwaters are formed in karst aquifer primarily in limestones of Triassic and Jurassic ages. Practically, whole Zlatar “lies” on qualitative ground waters, which are currently being used for the water supply of the Nova Varos municipality. The most significant springs of the north edge of Zlatar (the area of the Nova Varos municipality) from the point of view of both quantity and quality are: Lakomica, Gačevo vrelo, Bjelanac, etc.

During the year 2003 a serious chemical pollution with iron and manganese was recorded at the Bjelanac spring. This pollution resulted in the degradation of water quality of this spring. Thus the waters from it have been used only for technical purposes since that time. Before that the Bjelanac spring was used for the water supply of the Akmacici settlement with more than 2000 inhabitants. Also, in the last three years occasionally strong muddiness appeared out of the deposition of materials identical to the appearance of dissolved sawdust.

Although, in the beginning it was suspected that the source of pollution was a dairy nearby. After investigations were carried out, it was found out that the main source of pollution was, in fact, inadequately deposited sawdust in the broad neighbourhood.

The paper is structured in such a way that all results are given in phases, through a detailed survey of the applied methodology of exploration. They can be represented shortly as:

- The collection, a selection, an analysis, and the reinterpretation of all existing geographic, climatic, hydrographic, hydrologic, geologic, hydrochemic, and hydro geological data about the survey field i.e. the area of the recharge zone of the Bjelanac spring - *problem defining*

- The making of a 3D elevation and geological-hydro geological model of the broad neighbourhood of the spring, on the basis of which, possible physical models of groundwater movement in the zones of potential pollutants have been determined - *defining of the exploration directions*

- Hydrogeological reconnaissance and hydrogeological mapping, namely detailed recording of all hydro geological phenomena and buildings on the survey field and sampling for chemical analyses - *realization of the First phase of the field exploration*

- Geophysical exploration. In this phase, geoelectrical sounding, geoelectrical mapping (scanning) as well as, the application of the „mise a la masse" method were conducted. The mentioned investigations were carried out because of the space delineation, namely the delineation of water bearing horizon, as well as, direct determination of the direction of groundwater movement through the karst aquifer in the area of north edge of Zlatar Mountain – *realization of the Second phase of the exploration*

- Chemical analyses of samples of groundwaters and soil

- Analysis of obtained results and their interpretation

- Proposal of remediation measures for polluted aquifer

- Proposal of protection measures of "clear" groundwaters

Keywords: Hydrogeology, contamination, karst, ecosystems

Estimation and spatialization of leachate infiltration from municipal solid waste landfills. Approach by geophysics and water balance on the Etueffont experimental area (France).

[1,3]Emilien BELLE, [1]Elise GRISEY, [2]Thomas LEBOURG, [1]Jacques MUDRY, [3]Lotfi ALEYA

[1]Laboratoire de Géosciences, université de Franche-Comté, Besançon, France
[2]Géosciences Azur, Sophia Antipolis, Valbonne, France
[3]Laboratoire de Biologie Environnementale, université de Franche-Comté, Besançon, France

ABSTRACT

Household waste disposal sites, exposed to precipitation and often devoid of an impermeable bottom layer, produce leachates which threaten the water quality of both subjacent groundwater and surface water related to the landfill. No single method enables characterization, quantification and spatialization of these pollutant emissions. Only a combination of several methods can account precisely for this pollution. Two investigation methods were simultaneously used at the Etueffont landfill site (Northeastern France) to estimate infiltration on-site. This site is composed of two separate dumps. For 25 years, the first dump (old dump = OD), has stored grinded waste, dumped directly upon the schisteous bedrock. For the last four years, a new impervious compartment (new casing = NC) had succeeded the OD, in order to collect the same crushed waste, until the dump stopped operating. Each landfill has its own water collecting system, which transfers leachates to a natural lagoon (4 basins), for treatment. Piezometer 30 (PZ30), downgradient from the landill, is thus influenced by leachate infiltration. The use of geoelectric pseudosections has enabled the location of the infiltration plumes originating from the landfills. On the OD, a geoelectric pseudosection grid has enabled the creation of a 3D model of the pollution plume generated by leachate infiltration. Calculation of the water balance was made to quantify infiltrations of both landfills. On the OD, a 40% deficit versus effective rainfall was obtained. These losses represent the potential of the pollution plume. This study clearly shows the necessity of using a combination of geoelectrics, and water balance calculations. This double approach, spatialization-quantization, answers a lot of questions, but the local context of each study site still remains a determining factor.

Hydrochemistry evolution in neighbouring areas of landfills

[1]Vera LVO PEREIRA, [2]Alberto S LIMA

[1] Departamento de Ciências da Terra, Universidade do Minho, 4710-057 Braga, Portugal, e-mail: verapereira1977@portugalmail.pt
[2] Departamento de Ciências da Terra, Universidade do Minho, 4710-057 Braga, Portugal, e-mail: aslima@dct.uminho.pt

ABSTRACT

The main point of this work is to investigate the environmental impact of solid wastes deposits in groundwater. At the time of this research, we used, as a work support, an active landfill and two areas of uncontrolled waste refuse closed for approximately four years. They are located between Braga and Póvoa de Lanhoso cities (NW Portugal).

In geological terms two granites post-orogenic support the landfill: the Braga Granite and the Briteiros Granite. The Braga deposit of solid refuse, is set in a large metasedimentary rock and the Póvoa de Lanhoso deposit of solid refuse, just like the landfill, is also set in a region of granites – Agrela Granite. In these three areas of study we have been doing an inventory in total of 32 water points (11 in the landfill, 9 in Braga deposit of solid refuse and 12 in Póvoa de Lanhoso deposit of solid refuse) with the purpose of analysing its hydrochemistry evolution.

For approximately 10 months it has been registering the temperature values, electric conductivity, pH and Eh of its waters and three sampling campaigns have been made for laboratorial analyses. Concerning results, the groundwaters of the landfill revealed climatic conditions influence, mainly on the surface water points, like the P9 (Ribeira de Reamondes), and in the shallower groundwater points, like P3, P5 e P8. This influence created a major variation in the physical-chemistry parameters of these waters. All the sanitary landfill points yielded waters with mean temperatures between 12 ºC and 14,5 ºC and with an acid pH. Globally, these waters have a bicarbonate, chloride, sodium and calcium contents and in some points, with significant quantities of Al, Mn, Ba, Cu, Ni, Zn, Pb and As.

We can confirm that in the landfill, at the time of this study, we had detected some signs of quality degradation in waters of the southern sector. However, the results obtained did not allow us to relate the hydrochemistry evolution observed with the waste deposition cell, due to the presence of other structures inside the landfill, such as storage and treatment of leachate lagoons, capable to influence the water chemistry.

The Braga dunghill neighbouring waters presented medium conductivity values that range between 136 µS/cm and 5500 µS/cm. Taking in account the pH values registered, we can characterized these waters as acid waters. Considering the lower depths presented in some points, for example, points P1, P2 and P3, its waters seems to be influenced by the rainfall.

Like the sanitary landfill, the water points of this study area are also presented higher concentrations of bicarbonate, chloride, sodium and calcium. The ions Mn and Al also appear in higher proportions than the Parametric Value (PV) indicated in the Decree Law foe consumption waters, like the Cu. At some points, P2, P3, P4 and P6, we detected the presence of Cr, Ni and As in excessive values. The analysed data suggests the existence of two different water points groups. A first group composed of points P2, P3, P4, P5, P6 and P7 and a second one composed of point P8. The first group is composed of the points that presented the higher values during the monitoring period and for that reason they are influenced by dunghill. Concerning point P8, according to the analysed results, this seems to be the point less influenced by the dunghill presence. The reason for the values found could be the distance from the residual deposit area.

The inventory points next to the Póvoa de Lanhoso dunghill presented waters with medium conductivities between 38 µS/cm and 184 µS/cm. However there are two points, P3 and P12, that are different. Thee two points represent a higher influence of the dunghill on the waters chemistry composition, which showed elevated levels of cations and anions.

We verified that Braga and Póvoa de Lanhoso dunghills revealed a lower stabilized hydrochemistry evolution, showing the contaminated waters are related to decomposed waste processes that occur in these places. Nevertheless, in some points, it was difficult to separate a possible contamination due to deposits of solid refuse, from a possible degradation due to agriculture and cattle raising activities.

Keywords: Hydrogeochemistry, solid wastes deposit, landfill

Hyporheic communities in altered systems

[1]Annalissa RITCHIE, [2] Anne WEEKES

[1] Department of Animal and Plant Sciences, Alfred Denny Building, University of Sheffield, Western Bank, Sheffield S10 2TN, UK, e-mail: A.Ritchie@sheffield.ac.uk

ABSTRACT

The hyporheic zone is an important ecotone that offers conditions for unique faunal composition and ecosystem services. In the last 30 years, research in the hyporheic zone has vastly expanded. Many of these studies however have focused on alluvial flood-plain systems. Fewer studies have looked at hyporheic community structure within highly modified and urbanized catchments. In 2002, a pilot study was carried out on hyporheic invertebrate presence in Puget Sound urban streams (Washington State, USA). Selected streams were located in areas ranging from highly urbanized to semi-rural suburb land-uses. Preliminary analysis of the data in this pilot study demonstrated a wide diversity in hyporheic invertebrate distribution and abundance. As this was a preliminary exploratory study, sampling and processing were not at a detailed level. Even these cursory results, however, demonstrated large differences among some sites and some surprising results where streams with apparently healthy benthic invertebrate populations had almost no invertebrates in the hyporheic samples collected.

The current study aims to examine human influences on hyporheic community structure among streams within an urbanized catchment. Due to the coarsness of initial data collection, there are many questions that will not be able to be properly addressed with the Puget Sound study. In answer to this, an analysis of hyporheic invertebrate communities within the Don catchment in central England is underway for 2007-2008. This study will be in conjunction with other studies in the catchment, allowing for a more detailed approach to assessing the hyporheic community and its responses to different environmental conditions. The River Don catchment has undergone many anthropogenic alterations within the last 1000 years; from early weir placement and water extraction to the reservoirs and severe pollution in the 19th and 20th centuries. Since the 1970s, restoration efforts have begun in earnest, fuelled largely by poor water quality and the complete loss of salmon. Evaluation of the hyporheic communities in areas of differing anthropogenic impacts will add to the current benthic invertebrate and water chemistry monitoring already in place as well as helping to meet the ecology requirements under the EU Groundwater Directive. The hyporheic zone provides ecosystem services at the mixing of two important water resources. Exploring this zone may enable us to better explain river system responses to landscape alterations and remediation measures.

Keywords: Hyporheic zone, urban catchments, invertebrates

Competitive sorption isotherm model for prediction of complex binary sorption of Pb^{2+}, Zn^{2+}, Ni^{2+}, and Mn^{2+} onto laterite soil

[1]Aksara PUTTHIVIDHYA and [2]Srilert CHOTPANTARAT

[1]Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University, Thailand, dr.aksara.putthividhya@gmail.com
[2]Natural Resources Research Center for Environmental and Hazardous Waste Management, Chulalongkorn University, Thailand

ABSTRACT

Intensive mining industries all over the world generally produce substantial amounts of waste that eventually has leads to environmental pollution and a public health concern, especially when more than one metal exist in the system at a time since the metals' behavior becomes much more complicated. It is important to understand the releasing and sorption mechanisms of multiple metals in the subsurface in order to predict, control and transport characteristics of the contaminants in the environment and ecosystem. Since heavy metals have long been known to accumulate in biological systems; as well, it is necessary to initiate policy for pollution control and prevention. The sorption behavior of Pb^{2+}, Zn^{2+}, Ni^{2+}, and Mn^{2+} by laterite soil in single and binary (Pb^{2+}-Zn^{2+}, Pb^{2+}-Ni^{2+}, and Pb^{2+}-Mn^{2+}) systems is evaluated in terms of three-dimensional sorption isotherm surfaces as competitive sorption is expected to occur. The results suggest that carboxyl group in the clay fraction of laterite soil is partially responsible for the sorption of the heavy metals presented in the system as clay is accounts for more than 50% of the laterite composition. The experimental data of single isotherm sorption process was discovered to follow Langmuir isotherm model. A new modified empirical model incorporating the effect of secondary metal coexistence is being developed to better explain/predict the equilibrium competitive sorption behavior of the binary system using parameters previously estimated from single metal system. The model and experimental data of each binary component system consistently demonstrate that the presence of the secondary metal ion always reduces the total sorption capacity, no matter what the metals are, suggesting that limited binding sites for the sorption of all these heavy metal ions exists.

Keywords: binary sorption, heavy metals, competitive sorption, mining, laterite

Influence of soil chemical properties on oxidative activity of soils in Korea

[1] Chul-Min CHON, [1]Jae Gon KIM, [2]Gyoo Ho LEE, [3]Tack Hyun KIM

[1] Korea Institute of Geoscience and Mineral Resources, 30 Gajeong-dong Yuseong-gu, Daejeon 305-350, Korea, e-mail: femini@kigam.re.kr, jgkim@kigam.re.kr
[2] Korea Gas Corporation, 215 Jeongja-dong Bundang-gu, Seongnam, Gyeonggi-do 463-754, Korea, e-mail: ghlee49@kogas.or.kr
[3] Mine Reclamation Corporation, 79-4 Hwangji-dong, Taeback, Gangwon-do 300-090, Korea, e-mail: thkim@mireco.or.kr

ABSTRACT

The oxidation and reduction reactions of Cr in soil and groundwater are dependent on the presence of oxidants and reductants. The main oxidants of Cr(III) to Cr(VI) in soils are Mn oxides. On the other hand, Fe(II), organic matter, and reduced S can reduce Cr(VI) to Cr(III). The oxidation of Cr(III) to Cr(VI) in soils causes a significant environmental hazard due to the much greater toxicity and mobility of Cr(VI). Geochemical behaviour of manganese in soils and sediments plays an important role in contaminant fate, cleanup and Mn uptake by plants associated with redox condition. Our aim was to characterize the oxidative activity of the various soils, and to correlate the oxidation capacity with extractable soil manganese, Fe oxides and other soil chemical properties. In addition, the effect of the sample drying and the reaction time was discussed.

25 soil samples were collected from 7 soil profiles formed from the in-situ weathering of the bedrock in Korea (Fig. 1). The soil series sampled in this study were Songgog series (DJ, Typic Hapludults), Asan Series (SH, Typic Dystrudepts), Jigog Series (US and US1, Typic Dystrudepts), Taehwa series (YS and YS1, Typic Hapludults) and Guisan series (TG, Typic Dystrudepts) (NIAST, 2000). The six uncultivated soils were developed over the parent material of Jurassic granite (DJ), Precambrian gneiss (SH), Cambro-Ordovician limestone (US), Cretaceous serpentinite (US1), and Tertiary andesite (YS and YS1). TG soil had a profile consisting of Cretaceous sedimentary bedrock (R), texturally distinctive weathered material of the sedimentary rock (C), a buried rice paddy soil (PS), and two layers of overburden (OB1 and OB2). The bedrock shows a complex fracture network and consists of alternative shale and sandstone of Cretaceous age.

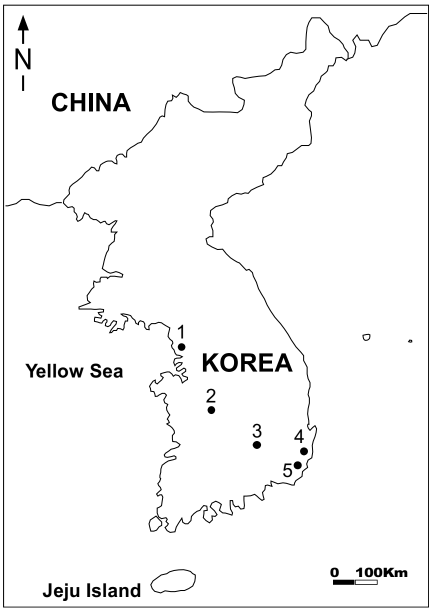


Fig. 1. Locations of the sites studied: (1) SH soil, (2) DJ soil, (3) TG soil, (4) US soil and (5) YS soil.

The moisture contents of the soil samples had little variance (10.64-28.65%) except for R horizons. The values of loss on ignition at 400 °C ranged from 0.71 to 12.65%. The SH soil profile and YS1-R1 had relatively high values. The US1 soil indicated a relatively high level of CEC (41.9-43.2 cmolc/kg). The acidity and electric conductivity (EC) of the YS1 soils were considerably high, especially for YS1-R1 (pH is 2.56 and EC is 746 μS/cm), because the bed rock originally contained pyrite, which was detected by XRD. Such soils are called potential acid sulfate soils (PASS) as they have potential to produce sulphuric acid when disturbed or exposed to air. Acid sulfate soils are the common name given to soils containing iron sulphides. The DJ, SH and TG soils had similar mineralogy (quartz, feldspar, mica, kaolin and vermiculite). The US soil had quartz, kaolin and hematite as major minerals. The US1 soil mainly consisted of amphibole and various types of Mg-clay minerals such as talc, vermiculite, chlorite and serpentine, and therefore had the highest CEC resulting from the large amount of the clay minerals. The YS1 and YS soils containing quartz and mica as major minerals had pyrite and some clay minerals as minor minerals, respectively.

The four Mn-extraction methods were used to understand the relationship between the stability of soil-manganese and the oxidation capacity in various soils. The aqua regia digestion was used for pseudo-total analysis of manganese and iron (Mn^a and Fe^a), as well as the heavy metals in soil samples. The other extractable manganese was extracted for Mn^d with DCB for 15 min at 75℃, for Mn^h with 0.1M hydroxylamine hydrochloride ($NH_2OH•HCl$) in 0.01M HNO_3 for 30 min, and for the easily reducible Mn (Mn^r) with NH_4OAc (pH 7.0) containing 0.2% hydroquinone for 6 hour at room temperature.

In the net Cr oxidation, the wet samples showed a higher Cr oxidation capacity than the dry samples, and the samples after 24 hour of reaction time showed a higher Cr oxidation capacity than those after 15 min because of sample drying and insufficient reaction time.

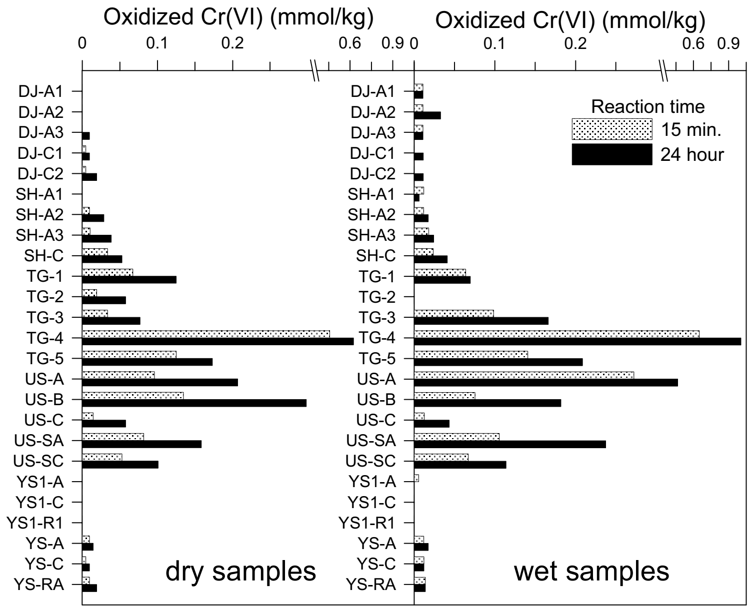


Fig. 2. The amount of total oxidized Cr(VI) (the net Cr oxidation) in the soil samples.

The amounts extracted by DCB (Mn^d), $NH_2OH·HCl$ (Mn^h) and hydroquinone (Mn^r) , were, in general, very similar except for YS1 soil and well correlated with each other. Only small proportions of either total, or DCB extractable manganese were extracted by $NH_2OH·HCl$ and hydroquinone in the YS1 soil, suggesting inclusion of $NH_2OH·HCl$ and hydroquinone-resistant Mn oxides such as lithiophorite or another more recalcitrant Mn mineral because these extractants are weaker reductants than DCB. The concentrations of aqua regia-extractable total Mn (Mn^a) had a good positive correlation with that of Mn^d, Mn^h and Mn^r (r = 0.840, 0.845 and 0.792, respectively; $P < 0.01$). The concentrations of Mn^h showed a significant positive correlation with those of Mn^r (r = 0.945; $P < 0.01$). All Cr oxidation tests were not closely related to the concentration of total Mn, but the three-extractable soil manganese showed a relatively high correlation with the Cr tests (r = 0.655-0.851; $P < 0.01$). The concentrations of Mn^d and Mn^h had a better correlation with the Cr oxidation tests than those of Mn^r. This result implies that the oxidation capacity in our soil samples can be better explained by Mn^d and Mn^h than Mn^r (Fig. 2).

Based on the first component of the principal component analysis (PCA), extractable soil manganese was the main factor controlling the net Cr oxidation in the soils. The total soil Mn, Fe oxides and clay fraction is crucial to predict the mobility of pollutants and heavy metals in soils. The second principal component indicated that the presence of iron oxides in soils had a significant relationship with clay fraction as well as the total manganese oxide, and also related to heavy metal (Zn, Cd, and Cu) concentration except for Pb.

Keywords: Standard Cr net oxidation test, manganese oxides, groundwater contamination, heavy metals, oxidation capacity

ISCO Decontamination on Chemopetrol Litvinov Site, Czech Republic

[1] Karel WASKA, [2] Petr KVAPIL, [3] Pavel HRABÁK, [4] Josef V. DATEL

[1] Charles University in Prague, Faculty of Science, Albertov 6, 128 43 Prague 2, e-mail: karlos.w@seznam.cz
[2] Aquatest Co., Geologicka 4, 152 00 Prague 4, e-mail: kvapil@aquatest.cz
[3] ARTEC Research Centre at Technical University in Liberec, Halkova 6, 460 00 Liberec, Czech Republic, e-mail: hrabakp@seznam.cz
[4] Charles University in Prague, Faculty of Science, Albertov 6, 128 43 Prague 2, e-mail: datel@natur.cuni.cz

ABSTRACT

The site is located in the area of Chemopetrol Litvinov chemical industry in Czech Republic. The main centre of contamination, for which the In Situ Chemical Oxidation (ISCO) process is to be used, is a former ethylbenzene-producing technology unit. The dominant portion of the contamination are monoaromate pollutants. The site has been broken down and has been under treatment since August 1999. The processes used were "Pump-and-treat"and (bio)venting.

The purpose of the project is to optimize the conditions for the process of ISCO for the conditions of Chemopetrol Litvinov site, contaminated by BTEX (Benzene, Toluene, Ethylbenzene, Xylene. These chemicals are comparatively well oxidised. Often, they are involved in contamination. Moreover, they are carcinogenic and are toxic to humans and the natural environment. The opening period of ISCO decontamination on the site includes background research aimed at those chemicals that contaminate by oxidising BTEX type (primarily Fenton's reagent (hydrogen peroxide (H_2O_2) and bivalent iron (Fe^{II+}) as a catalyzer) and disodium peroxodisulfate ($Na_2S_2O_8$), preparing and realization of tracer tests for checking local ground water flow directions and estimation of the local canalization system draining effects, data acquisition of the physiochemical parameters (pH,Eh, temperature) of the groundwater, evaluation of space distribution of these parameters concerning the habitation of oil hydrocarbons in free phase and amount of the contamination, and finally the interpretation of data and deciding on an alternative for oxidizer activation.

In situ chemical oxidation (ISCO) is a modern technique for groundwater decontamination. The advantages are a relatively simple result and a quick run of the reaction with nontoxic products and a small amount of waste. The aim of this is to find the optimal conditions for the oxidizing solutions to ensure the maximum effectivenes of treatment.

Most of the oxidizers exhibit, in addition to direct oxidation, a radical mechanism in which the reaction of reactive radical production starts. After this, the reaction of radicals and oxidable matter occurs, in which radicals are recombined and expand further. This phase happens very fast, and in higher concentrations, almost boisterously. After the utilization of oxidable matters (usually in orders of hours or days) the radical reaction stops.

The optimal oxidation course of set pollutant with specific oxidizer requires specific reaction conditions (in some cases also the inherency of catalyzer). Therefore the particular design of the ISCO usage in situ comes from detailed groundwater and soil chemistry knowledge. Before the contamination treating can happen, laboratory measurements and field tests (pilot tests) on the site must be done.

By contact between oxidizer and contaminated soil, the total oxidation of all oxidable matters takes place. Thus not only oxidation of the contamination, but also oxidation of consistent amounts of organic carbon on to which most pollutants have been adsorbed. Thus the adsorbed form of pollutants happens in the water phase and their removal from the soil is complete within the reacting solution. This is the most important advantage of ISCO method in comparison with the Pump-and-treat method, which has only minimal efficiency in promoting the adsorbed forms of contaminants. The side effect of ISCO is its support of bacterial activity (and consequently the attenuation) by enriching the contaminated collector with oxygen. Due to the speed of oxidizing reaction, the ISCO decontamination is preferred to the Pump-and-treat process, not only for higher effectiveness of treating, but also from the economical point of view.

The most used oxidizers for ISCO are hydrogen peroxide (H_2O_2), permanganate, ozone, persulphates and disodium peroxodisulphate ($Na_2S_2O_8$). For the decontamination of the Chemopetrol Litvinov site the usage of ozone was precluded. Its usage in of petrochemical productions would represent an extreme hazard. Another oxidizer which was precluded are the permanganates, because their target contaminants are primarily ethylenic hydrocarbons and phenols. For the dominant part of contamination (benzene and ethylbenzene) the use of hydrogen peroxide and persulphates is optimal.

The open oxidation of organic matters by hydrogen peroxide requires relatively high concentrated solutions and a large amount of it. If we supplement the solution with approximately 5 – 15 mg Fe^{II+}/l, the required amount of hydrogen peroxide is significantly lower. This is called the Fenton's reaction. Basically, it is creating OH hydroxide radicals. During this radical creation the Fe^{II+} converts to the Fe^{III+} form. But if the solution has a pH of approximately 2 – 5, the iron reacts as a catalyzer, generating OH hydroxide radicals.

In natural conditions contaminated groundwater often includes sufficient Fe^{II+}. If this is not so, it is necessary to add the Fe^{II+} continually (e.g. iron sulphate $FeSO_4$) to the seeping solution. An alternative way to lower the pH to value 2 – 5 is to keep a sufficient amount of iron in the Fe^{II+} form to add to chelation (e.g. EDTA - Ethylenediaminetetraacetic acid). This is called the Modified Fenton's reaction.

The most frequently used persulphate is disodium peroxodisulphate ($Na_2S_2O_8$). It is a stronger oxidizer than hydrogen peroxide. Like with hydrogen peroxide, it is possible to stimulate its oxidizing effects significantly by controlling the reaction conditions and activation of radical mechanism. It can be done by the input of bivalent iron, chelates of Fe^{III+}, hydrogen peroxide, temperature increase or pH value increase to 11. Two molecules of sulphate radicals SO_4 then generate from one molecule of disulphate anion $S_20_8^-$. In comparison to the hydroxyl radical creation by Fenton's reaction, this process of the creation and chain propagation of sulphate radicals is slower. Therefore the activation of persulphate requires more powerful support by one of the procedures mentioned above.

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Keywords: ISCO, In Situ Chemical Oxidation, BTEX, decontamination

Kopaonik - from the National Park to the urban and ecological chaos

[1]Ivan DJOKIC, [2]Vlade CANIC, [1]Mirko CEKIC

[1]Faculty of Mining and Geology, Djusina 7, 11000 Belgrade, Serbia, e-mail: djole.karavela@gmail.com
[2]Faculty of Mining and Geology, Djusina 7, 11000 Belgrade, Serbia, e-mail: vlade.canic@eunet.yu

ABSTRACT

Kopaonik, the biggest mountain in the central part of Serbia is experiencing an ecological crisis within the area of its tourist center, due to basic developing concept neglect, and exceeds its ecological capacity. The tourist center has all the features of the temporary city, containing specific forms of an ecological aggression, where both nature and visitors are concerned. The Kopaonik need to be rescued and cured, because..."mountains return to us everything we left on them"

The development concept of the National Park Kopaonik was founded to respect both natural and created values in the area. The vital part in the National Park proclamation had the geological and geomorphologic values, as well as the hydrogeological occurrences and objects. Eight of thirteen natural reserves are natural geological, geomorphologic and hydrological monuments of nature at the highest protection level (I protection degree - natural reserves), and they are very often directly related to the surface waters and groundwaters and their interaction (**Jankova bara**: *the largest wetland at Kopanik*; **Barska reka**: *hydrological monument and surface waterflow with waterfalls occurrences along the flow path and with the existence of the relict forests communities of common beech, fir and white arsenic fir*; **Samokovka reka**: *hydrological monument and the main surface waterflow at the Kopaonik plane with important community of wetlands*; **Metodje**: *the great number of relict floral species with an attractive occurrence of the cold water "geyser" with a height of 5-6 m, and the occurrence of the karstic spring "Gvozdac"*; **Duboka**: *geological-hydrogeological monument, the river Duboka catchment with several occurrences of active and fissile sinkholes with direct hydraulic connection between sinkhole and karstic spring "Duboka"*; **Jelovarnik**: *geological-hydrological monument, drain the south watershed of National Park. On the surface waterflow exists the most important natural occurrence of waterfall "Jelovarnik" with total cascade height of about 70 m)*. Conducted geological, hydrogeological and hydrological investigations had the purpose to build the foundation for further monitoring system construction on the abovementioned occurrences. Within the wider area of National Park there are 12 karstic springs with groundwater of very good quality, where regime parameters are continuously monitored on these springs.

Despite the facts that Kopaonik Mt. got priority in the new development of the mountainous regions in Serbia and has the title of "the first" mountain that had great capacity possibilities to receive the great return of the people to nature, it suffered the "strong hit" with severe consequences.

Unfortunately, Kopaonik Mt. and the National Park have paid the high price for not respecting the limits and the basic concept of the planned development. The development was relinquished to the specific form of "self-organisation" of the public and private sectors, where moral and professional standards have often been forgotten. The role of the vital organisation in charge of the protection and improvement of the area "PUC National Park Kopaonik" has been diminished to the role of a helpless observer who only points with no possibility to take action when decisions made are contrary to the development and protection documents.

In the last 20 years of the active existence of the National Park, many changes have happened in the area, where mountain, national treasure and real estate have suffered the damage. Specifically, construction is out of control and not in the plan in the wider area of the winter resort followed by higher demands than the infrastructure capacity allows, then traffic chaos caused by the active transit through the protected area, the unsolved problem of the solid waste disposal in the winter season, as well as a disabled system of the previous treatment of the sewage water that are now directly disposed into the first recipient along with mining and mine waters. These all indicate the misunderstanding of the resulting serious damage on the ecosystem of the central part of the Kopaonik Mt. They bring the evaluation of the area into the question, actually the existence of the National Park category.

Abovementioned activities have caused the continual emission of the waste directly to the top of the mountain and the surroundings followed by the noticeable non-ecological education of the visitors to the area of national interest. Consequences on nature and the environment and especially on the surface and groundwaters are as follows:

- surface and groundwater pollution with waste waters and solid waste;
- dewatering of the natural water habitats of the numerous springs;
- pollution of the soil and transit waters with lead and other toxic metals caused by the heavy traffic;

- degradation of the soil and surface cover by the action on the ski paths in the summer season, and by the accommodation construction;
- microclimate changes due to the warming effect in the settlement areas;
- destruction and endangerment of the variety of floral and fauna species in the ecosystems of the high mountains in the centre and surroundings.

The consequences are visible, but their dimensions and a degree are still unknown. Therefore, in the coming period the urgent identification and classification of the pollution sources and types have to be performed followed by proscription and implementation of the more severe and active protection measures (including even the penalty politics measures) in the area for visitors in the area of the National Park Kopaonik who have no conscience.

The segment of the surface and groundwaters protection (and their interaction) is especially endangered in the central part of the resort (the core of the National Park) where the most visitors' activities take place.

Here we mention only few examples of endangerment to the capacity and quality features of the water resources of the Kopaonik Mt.:

- waste waters from the resorts are disposed directly into the recipient at the top of the mountain with no previous treatment;
- war actions in 1999 did not avoid the Kopaonik Mt. where numerous cassette-bombs of unknown content were dropped in some watersheds. This caused degradation and infiltration into the soil and surface and groundwaters (areas of Baciste, Duboka, Gobelja, etc) in the high mountainous extreme conditions;
- mine waters from the abandoned mines are flowing freely into the all watersheds and permanently increasing the content of toxic metals;
- active transit traffic in the area, as well as oil from the parking lots flowing down with atmospheric waters leave toxic metals throughout the watersheds;
- non-professional and insufficient tapping of the numerous springs for individual objects and for construction and construction not according to plan;
- the great number of ski-buffets on the ski paths with no connection to the central sewage collector;
- timber cutting not on the plan and vegetation destruction have a direct influence on the recharging aquifer conditions.

To conclude, all the activities in the estimation of the ecological, material and any other damage have to be taken seriously and an approach has to be made to the realisation of the reconstruction and protection programme of the National Park Kopaonik. The example of Kopaonik must not be kept from the public and eye of the law. Nevertheless the causes and carrier of the urban and ecological violence must be indicated. "They" consciously destroyed the ideas of the "bringing the mountain into the city frames" (what we wanted), and created "the city on the mountain" (what we got).

Kopaonik Mt. as a national treasure must be cured and rescued.

Keywords: Kopaonik mountain, protection, ecological capacity

Relationship between hydrocarbon movement and fracture patterns in petroleum storage area, Korea

[1]Se-Yeong Hamm, Sang-Hoon RYU, [2]Seong JANG, [1]Jae-Yeol CHEONG, Jeong-Hwan LEE, Moon SON

[1]Division of Earth and Environmental System Sciences, Pusan National University, Pusan 609-735, Korea, e-mail: hsy@pusan.ac.kr
[2]Environmental Geology Team, Gyeongsangnam-do office, KRC, Changwon 641-733, Korea, e-mail: seong@ekr.or.kr

ABSTRACT

Since the early 1970s, Korea has constructed many large-scale underground energy storage caverns in response to energy resource demand by rapid industrial development. This study aims to assess hydrocarbon movement originating from crude oil storages (named U-2) in Geoje Island, Korea in relation to fracture patterns. U-2 is composed of units 1, 2 and 3. The crude oil storages are located at 30 m below the sea level with 30 m cavern height. Unit 3 is operated using complete water curtain system, while unit 2 has partial water curtain system and unit 1 utilizes natural water pressure only. The geology of the study area consists of Cretaceous sedimentary rock, andesitic rock, and Cretaceous granite intruding the sedimentary and andesitic rocks. Acidic, intermediate and basic dykes have intruded the above-mentioned rocks. NNE, SE and NE trending fractures have developed in the study area. Based on fracture density map, fracture density in the unit 1 area is relatively high due to not having water curtain system. 54 monitoring wells were used for hydrogeological investigation, and chemical compositions were analyzed from water samples of the monitoring wells. BTEX were detected at six wells in unit 1, ranging 0.3-64.1 μg /L with average 23.8 μg /L. The PAH concentration in unit 1 area ranges from 0.046 to 7.29 μg /L with average 0.63 μg /L. In unit 2 area, BTEX were detected at only two monitoring wells with the concentration of 0.63-1.9 μg /L. The average PAH concentration (0.16 μg /L) of unit 2 area is lower than that in unit 1. Thus, because of no water curtain system, BTEX and PAH concentrations in unit 1 area is higher than in unit 2 area. Lee and Song (2003) observed two joint sets (joint set 1 having dip direction 208° and angle 90°; joint set 2 having dip direction 113° and angle 90°) during the excavation of unit 2. These joint sets are related to NNE and NE trending fractures observed in the study area. In particular, vertical fractures trending NNE occur in a zone around Unit 1 area. This fracture patterns justifies detection of crude oil components in Unit 1 area. In addition, it is confirmed that joint set 1 observed in U2 oil storage cavern is related to fracture density distribution in U2 area.

Acknowledgement
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Lee, C. I., Song, J. J., 2003. Rock engineering in underground energy storage in Korea, Tunnelling and Underground Space Technology, 18(2003), 467-483.

Keywords: Petroleum storage, BTEX, PAH, hydrocarbon movement, fracture pattern

The sustainability of waste disposal: pollution of groundwater by leachates from old burdens (dumpsite)

Sokefun OLUSOLA BOLARINWA

The Bioscience Research Centre, Lagos State University, Ojo, PMB 1087 Apapa, Lagos, Nigeria.
E-mail: osokefun@gmail.com

ABSTRACT

The project assessed the elemental composition of groundwater around three dumpsite in Ibadan , the second largest city in Africa. to determine the extent of groundwater pollution from dumpsites around the three areas where ground water for analysis was taken. Consistently, areas around the dumpsites have higher quantities of the elements assessed namely sodium(Na) , calcium(Ca) , magnesium(Mg) and silicon(Si) and the quantities of these elements also exceeded the maximum permissible levels in water by the World Health Organisation (WHO). Areas father away from the dumpsite had lower levels of these elements. The amount decreased in the order: Ca, Na and Si. The nature of the substratum was found to play an important and significant effect on what finally seeps into groundwater as proof of the formation of ligands were seen.. Clay soil absorbs more of the pollutants than all other soil types. An urgent review of the use of dumpsites has now become pertinent, as they affect life and all life forms in there immediate vicinity usually adversely.

Keywords: Groundwater, leachates, soil pollution, old burdens, elemental analysis

TOPIC 05

Biological assessment of groundwater ecosystems

Assessing surface water impact on groundwater using invertebrate fauna and the GW-Fauna-Index for indicators

[1]Hans Jürgen HAHN, [2]Sven BERKHOFF, [3]Jörg BORK

[1]Hans Jürgen Hahn, [2]Arbeitsgruppe Grundwasserökologie, Universität Koblenz-Landau/Campus Landau, Abt. Biologie, Im Fort 7, D-76829 Landau, Tel.: 0049 (0) 6341 280-21,1Fax: 0049 (0) 6341 280-341, email: hjhahn@uni-landau.de

[2] Sven Berkhoff, Arbeitsgruppe Grundwasserökologie, Universität Koblenz-Landau/Campus Landau, Abt. Biologie, Im Fort 7, D-76829 Landau, Tel.: 0049 (0) 6341 280-157, email: berkhoff@uni-landau.de

[3] Jörg Bork, Arbeitsgruppe Grundwasserökologie, Universität Koblenz-Landau/Campus Landau, Abt. Biologie, Im Fort 7, D-76829 Landau, Tel.: 0049 (0) 6341 280-159, email: bork@uni-landau.de

ABSTRACT

The infiltration of surface water into aquifers is a potential hazard for groundwater quality, and may indicate changes in hydrology. The early detection of these processes is a central challenge for the protection of groundwater extraction wells for drinking water purposes, as well as for the management of wetlands and the conservation of pristine groundwater communities and species.

Subsurface invertebrate fauna depend strongly on organic matter (DOM and POM), which derives mainly from the soil surface and is transported to the groundwater by surface water recharging the aquifer. The amount and quality of the organic matter influences both the abundances and the structure of groundwater communities in a predictable way.

To assess the ecologically relevant impact of surface water on groundwater, a preliminary index, the GW-Fauna-Index, was developed and tested at several sites in Germany and in Korea. From all environmental parametres recorded, the GW-Fauna-Index correlated best with the subsurface invertebrate fauna. According to the GW-Fauna-Index, three groups of groundwater habitats with three different communities were identified. In this presentation, some of these results and possible applications will be discussed together with approaches to improve the index.

Keywords: Stygofauna, groundwater communities, assessment, gw-fauna-index

Development of a first concept for the ecological assessment of groundwater ecosystems

[1]Christian GRIEBLER, [1]Christian STEUBE, [1]Tillmann LUEDERS, [2]Heide STEIN, [2]Andreas FUCHS, [2]Hans Jürgen HAHN, [3]Simone RICHTER

[1] GSF – National Research Center for Environment and Health, Institute of Groundwater Ecology, Ingolstädter Landstrasse 1, 85764 Neuherberg, Germany, e-mail: christian.griebler@gsf.de; tillmann.lueders@gsf.de.
[2] University Koblenz-Landau, Campus Landau, Dept. Biology, Im Fort 7, D-76829 Landau, Germany, hjhahn@uni-landau.de;stainheide@uni-landau.de; fuchs@uni-landau.de.
[3] UBA – Federal Environment Agency, General Aspects of Water Quality and Management, Groundwater Protection, Wörlitzer Platz 1, 06844 Dessau, Germany, simone.richter@uba.de.

ABSTRACT

Healthy aquifers deliver important ecosystem services to society; e.g. the purification of infiltrating precipitation and surface water and the storage of high quality (drinking) water over decades in significant quantities. We are dependent on groundwater for drinking water and food production and for domestic, agricultural and/or industrial use. Besides that, the functioning of many terrestrial and surface aquatic ecosystems directly depends on groundwater and vice versa. Nowadays, legislation considers groundwater not only as a resource but as a living ecosystem. In our opinion, the assessment of ecosystems requires the consideration of ecological criteria. To date, no such criteria has been available for groundwater systems while the ecological status assessment is routine for surface aquatic ecosystems. In the frame of a national research project supported by the German Federal Environment Agency (Umweltbundesamt), we now aim to develop a first concept for the ecological assessment of groundwater ecosystems considering microorganisms as well as invertebrates as biological quality units, besides the physical-chemical parameters commonly monitored.

Keywords: bioindicators, ecological assessment, groundwater ecosystems

Patterns in hyporheic invertebrate fauna and physicochemical variables along the stream-groundwater interface in Ireland

Samuel KIBICHII, Jan-Robert BAARS & Mary Kelly-QUINN

School of Biology & Environmental Science, University College Dublin, Belfield, Dublin 4, Ireland.
Email: Samuel.Kibichii@ucd.ie, janrobert.baars@ucd.ie, mary.kelly-quinn@ucd.ie

ABSTRACT

Until 50-75 years ago, floodpalin aquifers, which are hydraulically connected to the open river channel and true groundwater were not included in conceptual models of freshwater ecosystems. The hyporheic habitat is a zone of interactions between surface- and ground-waters that create gradients in the physicochemical environment. This habitat supports material and species exchanges between the stream hyporheic habitat and the spatially linked groundwater ecosystem. Despite this ecological importance, there is relatively little that is known about the surface-groundwater ecotones of Irish rivers. An understanding of patterns in the hydrochemical and biological characteristics of unimpacted reference stream-groundwater systems is key to determining the extent of the ecotone besides giving useful ecological information that can be used as restoration targets in impacted systems.

A study was conducted in March, May and August 2006 in the Delour River to determine how the hyporheic invertebrate communities change from the wetted stream channel laterally into the alluvial aquifer. We took samples randomly within the main channel, below the floodplain and at the landward terrestrial margin (up to 8 metres from the wetted channel) at a depth of 0.5m. At each point, 5 litres of sample was pumped using a Bou-Rouch sampler, filtered through a 60 µm sieve, preserved and processed in the laboratory. Temperature, pH, conductivity and dissolved oxygen (DO) were measured on site using portable meters. A litre of sample (6^{th} litre from the Bou-Rouch) from each of the points was analysed in the laboratory for standard parameters, including alkalinity, nitrate, nitrite and ortho-phosphate, and various cations and anions. Only results for May for these latter variables were included in correlation analyses because only a few samples were analysed in March.

Overall, the hyporheic habitat of the Delour is highly variable in its physicochemical characteristics. However, there were significant differences between the surface and hyporheic waters in all variables. Although there were high variability in mean values for most variables measured from within the channel, there were no significant differences in the flood plain and the terrestrial margin. For example, there was a marked reduction in DO from ~11.0 mg/L in the stream to as low as 0.05 mg/L at the furthest lateral extent under the terrestrial margin. Along the same gradient, there was a marked increase in alkalinity and conductivity by a factor of up to 3 orders of magnitude between the surface water and samples from the hyporheic habitat under the stream, floodplain and terrestrial margin. However, seasonal differences in conductivity and alkalinity were noted, particularly between spring and the summer samples. Sodium did not show any particular patterns. Nutrient levels were low during the sampling periods, although concentrations were notable lower from the hyporheic samples in the floodplain and terrestrial margin.

The invertebrate fauna, in terms of abundance and taxon richness, also showed notable variation between sampling points. In March, mean abundances (individuals/5L sample) were 60.5±17.4 (mean±standard error) (below the wetted channel), 34.2±11.5 (floodplain) and 27.8±14.1 (terrestrial margin). In May, mean abundances were 84.9±22.9 (below the wetted channel), 40.0±9.4 (floodplain) and 26.0±8.9 (terrestrial margin). The abundances varied between samples, but the numbers were higher in the hyporheic samples under the stream in both spring and summer. There was a decreasing trend in taxon richness from the stream (8.33±0.9; mean±SE and 11.6±1.8) to the terrestrial margin (3.7±0.9 and 6.6±1.4) for March and May respectively. The cumulative taxa richness for the stream, floodplain and terrestrial margin were 26, 19 and 12 respectively for March and 25, 15 and 18 respectively for May. High taxon richness in the main channel was attributed to benthic-associated groups with burrowing habits, and also included Copepoda, Ostracoda, Cladocera, and Oligochaetes. Some seasonal variation in these taxon richness trends were noted. Significant correlations were found between the invertebrate abundances and calcium (r_s=-0.69; $p<0.05$) and magnessium (r_s=-0.87; $p<0.05$). Similarly taxon richness was correlated to, calcium (r_s=-0.84; $p<0.05$) and magnessium (r_s=-0.84; $p<0.05$). Taxon richness and abundance was also significantly correlated (r_s=0.84). The burrowing terrestrial beetles (Staphylinidae and Pteliidae) and the subterranean *Niphargus* spp. added to a mainly meiofaunal community.

Our findings agree with similar previous work on hyporheic habitats in Europe, showing that hyporheic habitats are highly variable in space and time, with sharp gradients marked by reductions in DO and lateral increases in ionic content, and reductions in the abundace and diversity of invertebrate fauna. Interestingly, we

observed a curiuos overlap of meifauna (Copepoda, Ostracoda and Oligochaeta), burrowing terrestrial beetles (Staphylinidae and Pteliidae) and subterranean invertebrates (*Niphargus* spp.) in the watertable below the vegetated terrestrial margin. This surprising finding shows that there is a potential link, not just between surface and groundwater ecosystems, but also the terrestrial habitat. This study is part of a larger project assessing the reference condition of hyporheic habitats and the potential impacts from intensive agricultural land-use.

Keywords: Surface-groundwater interface, invertebrate fauna

TOPIC 06

Subterranean ecosystems: biodiversity and habitat heterogeneity at spatial and temporal scales

Abundance and diversity of invertebrates in hyporheic and phreatic zone from four small rivers in central Slovenia

Anton BRANCELJ, Natasa MORI,

Vecna pot 111, Ljubljana, Slovenia, e-mail: anton.brancelj@nib.si

ABSTRACT

Hyporheic and phreatic zone of four rivers in central Slovenia, with a length between 20 and 30 km, were sampled. They are hard-water rivers with an average discharge of about 500 l s^{-1}. They emerge at an elevation between 380 and 420 m a.s.l., at 300 m a.s.l their flow continues along alluvial plains formed of gravel. After several kilometers the gravel in the riverbeds is replaced with impermeable clay deposits. Along the rivers there are different intensities of land use. Twelve sampling locations for phreatic and twelwe for hyporheic habitats were selected along each of the river channels. On each location an iron pipe for a Bou-Rouch pump was inserted 60 cm deep into the gravel in the middle of the stream (hyporheic zone). Five replicates of 10 l of water were pumped and filtered. Samples from phreatic zones were collected in the same way at least 1 m from the river channel. In total, about 96500 specimens were collected in the hyporheic zone and about 24800 in the phreatic zone. Representatives of 26 groups of metazoans were present in the samples. Special attention was placed on evident stygobitic taxa (Bathynellaceae, Isopoda, *Niphargus* spp. and *Parastenocaris* spp.). Thirteen taxa were determined in a preliminary detail survey of Harpacticoida (Copepoda) from hyporheic zone, and eight of them were stygobitic or at least stygophilic. The most common groups in both zones were Cyclopoida (26.5 % in hyporheic vs. 36.3 % in phreatic) and Harpacticoida (19.1 % vs. 11.5 %). They were followed by Nematoda, Oligochaeta and Gastropoda (Fig. 1). PCA and cluster analyses on log-transformed data of abundance showed distinct separation between hyporheic and phreatic zones. All five groups contributed to 79 % of specimens in hyporheic and to 88 % in phreatic zone. Representatives of strictly epigean fauna (Insecta) were common in the hyporheic (13.2 %) but not in the phreatic zone (3.4 %). Representatives of stygobitic groups (*Niphargus* spp., Isopoda and Bathynellaceae) prevailed in the phreatic zone but *Parastenocaris* spp. in hyporheic zone. There were some significant differences between the different river basins. Among the five most common groups Nematoda, Oligochaeta and Cyclopoida have relatively similar distribution between the river basins (range between 8 % - 20 % in hyporheic and 10 % - 16 % in the the phreatic zone). The most extreme differences existed in the phreatic zone in the distribution of Gastropoda (range between 1.6 % - 40.8 %) and Harpacticoida (1.4 % - 14.7 %). Fauna of the hyporheic and the phreatic zone is qualitatively and quantitatively very rich in four selected small rivers and is well represented by the stygobitic groups. Based on PCA log transformed abundance data, the hyporheic and the phreatic zone is well separated. The phreatic zone hosts less abundant fauna but is preferred by stygobionts. In the hyporheic zone epigean taxa are more abundant, but stygobitic taxa also persist there.

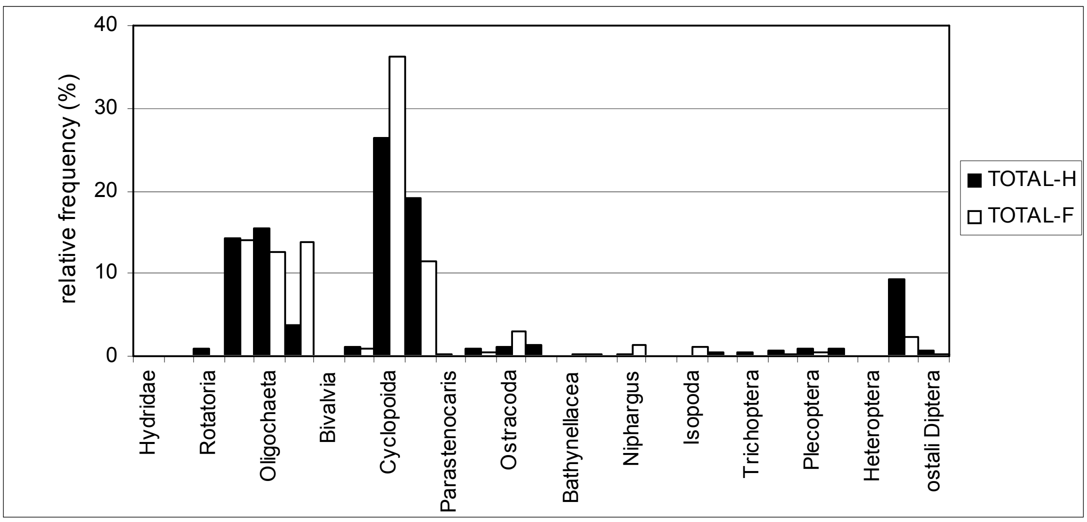

Fig. 1: Distribution of different taxa in hyporheic (H) (depth 30-60 cm) and phreatic zone (F) (60-90 cm) in four rivers in Slovenia

Keywords: hyporheic zone, phreatic zone, biodiversity, invertebrates

Dynamics of Microbial Communities in Karst Groundwater – a Case Study from Yverdon-les-Bains, Switzerland

[1]Michiel PRONK, [1]Nico GOLDSCHEIDER, [1]François ZWAHLEN, [2]Jakob ZOPFI

[1] Centre of Hydrogeology, University of Neuchâtel, Rue Emile-Argand 11, CP 158, 2009 Neuchâtel, Switzerland, e-mail: michiel.pronk@unine.ch, nico.goldscheider@unine.ch, francois.zwahlen@unine.ch
[2] Laboratory of Microbiology, University of Neuchâtel, Rue Emile-Argand 11, CP 158, 2009 Neuchâtel, Switzerland, e-mail: jakob.zopfi@unine.ch

ABSTRACT

Karst aquifers are increasingly considered as ecosystems harbouring their proper biocenoses. Yet ecological studies mainly dealt with invertebrates and larger animals (fish, amphibians, molluscs) in karst cavities; microbial ecology research was scarce and focused principally on the fate and transport of pathogens. A few studies investigated the role of microorganisms in precipitation or dissolution of minerals in caves but generally little is known about autochthonous microbial communities and their biogeochemical roles in karst aquifers. Studying these communities can help to better understand the ecological functioning of karst aquifers. Microbial communities and their spatial-temporal variability could potentially serve as natural tracers for the origin and transit times of the water. Furthermore, they could be used as indicators for groundwater quality. This reasoning is reflected in the Swiss Water Protection Ordinance (1998), which defines water quality standards and demands that the biocenosis in groundwater should be in a natural state and characteristic of water that is not or only slightly contaminated (see communication by Goldscheider et al. at this Congress).

System and Approach: The upper Jurassic (Malm) and Cretaceous limestones on the SE slope of the Jura Mountains form the main recharge area of the Yverdon-les-Bains karst aquifer that feeds principally two major groups of springs at *Moulinet* and *Cossaux*. These springs are additionally fed by the *Feurtille* swallow hole that drains an agricultural plain. The transit time between the swallow hole and the springs varies from 24 hours to 13 days during high- and low-flow conditions respectively (Pronk *et al*. 2006).

This karst system was investigated during a complete annual cycle by hydrogeological monitoring techniques (continuous measurements of discharge, temperature, conductivity, total organic carbon (TOC) and turbidity) combined with classical bacteriological tests (i.e. aerobic heterotrophic bacteria, coliforms, *E. coli*, Enteroccocci), and molecular methods from microbial ecology (Fig. 1). Microbial communities and their dynamics were followed at the swallow hole and the two spring groups by DGGE (Denaturing Gradient Gel Electrophoresis) fingerprints of 16S-rDNA PCR (Polymerase Chain Reaction) products. At 2 selected dates, representing contrasting hydrological conditions, a complementary cloning/sequencing approach was applied in order to obtain a more complete picture of the eubacterial diversity in the Moulinet spring water.

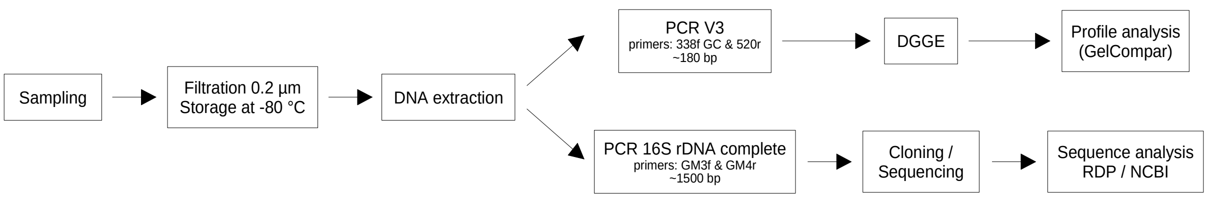

Fig. 1. Molecular methodology applied at the Yverdon-les-Bains karst system.

Results: The bacterial 16S-rDNA community fingerprints at the swallow-hole showed drastic changes from one sampling date to the next. A high bacterial diversity was observed but the community was typically dominated by the presence of a few abundant species. Fingerprints of the eubacterial community in spring water samples were clearly different from swallow-hole samples. A complex pattern with rather faint bands indicates the presence of bacterial communities that consist of a large number of more or less equally abundant species. The DGGE fingerprints of the hydrological cycle at the springs (21 samples) revealed a high overall similarity (> 85 %) among sampling dates, demonstrating the temporal constancy of the microbial community in the karst system and suggesting the existence of a stable autochthonous microbial endokarst community as described by Farnleitner *et al.* (Environ. Microbiol., 2005, 7:1248ff). Despite this high overall similarity, statistical analysis (Pearson correlation and UPGMA) revealed clusters of DGGE patterns that mirrored distinct hydrogeological conditions (Fig. 2). For example, the bacterial community in spring water at times when it was strongly

influenced by the *Feurtille* swallow, thus characterized by high allochthonous TOC, nitrate and faecal bacteria, was clearly differentiated from other hydrological conditions.
Short-term variations (daily samples) of the microbial communities in spring water were studied during distinct flood events. The response of the springs to a rain event can be divided in four stages: I) base-flow, II) discharge increase, with a slight increase in turbidity, while the other parameters remain stable, III) arrival of swallow hole water, peaks of discharge, TOC, turbidity, nitrate and faecal indicator bacteria, and IV) recession. DGGE fingerprints showed a high degree of constancy during the flood events. Nevertheless, small variations were correlated with the swallow-hole component arrival. Interestingly, the sample from the rising limb (stage II) is more closely related to the one taken during base-flow conditions (stage I), than to the swallow hole influenced stage III. It is hypothesized that the bacteria arriving at the spring during stage II represent remobilized autochthonous micro-organisms. Additional particle size distribution analyses confirmed the autochthonous origin of the turbidity peak during the discharge increase (stage II).

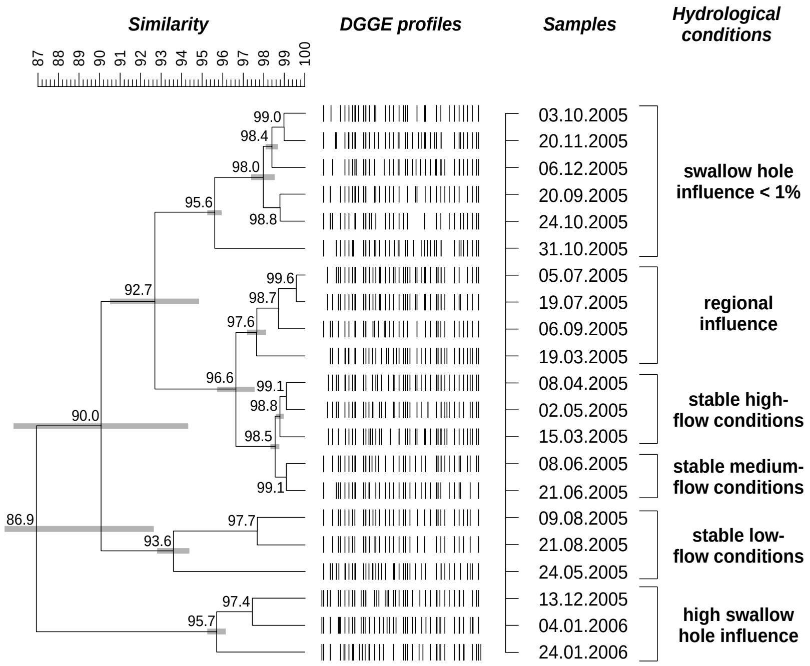

Fig. 2. Cluster analysis of DGGE profiles of bacterial communities at the Moulinet springs during the annual hydrological cycle.

As the majority of microorganisms in oligotrophic groundwater are not cultivable on traditional growth media, a cloning/sequencing approach was applied to two samples from the Moulinet spring. This approach provides an unbiased and more complete appreciation of the bacterial community composition during stable low-flow conditions, and high-flow conditions with a high swallow-hole influence, respectively. Although both samples revealed a high bacterial diversity, it was significantly higher for the high-flow conditions – possibly due to the washout of soil microorganisms into the karst system during rainfall. At both dates the bacterial communities in the spring water were dominated by *Proteobacteria* and by low G+C Gram-positive bacteria. However, notable differences exists between the two samples: I) 25 % of the clones retrieved during base-flow conditions, against 8 % of the clones of the high-flow conditions sample, could not be grouped into a taxonomic unit lower than the bacterial domain (Similarity to known sequences < 50 %, Bayesian rRNA classifier algorithm), indicating the distinctiveness of the habitat. II) Similarly, about 94 % and 79 %, respectively, could not be affiliated to known bacterial species (sequence similarity < 97 %). Also interesting is the repeated recovery of sequences affiliated to the currently uncultivated candidate divisions *OP11* and *WS3* during base-flow conditions.

References:
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Keywords: Karst, ecosystems, microbial diversity, DGGE, cloning/sequencing

Heterogeneous aquifers as habitats for microbial biocenoses

[1]Nico GOLDSCHEIDER, [1]Daniel HUNKELER, [1]Michiel PRONK,
[2]Pierre ROSSI, [3]Ronald KOZEL & [4]Jakob ZOPFI

[1]Centre of Hydrogeology, Univ. Neuchâtel, Switzerland, e-mail: nico.goldscheider@unine.ch,
daniel.hunkeler@unine.ch, michiel.pronk@unine.ch
[2]Laboratory for Environmental Biotechnology, EPFL, Lausanne, Switzerland, e-mail: pierre.rossi@epfl.ch
[3]Federal Office for the Environment, Bern, Switzerland, e-mail: ronald.kozel@bafu.admin.ch
[4]Laboratory of Microbiology, Univ. Neuchâtel, Switzerland, e-mail: jakob.zopfi@unine.ch

ABSTRACT

Aquifers are not only drinking water resources for human use, but are increasingly considered as ecosystems, consisting of habitats (i.e. the physical environment) and biocenoses (i.e. the organisms that live there), which interact in a complex way. This is also reflected in the Swiss Water Protection Ordinance, which demands that the biocenosis in groundwater should be in a natural state adapted to the habitat and characteristic of water that is not or only slightly polluted, as an indicator for a good groundwater quality status. As there were no clear criteria to characterise these biocenoses and to define their natural state, a detailed literature study was carried out in order to assess the current knowledge on groundwater habitats and biocenoses, and to evaluate available investigative methods (Goldscheider *et al*. 2006, Hunkeler *et al*. 2006). This communication focuses on aquifer heterogeneity and how it influences the microbial biocenoses and their characterisation.

Aquifers are heterogeneous on all scales and can be structured, from an ecological point of view, into a variety of macro-, meso- and microhabitats (Fig. 1). The contact or transition zones between habitats can be described as ecotones and are often characterised by increased biological activity and diversity. Ecotones can also be observed on all scales, e.g. contact zones between different aquifers and aquicludes, or between sand layers and clay lenses. Steep chemical energy gradients can be observed in such zones, for example at the groundwater table and in the capillary fringe, where reduced groundwater may come in contact with oxygen-rich percolation water. On a microscopic scale, interfaces between organic or inorganic particles and pore water can be considered as micro-ecotones. Karst aquifers are additionally characterised by strong temporal variability, which results among others in variations of the microbial composition of the spring water (e.g. Pronk *et al*. 2006).

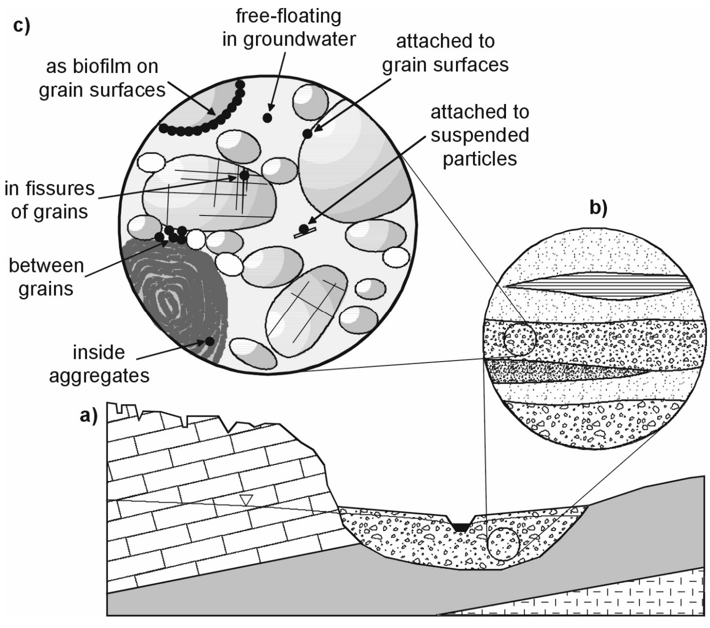

Fig. 1. Aquifer heterogeneity on all scales results in a great variety of macro- (a), meso- (b) and microhabitats (c) for biocenoses. The groundwater table and hyporheic zone are important ecotones on a macro- to meso-scale.

Microorganisms predominate in most groundwater environments, mainly bacteria (true Bacteria and Archea) and protozoans, but also fungi. Small invertebrates are also often present, while larger organisms (i.e. animals) are restricted to the wider voids in karst aquifers and the hyporheic zone. Due to the absence of light, groundwater biocenoses entirely depend on chemical energy, which is, however, scarce in non-polluted oligotrophic aquifers. All groundwater animals, protozoans and most bacteria are chemoorganoheterotrophic, i.e. they need organic carbon (OC) (Fig. 2). OC generally originates from the surface, and its concentration is rapidly decreasing within the unsaturated zone and aquifer. Chemolithoautotrophic bacteria are independent of OC as they can synthesise their biomass from CO_2 and inorganic energy sources. The heterogeneous distribution of all these energy and nutrient sources further increases the heterogeneity of the habitats and biocenoses, e.g. locally reducing conditions around organic particles in a generally oxidising aquifer; locally acid conditions around pyrite grains; locally nutrient-rich conditions around apatite grains, etc. Groundwater macro- and microorganisms developed specific adaptation strategies to survive nutrient-poor conditions: reduced sizes and activities, low population densities and reproduction rates, long lifetimes, and the effective use of energy resources.

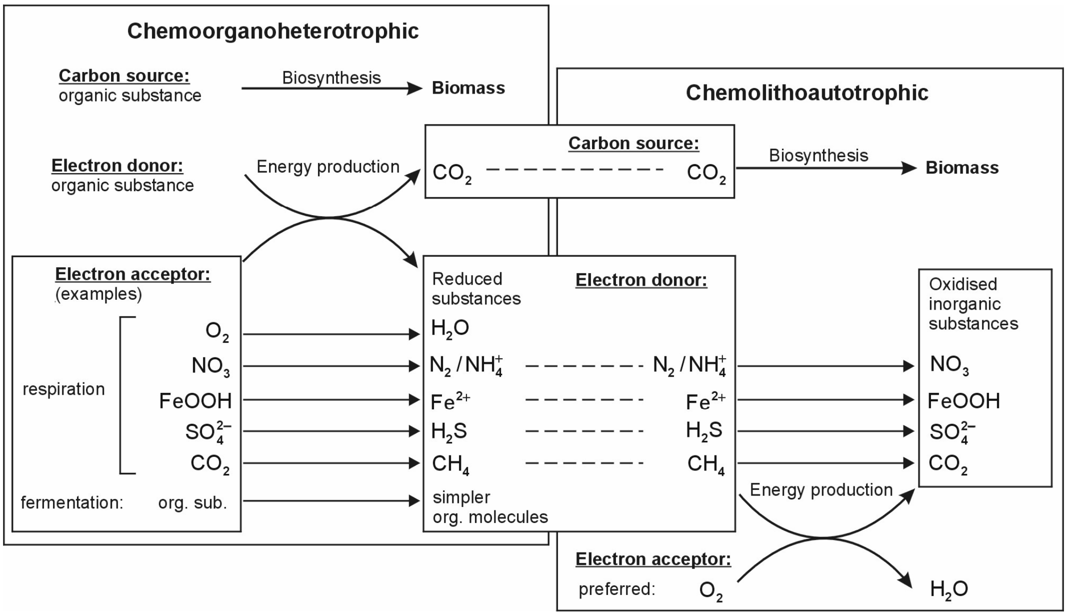

Fig. 2. Illustration of metabolic pathways in aquifer biocenoses. Reduced substances produced by heterotrophic bacteria serve as electron donor for autotrophic bacteria (modified after Goldscheider *et al*. 2006).

Various methods can be applied to investigate microbial biocenoses. Due to aquifer heterogeneity, representative sampling is a major problem. As most bacteria live attached on mineral grains while only a small percentage is planktonic, a complete characterisation of the biocenoses would require both solid and liquid phase sampling. However, samples of aquifer material are generally difficult to obtain, while groundwater samples mostly include planktonic organisms from highly permeable layers. Different analytical methods make it possible to count microorganisms, to identify species, to measure microbial activity, and to characterise the genetic, morphologic or metabolic microbial diversity. Classical cultivation techniques provide only an incomplete picture, as most groundwater bacteria are viable but non-culturable (VBNC) cells. Methods from molecular microbiology, such as PCR-DGGE, can produce a “genetic fingerprint” of the entire microbial community (see communication by Pronk *et al*. at this Congress).

Considering aquifers as habitats harbouring specific biocenoses has two major implications. First, the biocenosis can be used as an indicator for groundwater quality. However, at present there is no commonly agreed methodology to do so, although interesting approaches have been proposed. Second, the biocenoses can be considered as something valuable that needs to be protected. While microorganisms are generally not included in the concept of species protection, many animal species and even genera, families and orders are endemic to aquifers, often regionally very restricted, and thus contribute significantly to global biodiversity.

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Pronk M, Goldscheider N, Zopfi J (2006) Dynamics and interaction of organic carbon, turbidity and bacteria in a karst aquifer system. Hydrogeology Journal 14: 473-484.

Keywords: non-polluted aquifer, heterogeneity, environmental microbiology, microbial community

TOPIC 07

Biodegradation processes in contaminated aquifers and role of subsurface organisms in purifying groundwater

Assessment of the natural transformation of nitro-aromatic compounds in groundwater: first results of a case study - Portugal.

[1]Helena AMARAL, [2]Judite FERNANDES, [1]Michael BERG, [1]Rolf KIPFER

[1]Eawag, W&T, Überlandstr. 133, 8600 Dübendorf, Switzerland, e-mail: Helena.Amaral@eawag.ch
[2]INETI, Dept. of Hydrogelogy, Alfragide, Portugal.

ABSTRACT

We present a field study in Portugal, where nitro-aromatics originating from the production of explosives, have been found to pollute two aquifers. TNT and DNT were introduced to the groundwater after leaching from excavated lagoons where residual waters were disposed. The lagoons excavated in sands, were extremely permeable and unconfined, permitting the leakage of those compounds to the subsurface. Some of the most important characteristics of nitro-aromatic compounds in the environment are: persistence in oxic conditions and degradation under anaerobic conditions, sorption to clay minerals, density greater than water and low soluble to insoluble in water. They are highly toxic and carcinogenic.

To assess the natural attenuation of the TNT and its metabolites in aquatic systems, we propose the combined use of isotopic techniques and groundwater dating methods. The combination of these methods allows the occurring processes and degradation rates to be determined, and the temporal evolution of an organic pollutant to be evaluated. Thus, environmental tracers are used to characterize the groundwater flow and to determine groundwater residence times, whereas measurement of the concentration of the pollutants and their compound-specific isotopic signatures allows the quantification of the transformation of the organic substances. The application of these methods at the field scale is an important tool when remediation strategies have to be drawn.

The site is located in the left margin of the River Tejo – Portugal. The hydrogeology of the area is characterized by complex multi-layered porous aquifers: an upper unconfined aquifer locally highly contaminated, and a lower semi-confined aquifer with traces of contamination by nitro-aromatics. The upper aquifer consists of Pliocene heterogeneous sediments of fluvial or estuary deposition, whereas the lower aquifer consists of Miocene calc-sandstones. At present the lower aquifer is being exploited for civil and industrial water supply, while the upper one serves private dug-well owners for agriculture, drinking resources and other utilities. Under the prospect that people are at risk of being affected by this contamination, it is important to understand the distribution of those compounds in the aquifers over-time.

Groundwater age, determined by the method ^3H-^3He, indicates that the groundwater residence time in the upper aquifer ranges between 23 to 25 years, while the lower aquifer seems to have no tritium at all, indicating that the groundwater has been recharged for more than 50 years at least. Nitro-aromatics found in both aquifers show the existence of a hydraulic connectivity, allowing the percolation of those compounds from the upper aquifer to the lower aquifer. The main hotspot of contamination is located just northeast of the area of the explosives production, where the concentration of TNT reaches 33mg/L. High values of TOC and DOC suggests, moreover, the degradation of those compounds, despite the presence of oxygen.

Keywords: environmental tracers, isotopic techniques, natural degradation, nitro-aromatics.

Biodegradation potential in karst settings indicated by the pyranine dye tracer

Michael SINREICH

Centre of Hydrogeology CHYN, Neuchâtel University, Switzerland, e-mail: michael.sinreich@unine.ch

ABSTRACT

Many karst settings are typically characterised by thin soil cover, preferential groundwater flow and short residence times. These features commonly favour rapid contaminant migration, while limiting natural attenuation processes, such as the biodegradation of organic compounds. This is presumably due to the lack of sufficient interaction between rock surfaces coated with micro-organisms and rapidly flowing water passing through karst systems. This study employed breakthrough curves generated during karst groundwater tracing experiments in the Swiss Jura Mountains to determine degradation rates for the dye pyranine, by comparing its response to that of a persistent tracer (uranine). Subsequent batch tests using aquifer material and associated groundwater proved biotic degradation to be responsible for pyranine mass loss.

Field tracing comprised simultaneous injection of uranine and pyranine dye tracers. Both dyes are considered mobile and were believed to behave conservatively, according to the literature. Water samples were collected and stored in a cool dark environment until dye concentrations were determined by means of a laboratory fluorimeter. The results of these analyses were plotted as dimensionless concentrations (C/C_0) in order to permit transport parameters to be compared. The results have allowed the degradation of pyranine to be estimated with respect to uranine.

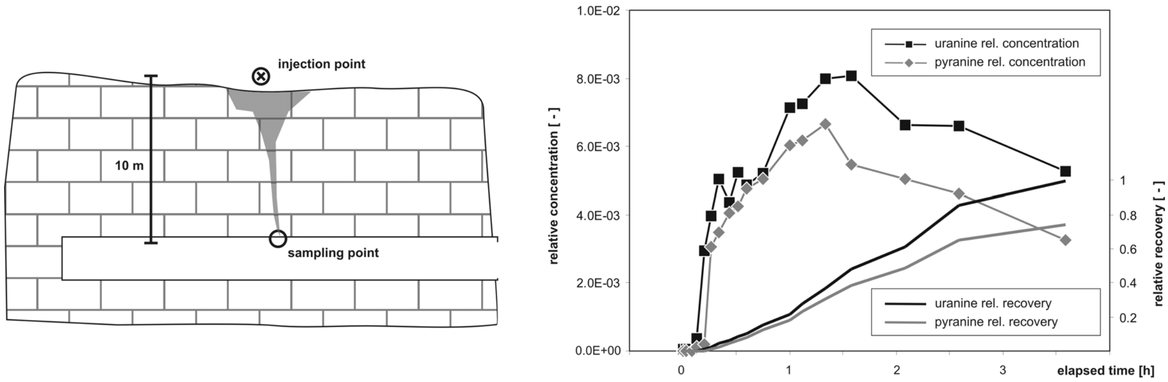

Fig. 1. Vadose zone field experiment.

Vadose zone field experiment: In order to assess biodegradation rates within the vadose karst zone, both tracers were applied to the ground surface overlying an unlined tunnel, where seepage water samples were subsequently collected (Fig. 1). Tracer breakthrough curves demonstrate increasing divergence between uranine and pyranine relative concentrations with time. At the end of the experiment, i.e. 3.5 hours after injection, pyranine reached only 2/3 of uranine's relative concentration, while the mass recovery of pyranine reached 75 % of that of uranine. More precisely, the results demonstrate that no significant discrepancy arises between both tracers' breakthrough curves until 45 minutes after injection. This is suspected be due to the arrival of preferential flow components at the beginning of the test, while slow flow components arrived at later times. This later arrival possibly reflects a greater role played by soil and/or epikarst pore volumes, where higher microbial activity may by possible. Pyranine-specific attenuation was thus modelled by employing first-order degradation rates in the range of 0.1-0.2 h^{-1} during vadose karst zone passage.

Saturated zone field experiment: A second experiment, selected to investigate biodegradation in the saturated karst zone, employed a similar approach. The contaminant attenuation capacity of saturated karst is normally regarded as insignificant, particularly if conduit flow dominates. However, breakthrough curves plotted in Fig. 2 once again demonstrate considerable discrepancy between uranine and pyranine responses. By the end of the test, pyranine recovery reached just over 50 % of that of uranine after travelling through 3 km of an open conduit cave system.

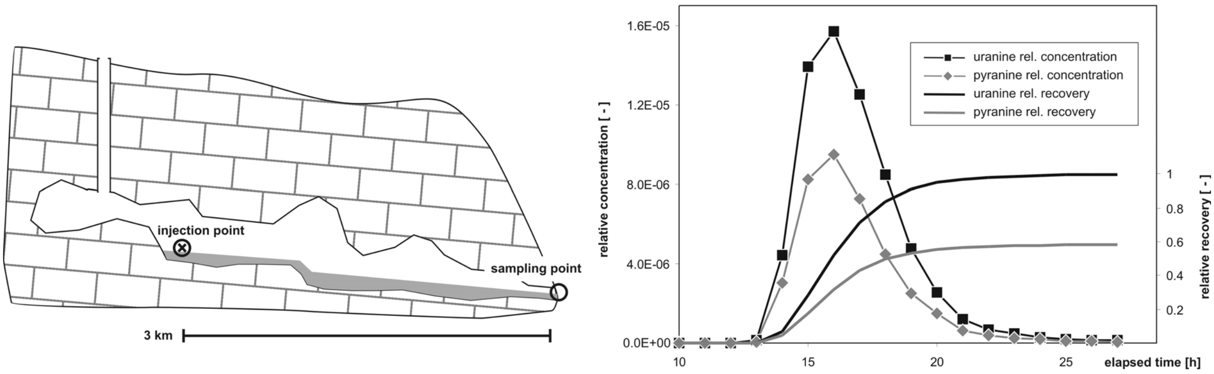

Fig. 2. Saturated zone field experiment.

Batch experiments: Room temperature batch tests, performed to identify the attenuation process that caused the pyranine response observed in the saturated karst experiment employed 100 g aquifer material gathered from the conduit's streambed and 100 ml water from the associated spring. Fig. 3 presents changes in concentration in water spiked with pyranine and uranine at concentrations resembling those employed during the field experiments, over a 48-hour period. While there is a strong decline of pyranine concentration within few hours in samples derived from the batch employing pristine aquifer material, no significant degradation can be observed for the same material without micro-organisms (i.e. treated with H_2O_2) or in the experimental control. This confirms that biodegradation is responsible for pyranine attenuation. Furthermore, testing for desorption by placing solid matter into untraced water at the end of the experiment demonstrated that adsorption was not the prime cause for attenuation. Using limestone material from the aquifer's unsaturated zone similar to that taken from the streambed resulted in intermediate pyranine degradation rate. The same test series using uranine instead of pyranine data yielded constant values equal to initial uranine concentration for all four cases.

The second graph of Fig. 3 compares pyranine degradation rates for different initial concentrations, showing mass loss up to 1 mg within 24 hours. These curves follow second-order degradation kinetics and are possibly the result of induced bacterial growth under favorable laboratory conditions.

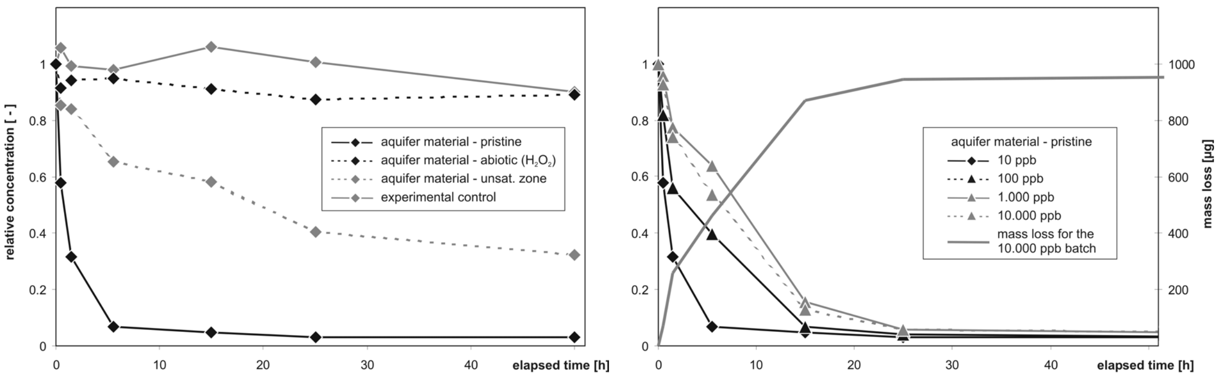

Fig. 3. Laboratory batch experiments.

By combining field and laboratory experimental data natural attenuation of pyranine in karst can be identified. Batch tests with aquifer material have demonstrated the existence of an intact biofilm coating limestone surfaces. These films are believed to be responsible for biodegradation, which is suspected to be driving process for pyranine attenuation during the saturated zone experiment. Consequently, significant degradation may occur despite limited contact surface area between the solute and the solid material. In the case of the vadose zone experiment, microbial activity in the soil and epikarst is suspected to be responsible for pyranine degradation.

These results demonstrate significant biodegradation may occur in karst settings where microbial activity is high. Organic contaminants, such as some pesticides, may possibly be removed from karst groundwater, particularly if relevant storage volumes permit prolonged residence times. These points in turn, provide quantitative information on tracer degradation rates and the processes that may possibly be of assistance in identifying flow and storage components in karstified systems. Finally, these experiments highlight the risk of misinterpretation of tracing tests results, if tracer-specific properties are inappropriately accounted for.

Keywords: natural attenuation, comparative tracing, pyranine, biofilm, karst

Biogeochemical mediation of groundwater borne nitrate seepage into the Ria Formosa Coastal Lagoon by beach-face sandy sediments

[1]J. Severino P. IBANHEZ, [1] Catarina LEOTE, [1] Carlos ROCHA
[1]Biogeochemistry Research Group – CIMA/IMAR, Campus de Gambelas – Faro, Portugal,
e-mail: jibanhez@ualg.pt, cleote@ualg.pt, crocha@ualg.pt

ABSTRACT

Coastal Groundwater Discharge (CGD) can be an important source of fresh-water to the coastal ocean. It is estimated that between 10 and 30% of the total fresh-water input to these environments could originate in CGD, eventually reaching 100% in particular cases. Depending on the land-use of the recharge area of coastal aquifers, this freshwater can be associated with important inputs of nutrients and contaminants to the coastal ocean. In this light, all biotic and abiotic processes that occur on the aquifer itself and on the associated freshwater/saltwater interface are crucial to the enhancement or mitigation of the impact of these compounds over the discharge area. Using a combination of Lee-type seepage meters, specially designed in-situ benthic porewater profilers and modelling techniques, we identify and characterize sites on the Ria Formosa coastal lagoon (Portugal) locus of CGD with high nitrate content and studied the biogeochemical mediation of these seepage fluxes at the sediment-water interface. To our knowledge, these are the first findings of this nature on the Ria Formosa.

We identified the tide as the main function on the discharge of CGD at the beach-face of the barrier islands. Tidal period determines the cycle of seepage. In accordance to the forcing exerted by tidal oscillation, the highest nitrate fluxes from the sediment to the lagoon were measured during sediment exposure. These fluxes could reach values of 5.5 mmol m^{-2} h^{-1} of DIN (Dissolved Inorganic Nitrogen). Tidal range and period also determines the extent of the biogeochemical mediation exerted by the sandy sediments through which the major seepage occurs (Fig. 1). We show that the surface sediments locus of the highest vertical seepage rates support a net loss of DIN before the contaminated waters reach the water column of the lagoon.

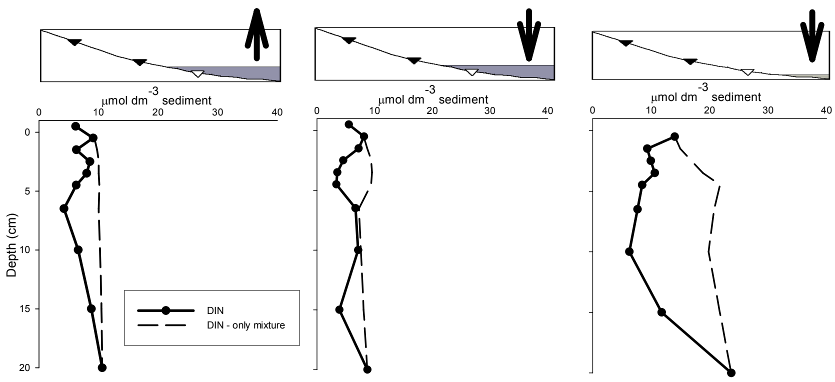

Fig. 1. Tidal influence over DIN theoretical mixing profiles on the first 20 cm of the sediment, modelled using salinity as a conservative tracer, compared with the observed distribution in-situ during November 2005. Topmost drawings show water level at the time of porewater profile collection and the beachface profile at the sampling transect. Triangles indicate location of deployed in-situ profilers: open symbols identify the location of the profile depicted on the lowermost plots

To evaluate more precisely the biogeochemical reactivity of the sediments subject to groundwater-borne nitrate inputs, and therefore predict local nitrate fluxes reaching the lagoon, a deterministic diagenetic model was applied to simulate the observed results, with fluid advection set as the main driving force for transport of the porewater. Nitrification and apparent denitrification were considered the main reaction pathways affecting the nitrate pool. The possibility of occurrence of carbon limitation was also included in the model.

Sensitivity analysis of the model runs on 96 different in-situ porewater nitrate profiles sampled throughout one year shows that the advective velocity is the main factor controlling pore-water nitrate distribution and concentration levels. We subsequently report preliminary inverse modelling results, which demonstrate a good correlation between model simulations and the observed distribution in-situ (Fig. 2). From these model fits, high rates of nitrate transformation were derived; nitrification rates obtained this way typically varied between 0 and 4 mmol m^{-2} h^{-1}, and apparent denitrification between 0 and 2 mmol m^{-2} h^{-1}, representing the removal of a high percentage of the upward-seeping nitrate. Some carbon limitation of apparent denitrification rates was also shown to occur, confirming the high reactivity of the system.

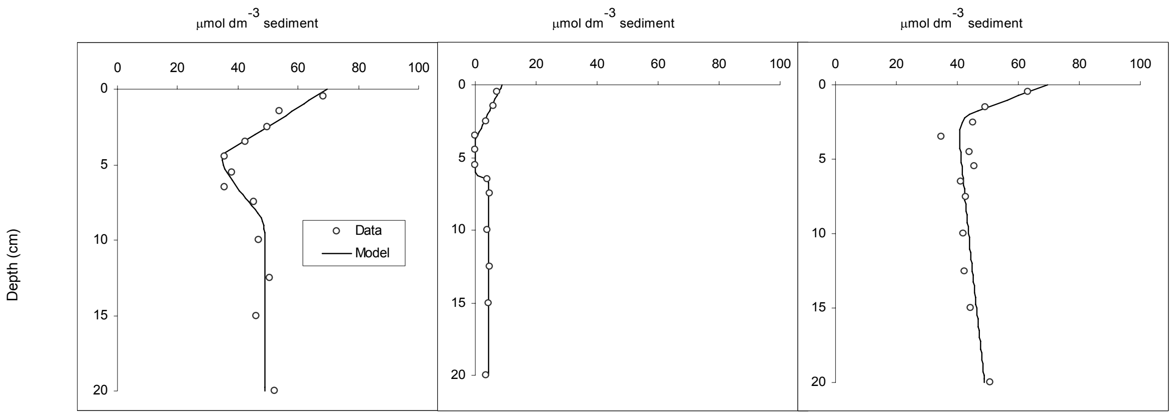

Fig. 2. Model fits of observed profiles of pore-water nitrate distribution at a sandy beach site locus of CGD, at the Ria Formosa, corresponding to the different tidal stages depicted on Fig. 1.

Good correlation between measured sediment-water fluxes of nitrate and model outputs was also found, validating the model for predictive use, namely to simulate and anticipate the response of the system to changing nitrate contamination levels and porewater seepage rates. In our view, these results confirm the great influence of CGD on internal nutrient loading of the Ria Formosa lagoon.

Keywords: CGD, Nitrate, Beach, Diagenetic Modelling, Reactivity

Characterization of a BTEX contaminated aquifer by using compound-specific stable carbon and hydrogen isotope analysis

[1,2]Jeroen VERHACK, [1]Jan BRONDERS, [1]Ilse VAN KEER, [2]Rudy SWENNEN, [3]Harry VELD, [4]Jan SCHWARZBAUER

[1] Flemish Institute for Technological Research (VITO), Boeretang 200, B-2400 Mol, Belgium
e-mail: jeroen.verhack@vito.be
[2] Geology, Catholic University Leuven, Celestijnenlaan 200E, B-3001 Heverlee, Belgium
[3] Netherlands Institute of Applied Geoscience TNO, Budapestlaan 4, Postbus 80021, 3508 TA Utrecht, The Netherlands
[4] Institute of Geology and Geochemistry of Petroleum and Coal, RWTH Aachen University, Lochnerstrasse 4 - 20, D-52056 Aachen, Germany

ABSTRACT

Release of hydrocarbon contaminants into the environment is a significant problem, not only from an environmental hazard and cleanup point of view, but also in terms of liability assessment. Unfortunately, source apportionment and determination of spill migration is not always straightforward, since hydrocarbon releases often occur from multiple sources. Furthermore, hydrocarbons in the soil are subjected to degradation processes and transport can also be very complex. (Wang *et al*., 1999). Due to the recent developments in compound-specific stable isotope analysis (CSIA) a lot of new and unique data has become available, which have been shown to have a great potential for source apportionment and assessment of microbial degradation (e.g. Slater *et al*., 2003; Meckenstock *et al*., 2004). Still, less is known about the benefits and pitfalls of the application of CSIA to characterize more complicated contaminations. Therefore, the usage of CSIA was studied to distinguish the impact of multiple sources on an aquifer and to evaluate the presence of degradation processes.

The contaminated aquifer is located in the industrial area of Vilvoorde (Belgium). Soil investigations carried out at and around the site, indicated the presence of soil and groundwater pollution with volatile organic hydrocarbons, including BTEX and chlorinated aliphatic hydrocarbons (CAHs). The aquifer contamination is caused by two distinct sources. A first source 'Source area 1', located at the site of a former paint and varnish factory, resulted in a groundwater plume of dissolved BTEX compounds. Chemical analyses indicated that below depths of 7.5 m, the contamination is at least partly caused by an upstream second contaminant source also containing CAHs, defined as 'source area 2'. This second source area, is related to the activities of a former solvent recycling factory. The field situation is given in Fig. 1.

Both source areas show a distinct $\delta^{13}C$ - $\delta^{2}H$ signature (Fig. 2). Strong evidence for *in situ* microbial degradation of the BTEX compounds was also given by compound-specific stable isotope analyses. The range of biodegradation was estimated using only isotope measurements.

The presentation will deal with the approach, method and results for the selected site.

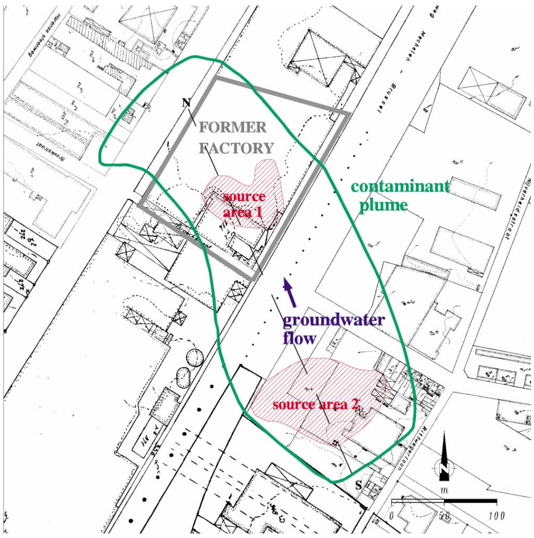

Fig. 1: location of the BTEX plume and of the source areas

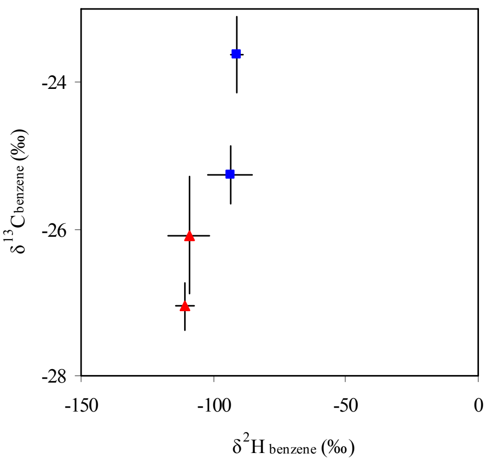

Fig. 2: Plot of $\delta^{13}C$ vs. $\delta^{2}H$ for benzene of the groundwater source samples

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Keywords: Source characterisation, Compound-specific stable isotope analysis, Carbon isotopes, Hydrogen isotopes, In situ biodegradation

Evaluation of biodegradation processes in an aromatic hydrocarbon plume by high-resolution analysis of biotic and abiotic gradients

[1]Bettina ANNESER, [2]Lars RICHTERS, [1]Christian GRIEBLER

[1] GSF – National Research Center for Environment and Health, Institute of Groundwater Ecology, Ingolstädter Landstrasse 1, 85764 Neuherberg, Germany, e-mail: bettina.anneser@gsf.de, christian.griebler@gsf.de
[2] Stadtwerke Düsseldorf AG, Höherweg 200, 40233 Düsseldorf, Germany, e-mail: LRichters@swd-ag.de

ABSTRACT

The distribution of organic contaminants within porous aquifers is subject to a variety of physical-chemical and microbiological processes. Implementation of efficient bioremediation strategies therefore requires comprehensive knowledge on the hydrology and biogeochemistry of the site and a perception of the factors controlling biodegradation. In this regard, a key role is attributed to transverse dispersion at the plume fringe, which provides mixing of electron donors from the plume center with electron acceptors from the surrounding groundwater. In the resulting transition zone, which exhibits a thickness of only a few centimeters to decimeters, steep gradients and, concomitantly, enhanced bioactivites are likely to arise. The identification of such small-scale gradients and the precise localization of biodegradation processes, however, have so far been hampered by the low spatial resolution of conventional sampling and monitoring techniques.

By means of a novel, high-resolution multi-level well (Fig. 1) that was installed at a tar oil-contaminated sandy aquifer in Duesseldorf, Germany, we were able for the first time to successfully demonstrate the occurrence of steep physico-chemical gradients in the cm- to dm-scale at the plume fringe and to identify the controlling redox processes in the investigated aquifer section.

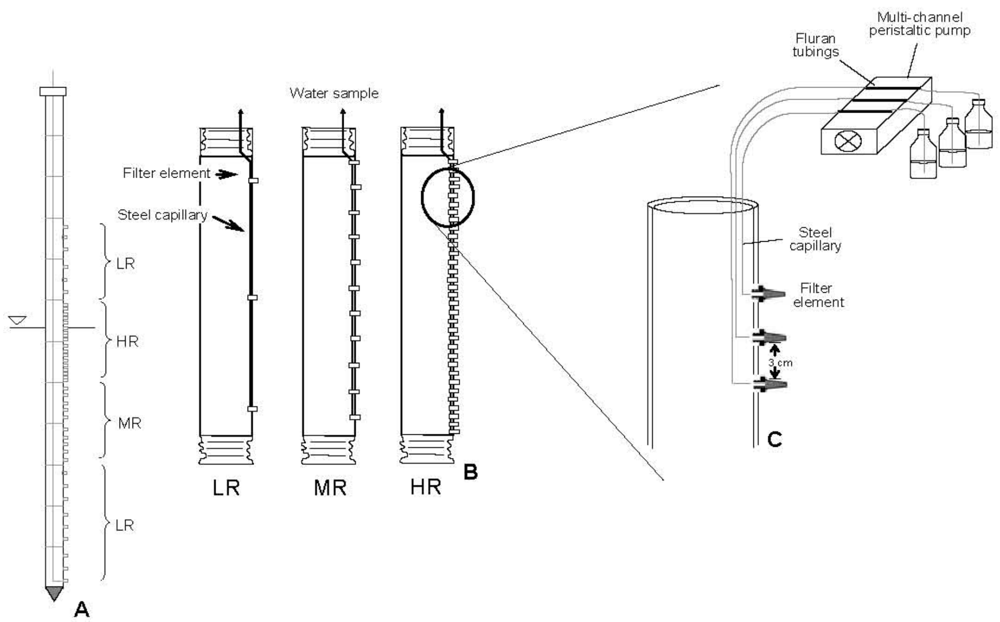

Figure 1 Schematic drawings of the high-resolution multi-level well. A) arrangement of the modules in the mounted well; B) modules with filter screen intervals of 33 cm (low resolution; LR), 10 cm (middle resolution; MR) and 3 cm (high resolution; HR); C) detailed view of filter screens and sampling equipment assembly.

As can be seen from Fig. 2, the decrease in contaminant concentration coincides with an increase in sulfate, sulfide and ferrous iron, thus indicating sulfate and iron (III) reduction as major biodegradation processes and, furthermore, suggesting the co-occurrence of both processes rather than a clear succession of thermodynamically favourable reactions, as it is frequently described in classical textbooks. While iron (III) reduction seems distributed all over the contaminated aquifer, sulfide production is almost exclusively found in the lower fringe zone of the BTEX plume (Fig. 2). A comparison of data derived from the novel high resolution multi-level well (HR-MLW, 3 to 30 cm screen) with data from a neighbored conventional multi-level well (C-MLW, 0.5 to 1 m screen) clearly shows the loss of information with decreased spatial sampling resolution (Fig. 2).

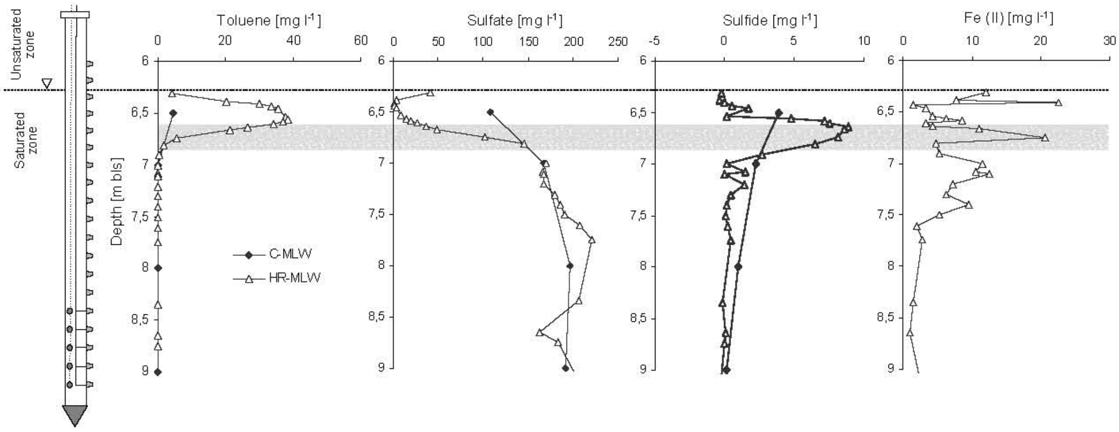

Figure 2 Vertical profiles of toluene, sulfate and dissolved sulfide and Fe (II) as determined in groundwater samples from the high-resolution multi-level well (HR-MLW; white triangles) and a conventional multi-level well (C-MLW; black diamonds). The grey area highlights the lower fringe zone characterized by steep, small-scale gradients.

Compound-specific stable istotope analysis of toluene and sulfate exhibited a significant shift in the isotope ratios of $^{13}C/^{12}C$, $^{34}S/^{32}S$ and $^{18}O/^{16}O$ at the plume fringes, thus unambiguously confirming biodegradation of toluene via sulfate reduction and additionally pointing out the importance of transversal dispersion (data not shown).

Comparing the results of four sampling campaigns that were performed within the time period of a year revealed pronounced variations in maximum concentrations and distinct vertical shifts of individual gradients with time (Fig. 3). Astonishingly, these variations could not be attributed to significant fluctuations of the groundwater table. Focus of future investigations is on the reasons behind these spatial and temporal variations and on its impact on biodegradation.

Statistical evaluation of biotic and abiotic parameters as well as integration of empirically derived data into reactive transport models will improve the conceptual evaluation of biodegradation processes and its limitations and thus promote the performance and predictability of natural attenuation strategies.

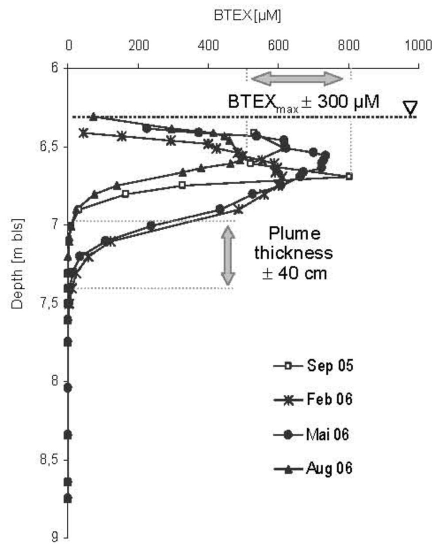

Figure 3 Vertical distribution of total BTEX concentration measured during four sampling surveys between September 2005 and August 2006. Arrows indicate variations in maximum BTEX concentrations and plume thickness, respectively.

Anneser B., Meckenstock R.U., Richters L., Griebler C. (2007): High-resolution analysis of physical-chemical gradients in a tar oil-contaminated aquifer. Submitted to *Appl. Geochem.*

Keywords: biodegradation, plume fringe, small-scale gradients, high-resolution sampling

Spatial distribution of benzene and microorganisms after simulated gasoline spill in loess

[1]Melissa LENCZEWSKI, [2]Rosa LEAL-BAUTISTA [3]Heidi KELLY, [3]Lesley Rigg

[1]Northern Illinois University, Geology and Environmental Geosciences, DeKalb, IL U.S.A., e-mail: Lenczewski@niu.edu
[2]Centro para el Estudio del AGUA, CICY-Unidad Quintana Roo, Mexico, e-mailrleal@cicy.mx
[3]Northern Illinois University, Geography, DeKalb, IL, e-mail: hkelly@niu.edu, lrigg@niu.edu

ABSTRACT

The objective of this research was to determine if the presence of fuel oxygenates (MTBE and ethanol) or natural physical heterogeneities found in soil, influence the spatial distribution of benzene and microbial communities after a spill has occurred. Undisturbed columns of loess were collected in northern Illinois and injected with benzene, benzene amended with MTBE, benzene amended with ethanol, or groundwater, for 90 days. Microcores were collected in a 10 cm x 10 cm grid-like fashion from three different slices and analyzed for benzene and microorganisms. The results indicated that both fuel oxygenates influenced the amount of benzene remaining in the soils with the highest concentration of benzene in the ethanol amended column (Fig. 1). Increased microbial activity (Fig. 2) and a microbial community shift caused enhanced mineral weathering via dissolution in the ethanol-amended column (Table 1). In conclusion, natural attenuation of oxygenated fuels can be better understood by examination of the spatial distribution of benzene and microorganisms. More information is obtained about the geochemical and microbial properties that are observed in the effluent of columns. These results can also be applied to aquifer systems. Typically, only water from observation wells is examined to imply processes that are occurring in the subsurface. These types of experiments allow for the determination of the factors that influence the fate and transport of contaminants that cannot be obtained by examination of groundwater only.

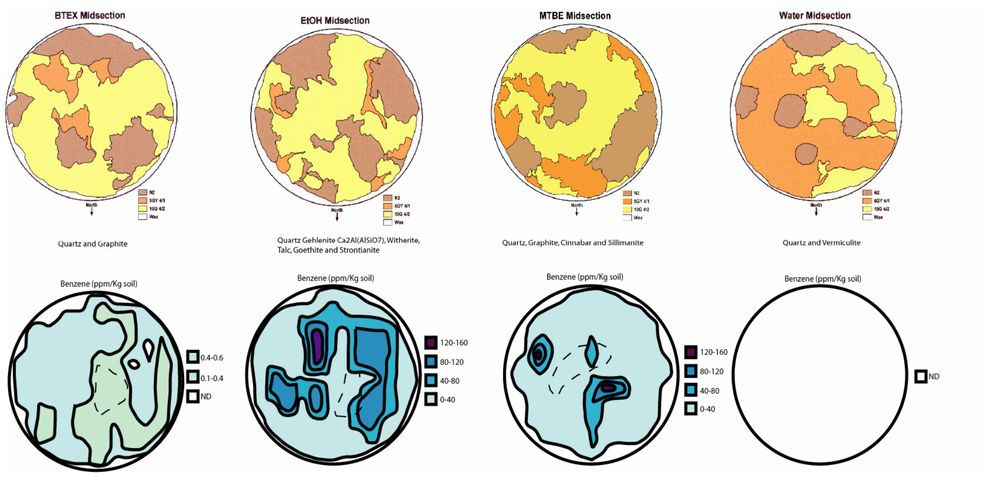

Fig. 1. Map of the midsection of the four columns (from left to right: BTEX, BTEX + EtOH, BTEX + MTBE, and control) A) Map of heterogeneity of the lithology and B) Spatial distribution of benzene (mg benzene/Kg soil).

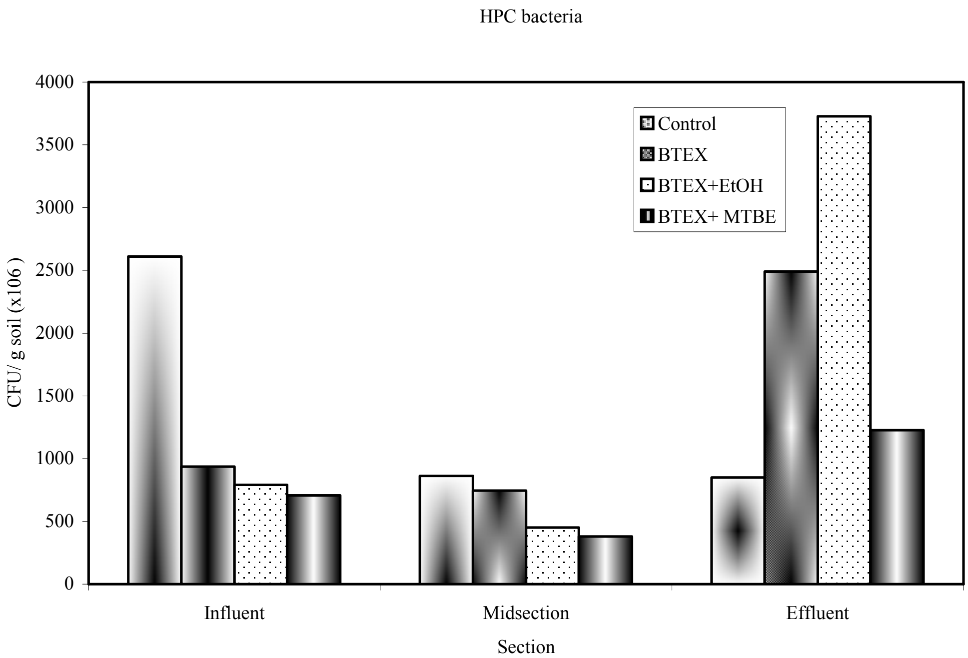

Fig. 2. Highest concentration of heterotrophic plate count microorganisms in the different columns.

Table 1. Clay minerals description before and after injection of oxygenated fuels.

Column	Description
Before Injection	Smectites with limited swelling indicating that interlayers are partially cemented with hydroxide phases of Fe and/or Al (HIS).
BTEX	HIS with enhanced interlayer cementing (reduced swwlling capacity) due to organic molecules (the swelling is lower than the one detected in the material before injection).
BTEX+EtOH	Trace of kaolinite, HIS with enhanced cementing due to organic molecules.
BTEX+MTBE	HIS with enhanced cementing due to organic molecules.
Control	HIS with enhanced cementing due to organic molecules.

Keywords: BTEX, Ethanol, MTBE, biodegradation, minerals

TOPIC 07

Biodegradation processes in contaminated aquifers and role of subsurface organisms in purifying groundwater

Ecosystem services in BTEX degradation

[1]Susanne I SCHMIDT, Christian GRIEBLER, Piotr MAŁOSZEWSKI

[1]GSF, Institute of Groundwater Ecology, 85764 Neuherberg, Germany, email: susanne.schmidt@gsf.de, christian.griebler@gsf.de, maloszewski@gsf.de

ABSTRACT

BTEX degradation by groundwater bacteria has been extensively studied in laboratory (Meckenstock et al. 1999) and field studies (eg. Richnow et al. 2003). Two major factors influencing degradation are hydraulic flow (Mauclaire et al. 2006) and grazing (Mattison and Harayama 2001). However, experiments relating degradation to hydraulic flow and grazing by not only protozoa but also invertebrates in the same setup are still missing. Therefore, at the GSF Neuherberg, BTEX degradation will be studied as a function of the ecosystem processes in a mesoscale experiment. To this aim, microbial degradation will be related to abiotic processes such as hydrological processes on the one hand and biological processes on the other hand. A flow system is set up which will be run by quaternary groundwater through quaternary sand with its natural microbial community. A contaminant plume will be established and degradation will be studied on small spatial and temporal scale in terms of both microbial and invertebrate contribution.

While it has been long known that bacteria and archaea degrade organic contaminations (natural attenuation), the mechanisms with which other microorganisms, such as flagellates, participate in degradation have been studied much less. Flagellates have been shown to enhance bacterial degradation by 1) maintaining the porosity of soils (Zarda et al. 1998, Mattison et al. 2002), and also by 2) stimulating e.g. toluene consumption (e.g. in *Pseudomonas* sp., when preyed on the protozoan *Heteromita globosa*; Mattison and Harayama 2001). However, adverse effects by protozoan grazing were demonstrated when microbial degradation of BTEX was enhanced after protozoa were inhibited by cycloheximide (Kota et al. 1999). Groundwater invertebrates (mostly worms and crustaceans) are known to graze on bacteria and protozoa and thus are believed to play an active role in biodegradation. However, their exact role within a complex near-natural system that offers ample opportunities for sampling has never been tested so far.

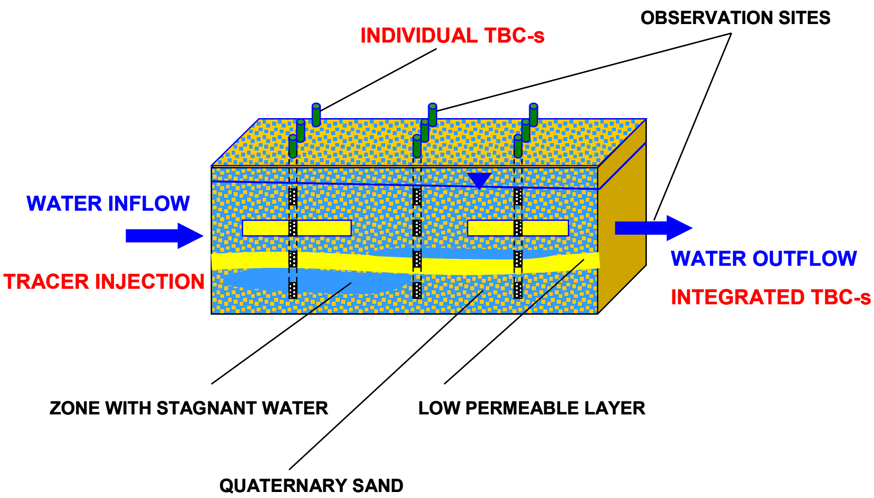

Fig. 1: Experimental set-up – large scale aquifer mesocosm (TBC – observation places were the tracer breakthrough curves are measured).

Especially groundwater invertebrates are known to be related to hydrogeological conditions, specifically hydrologic exchange intensities (Schmidt et al. in press). Therefore in a system as described above it is crucial to describe hydrologic patterns in as much detail as possible. This will be achieved by analytical and numerical mathematical modelling techniques based on data obtained by artificial tracer experiments in a similar way as it was described by Maloszewski (1994) or Einsiedl & Maloszewski (2005). The aim is to analyse transport and water fluxes in heterogeneous aquifers with stagnant water zones in the large scale aquifer mesocosm present in Fig. 1. The water flow-paths are represented by the blue box in Fig. 2. After describing the flow-pattern, determining transport parameters of an ideal (non-reactive) tracer and the transit time distribution functions of water in the system, the spatial and temporal distribution of degradation activities will be analysed.

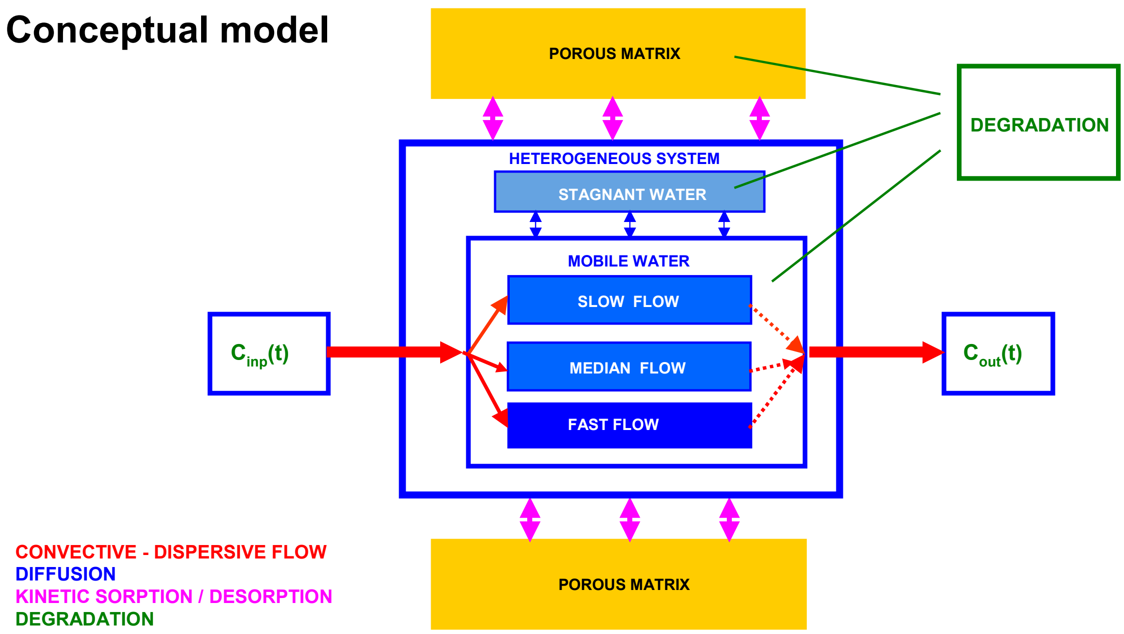

Fig. 2: Conceptual representation of the analytical modelling of the hydraulic flow and exchange between mobile and immobile water parcels.

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Keywords: Hydrogeology, contamination, ecosystems, microbial degradation, groundwater invertebrates

Impact of chelate concentration and iron character on hydrogen peroxide decomposition in the Fenton's reaction : implications for groundwater remediation

[1]Andrew L LYNCH, [2]Dibakar BHATTACHARYYA

[1]Department of Chemical and Materials Engineering, University of Kentucky, 199 F. Paul Anderson Tower, Lexington, KY 40506, e-mail: andrew.lynch@uky.edu
[2]Department of Chemical and Materials Engineering, University of Kentucky, 199 F. Paul Anderson Tower, Lexington, KY 40506, e-mail: db@engr.uky.edu

ABSTRACT

The Fenton's reaction provides a powerful oxidizing mechanism for the breakdown of toxic halogenated organic contaminants in aqueous systems. When applied to near-neutral pH aqueous systems, such as during groundwater remediation, chelate can be used to bind ferric iron in solution and thus provide for continuous generation of hydroxyl radicals and sustained contaminant breakdown. This study explores the impact of chelate concentration on the rate of contaminant breakdown under the aforementioned near-neutral conditions by using the breakdown of hydrogen peroxide as an analog for hydroxyl radical production and thus contaminant breakdown rate.

This study also examines the impact of iron character on Fenton's reaction contaminant breakdown kinetics, again using the hydrogen peroxide analog. While the Fenton's reaction is classically initiated using ferrous iron, ferrous and ferric iron are cyclically interconverted as the reaction progresses and thus there is no mechanistic distinction between ferrous-initiated and ferric-initiated Fenton's reaction. However, as this study demonstrates, initial iron character is an important determinant of Fenton's reaction rate.

The implications of this study on groundwater remediation efforts using the Fenton's reaction are significant. As previously mentioned, the use of chelate is crucial to the application of the Fenton's reaction to the near-neutral pH conditions in most groundwater; if this modified-Fenton's process is to be optimized the impact of chelate concentration on Fenton's kinetics must be established. The impact of initial iron character on Fenton's kinetics is also highly relevant; ferric iron is often present naturally in groundwater systems and if this iron form is to be utilized as a Fenton's reagent, then its impact on Fenton's kinetics as compared to the traditional ferrous iron reagent must be understood.

More broadly, this study also has ecological implications for groundwater contamination. The Fenton's reaction utilizes merely non-toxic iron and low concentrations of hydrogen peroxide; by studying the adaptation of the Fenton's reaction to groundwater systems, this research works to promote ecologically-friendly groundwater remediation techniques.

Keywords: Fenton, remediation, contamination

Pollution by toxic metals of underground waters of mining in Georgia

Guram BUACHIDZE, Linette TSERTSVADZE, Shorena PETRIASHVILI

31 Rustaveli Ave, Tbilisi, 0108, Georgia

ABSTRACT

The results of the study of the possibility of bacterial leaching of the waste of mining-dressing industry for the purpose of decreasing the concentration of toxic metals which are washing out by sewage from the tailing dump and disposal area, causing pollution of underground waters and soils within the territory of industrial cities.

The results of bacterial processing of tailings and waste, based on the application of natural biochemical process of weathering and leaching, are presented.

According to the experimental data, even the first cycle of bacterial leaching decreases the content such as metals as: U, Cd, As, Mo, Sb, Co, W, V, Cr, Ni, Sr, Zn, Mn, etc. by 50% and more.

The example of Chiatura city and the industrial center of Kazrety, shows that the usage of this method in the technological processing of ores decreases considerably the risk of the pollution of waters and soils by toxic metals and promotes to the improvement of the ecological situation and a more rational usage of natural resources.

Keywords: pollution, underground waters, mining, Georgia

Possible Technology of Remediation of Ground Water and Soil in Territory of Oil Refinery.

Buachidze GURAMI, Petriashvili SHORENA, Tsertsvadze LINETA

Inst. Hydrogeology, Tbilisi, Georgia

ABSTRACT

This Refinery is on the East coast of the Black Sea. Research work has been conducted to determine the sources and levels of oil contamination. Pollution of soil and ground waters has been detected at the depth of 70 m in the drilled wells and on the sea bottom at a distance of 4 km.

In the laboratory we investigated the influence of *Pseudomonas bacterium* extracted from the humid subtropical soil on oil. Results show we have very high activity in assimilation of heterocyclic and aromatic combinations. The optimal regime and elaborate remediation technology for underground waters and soil was found.

The investigation showed that the optimal version for recultivating oil- and petroleum-product-contaminated *terra rossa* and ground waters was the sample with green peas for seeding in the presence of biogenic material - peat, and the biomass of *Pseudomonas* accumulative cultures. In this version 87% of petroleum products is degraded, while the survivability of oil-destroying microbes is $13{,}04\times10^{2}$ cells per 1 g dry soil.

Key words: remediation, ground water, soil, oil refinery, Black Sea, Georgia.

Use of acetate as an electron donor for reductive dechlorination of trichloroethene to ethene

[1]Anthony S DANKO, [2]Leo LEHMICKE, [3]Audrey J BONE, [3]David L FREEDMAN

[1]Universidade do Minho, Centro de Engenharia Biológica, Campus de Gualtar, 4710-057 Braga, PORTUGAL, e-mail: asdanko@deb.uminho.pt
[2]Hargis + Associates, Inc., 17728 NE 131st Place, Redmond, WA 98052, USA, e-mail: LLehmicke@ HARGIS.COM
[3]Clemson University, Department of Environmental Engineering & Science, Box 340919, Clemson, SC 29634, USA, e-mail: abone@clemson.edu,dfreedm@clemson.edu

ABSTRACT

Tetrachloroethene (PCE) and trichloroethene (TCE) continue to be the most persistent groundwater contaminants in the United States. The use of biostimulation to enhance in situ removal of chlorinated ethenes has gained considerable momentum. If the necessary types of chlororespiring microbes are present, addition of an electron donor can significantly accelerate the rate of reductive dechlorination when the background level of donor is insufficient. A variety of electron donors have been evaluated, including organic acids (e.g., lactate, acetate), carbohydrates (e.g., corn syrup, molasses), alcohols (e.g., ethanol, methanol) and vegetable oil. Hydrogen is widely regarded as a universal electron donor but direct addition to groundwater is seldom used. Hydrogen is typically generated in situ via fermentation of organic electron donors.

Acetate offers a number of advantages as an electron donor, including its low cost, lack of toxicity, and ease of regulatory acceptance. Acetate is also known to serve as the required carbon source for a number of chlororespiring microbes. However, use of acetate as an electron donor has been limited. Previous studies indicate that acetate is effective as a donor only for reduction of PCE and TCE to *cis*-1,2-dichloroethene (DCE), by microbes such as *Desulfuromonas*, *Desulfitobacterium, and Geobacter* spp. Complete reduction to ethene requires the presence of *Dehalococcoides* spp., which reportedly do not use acetate as a sole electron donor.

At a former hazardous waste recycling facility in Washington State, biostimulation was pilot tested 10 years ago to enhance in situ reductive dechlorination of TCE to ethene. Acetate was used as the electron donor in the pilot test; at that time its effectiveness as a donor was not known. During the pilot test, the injection well received a much higher dose of acetate when the electron donor tank accidentally siphoned into the well. At the next sampling event, groundwater monitoring results revealed the complete reduction of TCE to ethene. As ongoing studies of reductive dechlorination continued over the years and showed acetate to be a comparatively inefficient donor, the pilot test results represented a surprising outcome. Bioremediation was not used at full-scale because it could not meet the timetable for capping of the site. The objective of this laboratory study was to confirm the use of acetate as an electron donor for complete reduction of TCE to ethene.

The area where the pilot test had taken place had since been covered with a cap. A sample of "first-flush" groundwater was obtained from a well at the site, approximately 200 m down gradient of the well that received the high dose of acetate. In this down gradient portion of the plume, natural attenuation had completely reduced all chlorinated ethenes to ethene and ethane. Microcosms were prepared with 100 mL of groundwater in 160 mL serum bottles. Sediment was not available, although it was hypothesized that the first-flush groundwater would contain enough microbes to provide an inoculum. The initial TCE concentration in the microcosms was 4.3 mg/L. Five of the microcosms received repeated additions of acetate and four received no acetate. Triplicate water controls (100 mL of distilled deionized water) were also prepared.

Representative results for microcosms that received acetate and those that did not are shown in Fig. 1. In the biostimulated microcosms, there was no apparent lag in reduction of TCE to *cis*-DCE. Reduction of *cis*-DCE to vinyl chloride (VC) started once the TCE was consumed and occurred more slowly. A similar pattern emerged for reduction of VC to ethene. After 163 days of incubation, ethene production had occurred in all of the biostimulated microcosms, although complete reduction was observed in only one (Fig. 1a). As expected, reduction of VC to ethene is the rate limiting step. In the microcosms with no acetate added, TCE has persisted over the same incubation period (Fig. 1b). A small but notable amount of reductive dechlorination was observed, indicating that the groundwater contains a limiting amount of electron donor. No reductive dechlorination occurred in the water controls.

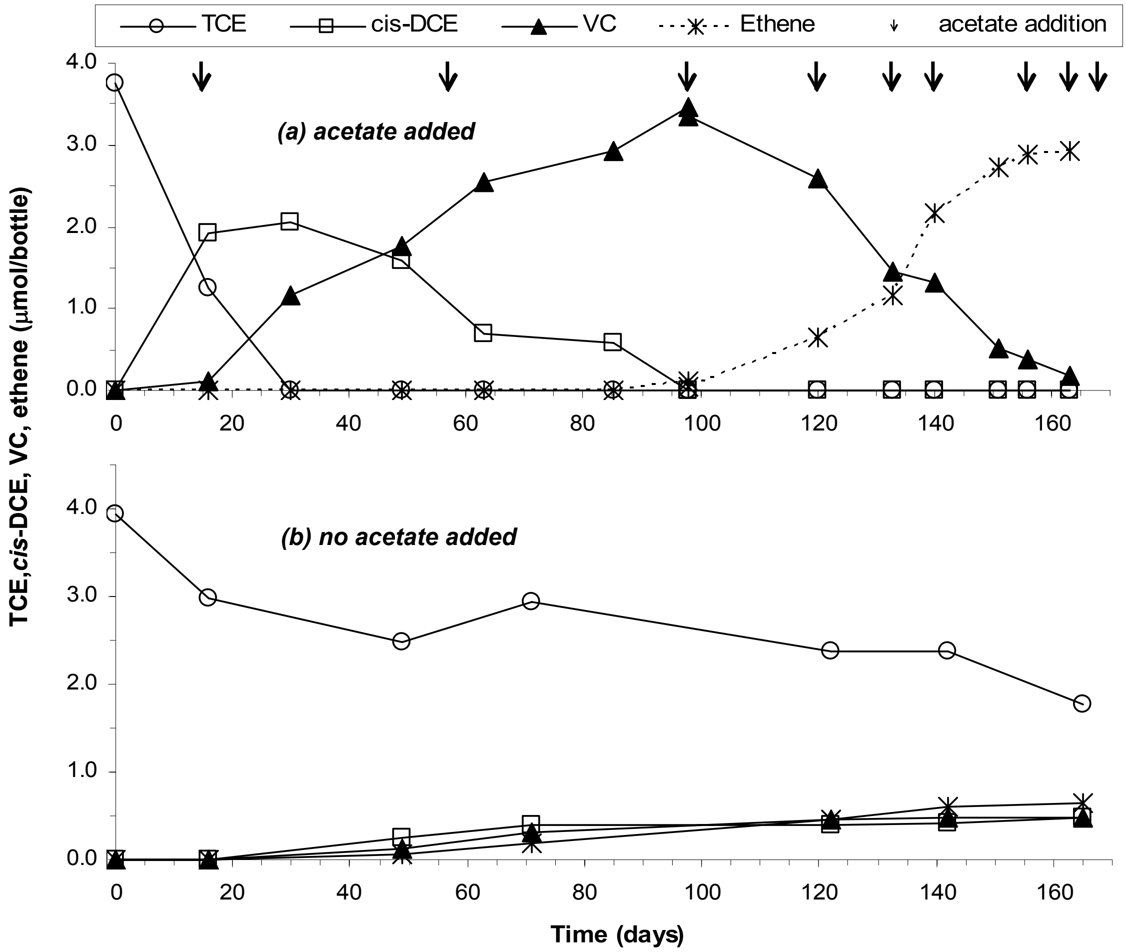

Fig. 1. Reductive dechlorination of TCE in a representative microcosm (**a**) with acetate added (each arrow represents 0.61 mM acetate) and (**b**) no acetate added. Results are expressed in µmol per bottle to reveal the stoichiometry of TCE reduction to daughter products. To convert from µmol per bottle to mg/L, multiply TCE by 1.09, *cis*-DCE by 0.894, VC by 0.390, and ethene by 0.0524.

Monitoring of the microcosms is in progress. Increasing amounts of TCE will be added once reduction to ethene is complete, with the intent of enriching for the chlororespiring microbes.

The total amount of acetate added during the 163 days of incubation was 49 mM. Analysis by high performance liquid chromatography indicated that only a small percentage of the acetate added has actually been consumed. No other organic acids were detected. It is not yet known if the acetate is being used directly as the electron donor, or if it is being oxidized by syntrophic anaerobes to carbon dioxide and hydrogen, which is then being used for reductive dechlorination.

The results of this study are the first to conclusively demonstrate the use of acetate as an electron donor for the complete reduction of TCE to ethene. Further enrichment and characterization of the culture could lead to its use for in situ bioaugmentation.

***Keywords*:** Trichloroethene, groundwater, biostimulation, acetate, dechlorination

TOPIC 08

Different approaches towards mapping groundwater vulnerability and dependent ecosystems

Interactions of Kalahari savannah trees with soil moisture and groundwater

[1] Maciek W. LUBCZYNSKI, [1,2] Obolokile O. OBAKENG

[1] ITC, P.O. Box 6, 7500 AA Enschede, The Netherlands. [2] Geological Survey of Botswana. Lobatse.

ABSTRACT

Sustainability of groundwater resources in dry environments is constrained not only by recharge (R) to the aquifers but also by discharge from them. Natural groundwater discharge takes place in 3 different ways, as aquifer groundwater outflow, direct tree root water uptake called groundwater transpiration (T_g) and as upward vapor-liquid water movement called groundwater evaporation (E_g), the latter two are known as groundwater evapotranspiration (ET_g). In dry environments recharge is typically low, so the discharges by E_g and T_g can be relevant for groundwater balance.

Kalahari savannah environment, where this study was carried out, is characterized by deep groundwater table >60 m. Semi-arid conditions in combination with thick unsaturated zone result in very low mean yearly net recharge (R_n=R-ET_g) in the order of few millimetres. R_n in Kalahari is highly variable in time and space and can vary from negative values, when ET_g>R to even >40 mm/y for "wet" years. This is why not only recharge but also discharge, particularly ET_g is important in arid and semi-arid conditions. The large depth of the groundwater table in the Kalahari implied that E_g in this study was assumed to be a negligible component of groundwater balance. T_g however could have not been treated the same way because earlier studies in Africa documented fragments of tree roots of *Boscia albitrunca* and *Acacia erioloba* found in borehole cores at depth >60 m comparable with the groundwater table depth. This indicated that in the Kalahari there could be not only trees that survive dry season on minimum quantity of soil moisture but also others that can uptake groundwater from aquifers or capillary fringe even if groundwater table deeper than 60 m. This phenomenon is emphasized in the field by freshly green appearance of certain tree species throughout dry seasons.

This study was carried out through hydrological monitoring consisting of 10 hydrological, multi-sensor towers and 17 groundwater monitoring points. In order to assess the evapotranspiration contribution to the overall water balance and eventually deduce recharge, actual evapotranspiration (AET) was estimated by the Bowen-ratio (BR) and temperature-profile (TP) surface energy balance methods while potential evapotranspiration (PET) by the Penman-Monteith method. Both BR and TP methods overestimated AET, as compared with rainfall, on an annual basis so the recharge could have been deduced only indirectly through 1D recharge modeling with PET used as input.

For understanding the impact of trees upon groundwater recharge, sap flow was monitored for 2 years using the Granier method on 41 trees of 9 species. This was done mainly to quantify the amount of subsurface water loss through transpiration. The plot transpiration assessment was carried out in 8 plots of 30x30 m by multiplying temporally variable sap velocities averaged per species by corresponding tree sapwood areas upscaled using predefined biometric upscaling functions (defined on the base of 220 tree samples). The obtained plot tree transpirations showed large spatio-temporal variability of 3-71 mm/yr and occasionally exceeded recharge. Soil moisture movement and groundwater recharge were investigated by monitoring soil moisture (the deepest profile down to 76 m depth) and groundwater table fluctuations at various depths. The soil moisture results revealed a complicated pattern characterized by a combination of diffuse and preferential flow while groundwater levels reflected varying degrees of responses to rainfall in spite of similar geological situation. Due to the complexity of the hydraulics of unsaturated zone, recharge was evaluated by a simple 1D lumped parameter model which indicated 0-50 mm/yr recharge.

In order to confirm the depth at which trees take up water, lithium tracer was injected at various depths below the ground surface. The results showed that all investigated trees were able to absorb the lithium at depths ranging from 8-70 m and transmit it to the leaves within 1-3 days. This way it was also confirmed that certain species can uptake water from a depth exceeding even 70 m. Other stable isotope experiment, involving tracing of soil moisture, tree sapwood water and groundwater revealed that some trees predominantly used soil water from below the main root zone of shrubs and grasses while others used water mainly from the upper layers, even if it meant exerting suctions below the widely accepted wilting point of -1.47 MPa. The collective results of the Kalahari tracer experiments indicate that most of the water that moves down in the unsaturated zone is lost to evapotranspiration. The main part of it is lost within the first 4 meters considered as the main root zone, majority within the upper ~25 m and only some of it reaches the groundwater table where it still has the possibility to be extracted by the deep rooting systems of Kalahari savannah trees such as *Acacia albitrunca* and *Acacia erioloba*.

In dry environments, typically characterized by very low recharge, ET_g can represent significant component of groundwater balance even in the conditions of large depth to groundwater table. Therefore it cannot be underestimated in any groundwater sustainability studies particularly in dry arid conditions.

Spiny rush as indicator of deep groundwater flows in hard rocks of Spanish Central System

[1] Martín-LOECHES, M. and [2] YÉLAMOS, J. G.

[1] Geology Department. Science Faculty. Alcala University. 28871-Madrid, Spain. miguel.martin@uah.es
[2] Geology & Geochemistry Department. Autonomous University of Madrid. Campus de Cantoblanco s/n 28048. Madrid, Spain. javier.yelamos@uam.es

ABSTRACT

The Spanish Central System (SCS) is a mountain range, with SE-NW direction located in the central part of the Iberian Peninsula. It is one of the borders of two Tertiary basins, Tajus at the south and Duero to the north. SCS is constituted by many types of hard rocks, granite being the most abundant rock in its occidental part; meanwhile high and low grade metamorphic rocks are predominant on the oriental sector.

The groundwater has a low infiltration rate, hardly 10 % of the precipitation, and occurs preferably through weathered or fractured areas. Most of the infiltrated water discharges on the surface after short time by springs whose yield hardly reaches 1L/s, with a big seasonal variation. The water is of low mineralization and Ca-CO_3H- or Ca-Na-CO_3H- type, although the local presence of pyrite or metamorphic rocks can cause some variations. Nevertheless, a small percentage of the infiltrated water reaches greater depths through the fracture systems that affects the massifs and after a distance, emerges in small springs of constant yield and Na-CO_3H hydrochemical facies. Often these waters have a sulfhidric odour. They can be considered as groundwater of medium flow or semi-large evolution.

Apart from these waters, there are some springs and wells throughout the southern border of the SCS (contact Tajus SCS- Basin) that go over crystalline rocks and have a clear Na-Cl or Na-Ca-Cl- character and relatively high salinity whose link with the previous mentioned scheme is not yet clear. Some hypothesis may be constructed in the future in the light of new data. It must be noted that these types of waters are different than the discharge water of the Tajus detrital basin due to their scarcity in SO_4^{2-} and their high content of Ca^{2+}. Also their position in hard rocks makes it difficult from a hydrodynamic point of view a if waters from the Tertiary basin has a direct influence over them. The isotopic composition of this water reflects a mixture with surface water due to the high difficulty of the collection of the water.

For the purposes of this paper we consider the chloride waters in hard rocks of the SCS as the final point of evolution of the groundwater on hard rocks and so may be considered as waters of deep flows.

Taking into account its scarcity, the location of medium or deep flow discharge points in the SCS is very difficult. CO_3H-Na sulphide waters, and even some of chloride type, have been used for therapeutic purposes, therefore the local names can be of a great help ("Los Baños", "Fuente Milagrosa"). Also the flavour of the water shows the presence of water with relatively high TSD ("El Salobral", "La Salabrosa", and "El Sarguero"). But apart from those used (at present or in the past) or the indicated water points, there are some others whose presence is not known. Its location is of high interest to know how the system works

Figure 1 shows all the points with Na-CO_3H (sulphide or not) and Cl types in the southern side of SCS where the authors made a detailed inventory of wells and springs, in the context of the work of their respective doctoral thesis.

It has been observed that in most of the points with alkaline or chloride waters, there is at least one bush of *Juncus acutus* (Spiny rush), see Fig. 1. This rush is characteristic of alkaline or saline soils on arid areas. Its presence over crystalline rocks is very rare. Although quite frequent in the discharge areas of the detrital aquifer of the Tajus Basin its presence over hard rocks in the SCS was not described before the investigation by the authors. Fig. 1 indicates the positions where spine rush has been observed so far in the south fringe of SCS and in all cases that position match with either alkaline or chloride water points.

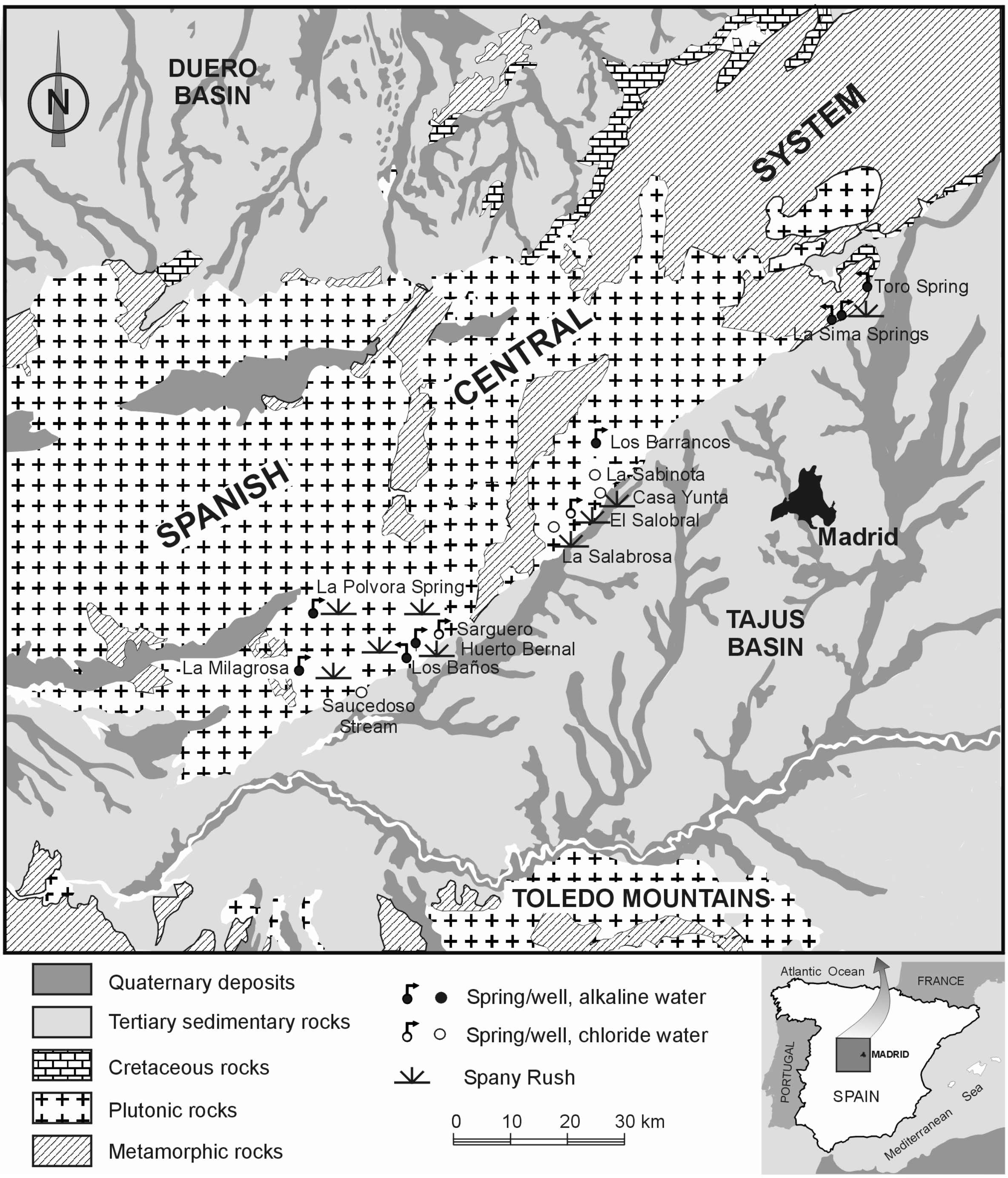

Fig. 1. Location of deep flow waters and spiny rush on hard rocks of Spanish Central System.

Other indicators may be present among the vegetation around a certain point, but Spiny rush is by far the easier to recognize because of its characteristics.

This work shows how the presence of Spiny rush is certainly a clear and effective indicator of the discharge of medium or large flow groundwater in the hard rocks of SCS and so can be used well as a field tool.

Keywords: Spiny rush, hard rocks, Spanish Central System

TOPIC 08

Different approaches towards mapping groundwater vulnerability and dependent ecosystems

Groundwater dependence of natural habitat types in southern Kiskunság (Hungary)

[1]János SZANYI, [2]Katalin MARGÓCZI, [2]Eszter ARADI

[1]Department of Earth Sciences, University of Szeged, Hungary, szanyi@iif.u-szeged.hu
[2]Department of Ecology, University of Szeged, Hungary, margoczi@bio.u-szeged.hu

ABSTRACT

Kiskunság is an inland sand dune area in Hungary between the Rivers Danube and Tisza. In the south-eastern part of the sand table-land, the natural vegetation survived in the wind formed dune slacks, while the remaining area was ploughed and used for agriculture from the 19th century. The vegetation of these remnant dune slack meadows (DSM) is species rich and has high natural value. The following natural habitat types of Community interest occur in these meadows:

- Pannonic salt steppes and salt marshes (Natura 2000 code: 1530)
- Molinia meadows on calcareous, peaty or clayey-silt-laden soils (Natura 2000 code: 6410)
- Pannonic sand steppes (Natura 2000 code: 6260)

The dune slack meadows are groundwater dependent ecosystems, therefore the knowledge of groundwater systems is one of the most important aspects in the protection of ecologically valuable areas. In the last decades, a considerable groundwater decrease was detected in the Kiskunság. Perhaps the vegetation of dune slack meadows is endangered because of this process, but there is no evidence of this in the scientific literature. Information about the hydrological conditions of dune slack vegetation is needed to understand the natural processes and to plan habitat management or restoration.

The main goal of this study is to reveal the connection of hydrological backgrounds and vegetation pattern. Two stands of about 100-100 ha large dune slack meadows were chosen for detailed botanical and hydrogeological investigation: Csipak-semlyék (CS), and the so called „Magic" Meadow (MM) (this nickname was given by botanists because of its unusual richness in protected plants). Both area are involved in the Natura 2000 network. The studied MM site is near to the top of the large sand tableland between 102 and 104 m elevation above Baltic Sea level, rather on a „terrace" than in a depression. The CS site is on a lower level, toward the feet of the tableland between 91.5 and 93.5 m, and really in a depression. The studied areas are situated near to the midline zone of groundwater flow system regionally, but they bear marks of discharge zone locally.

According to the pressure-elevation profile computed from the data of deep wells situated in similar elevation and position to the two studied sites, the vertical pressure gradient is similar to the hydrostatic gradient. This indicates a through-flow system. But in the surroundings of CS region the gradient is higher than the hydrostatic one from the depth of -500 (a.s.l.) m downward. Thus the direction of vertical movement of the water is ascending in this zone. To determine the characteristics of groundwater levels during the study period, two observation wells were drilled in both study area.

The vegetation was sampled along a 500 m long transect in site CS and a 380 m long transect in site MM, respectively. The transects were positioned approximately along the line determined by the observation wells, crossing stands of the relevant vegetation types. Coenological relevés were made in 5x5 m quadrates and the percentage cover of plant species was recorded in June, 2005. In the same year, a vegetation map was prepared of about the two study areas.

The dune slacks in the southern Kiskunság usually contain small sand hills within the depression, and a certain vegetation zonation can develop in them. On the top of the sand hills, Pannonic sand steppes (Astragalo-Festucetum rupicolae) are found at a lower elevation. On the side of the sand hills a fen meadow (Molinietum) develops, and on the deepest areas fen or marsh vegetation occurs. If there is a salt effect, Molinietum is replaced by alkali meadow (Agrostio caricetum distantis) and in the deepest areas, salt marsh or sometimes alkali lakes can be found. The transitional zones are often very wide. The main difference of the vegetation between the two studied sites is the following: in CS site the salt effect is considerable, alkali vegetation occurs, but the vegetation shows no salt effect in the MM site.

The shape of the duration lines of the piezometers indicated that the two study areas belong to different hydraulic regimes. In MM site the slope of the duration line is deep, but in CS site the high water period is prolonged, occurs circa 75 % of the year. If we take into consideration the potentiometric level of the shallow groundwater as upper boundary condition in our hydrodynamic model, than the studied areas behave as discharge areas. The difference between the investigated areas lies in groundwater travel paths: while CS belongs to the intermediate flow system, till MM belongs to the local flow system (Fig. 1.).

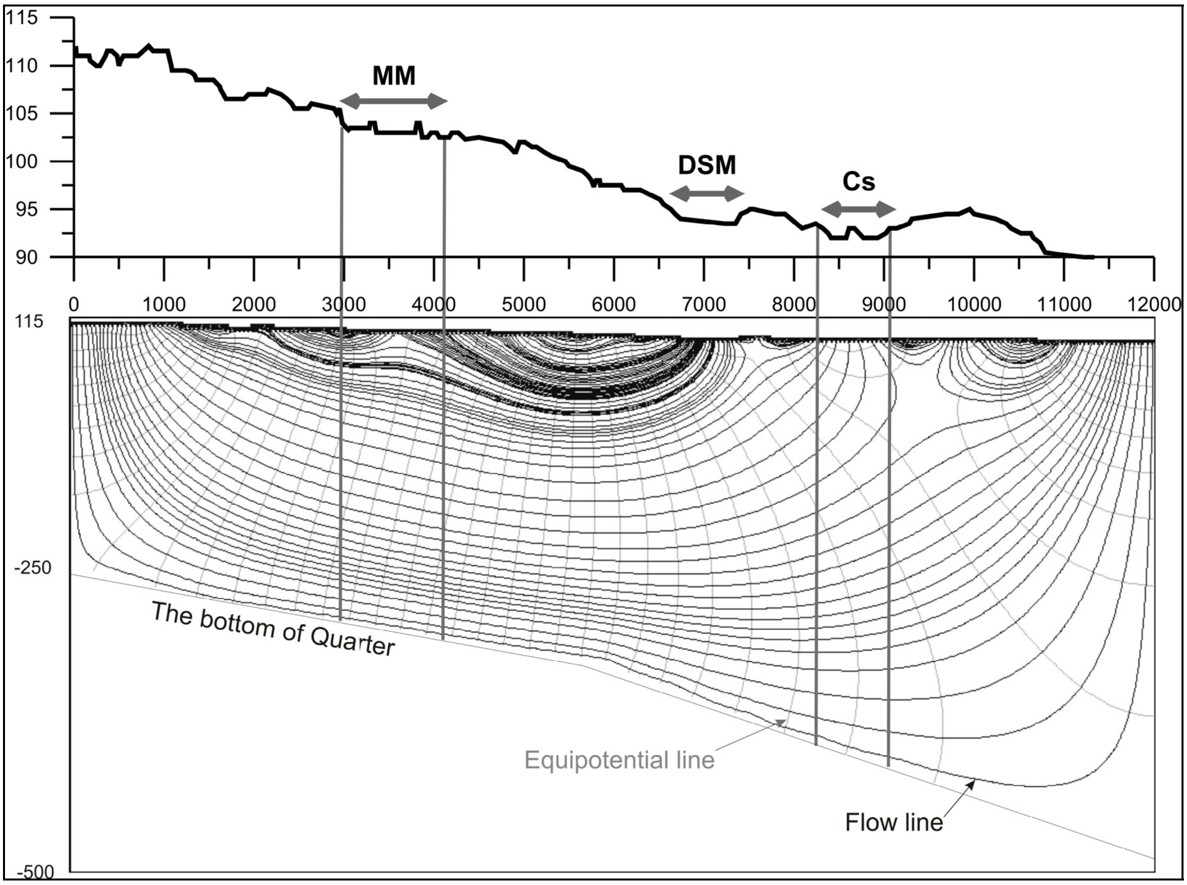

Fig. 1. Model of hydraulic flow system with exaggerated groundwater-level line (black: flow lines, grey: equipotential lines, MM and CS are the studied areas, and DSM is a third, similar meadow.)

In conclusion, we can say that the distinct hydraulic characters are the source of the different vegetation patterns in the studied areas. We suppose that the upward flow plays an important role in salinization, and the consequent development of alkali vegetation. With the hydrochemical analyses, presently in progress, we will be able to confirm our hypothesis. In the southern Kiskunság there are several other meadows with similar vegetation, as described in this paper. The quick and strong regional hydrological changes, especially the decrease of groundwater level, could endanger this valuable vegetation, but a certain resistance and plasticity of it is possible.

Keywords: hydraulic regime, potentiometric level, vegetation pattern

Groundwater dependent ecosystems in an area characterised by Na-Cl mineralised waters, South Alentejo, Portugal

[1]António CHAMBEL, [2]Rodrigo PAIVA-FERREIRA, [2]Carlos PINTO-GOMES

[1]Geophysic Centre of Évora, Geosciences Department, University of Évora, R. Romão Ramalho, n.º 59, 7002-554 Évora, Portugal, e-mail: achambel@uevora.pt
[2]Ecology Departmemt., University of Évora, Rua Romão Ramalho n.º 59, 7002-671 Évora, Portugal, e-mail: rodpaivaferreira@netvisao.pt, cpgomes@uevora.pt

ABSTRACT

The Pyrite Belt, a WNW/ESE strip in South Alentejo, South Portugal, gets it name from the pyrite ore masses distributed along this strip. In the vicinity, both north and south, anomalous high values of groundwater mineralisation occur.

The base rock consists of sedimentary and volcany-sedimentary rocks affected by the Hercynian Orogeny, with the most competent rocks being the most fractured. So, it seems that some areas of the Pyrite Belt, namely the Volcano-Sedimentary Complex, are particularly vulnerable to this upwelling of highly saline deep groundwater.

The chemical analyses show that these waters tend to be Na-Cl type with a previous investigation confirming that two kinds of processes must be involved because of its presence in these specific areas (Chambel 1999):

- deep faults that can transmit highly mineralised waters from depth to surface
- the concentration of salts at surface, caused by high evapotranspiration values

The transmission of water from depth is confirmed by the chemical analysis of the groundwater present on a pyrite mine going to 700 m depth on the Pyrite Belt, Neves-Corvo, where research has shown that the increase of mineralisation with depth corresponds to about 475 μS/cm in EC for each 100 m depth, as well as 150 mg/L of chloride and 140 mg/L of sodium for the same 100 m depth (Fernández-Rubio *et al.* 1988; Fernández-Rubio & Carvalho 1993; Fernández-Rubio *et al.* 1994).

The concentration of salts at surface reflects a process which occurs essentially in flat areas, where the groundwater gradient is very low, the ascending groundwater is resident for longer periods in the upper part of the soils, concentrating salts due to the high ratios of evaporation in the area where the summer day temperatures can reach more than 40 ºC for several days in a year. Normally these kind of high mineralised waters do not occur in sloping areas, where the water flows more quickly in the direction of the main streams. In such areas, all the processes must be a balance between salt concentration caused by groundwater upwelling, and the concentration of salts by evapotranspiration and dilution processes in winter – when most of the rain falls – together with the hydraulic gradients in the different areas.

The precipitation occurs mainly between October and March/April, with little or no precipitation occurring in the hot season.

An example of the chemical composition of these waters is shown in Table 1, with the average and median of the main ions for the waters with EC higher then 4,000 μS/cm only. The waters clearly show a Sodium-Chloride facies.

Table 1. Main composition of the groundwater in the area of the more saline waters. The average and the median were calculated using waters that have been sampled for chemical analysis with ECs greater then 4,000 μS/cm only.

	Ca (epm)	Na (epm)	K (epm)	Mg (epm)	HCO_3 (epm)	Cl (epm)	SO_4 (epm)	Number of samples
Average	8.52	35.35	0.10	17.29	9.12	48.14	7.07	22
Median	6.56	32.12	0.05	16.10	8.94	39.37	5.35	22

It was also identified those areas with more saline groundwater have a specific kind of plant association, defining special ecosystems. In subsequent years, an investigation concerning groundwater quality and its relation to the soil salinisation and associated ecosystems has been developed in these areas of Alentejo.

In terms of vegetation dynamics, these are territories with heavy farm activity, with potential *Quercus rotundifolia* - round-leafed oak - (*Pyro bourgaeanae-Querceto rotundifoliae S.).* However, the human influence

had promoted the changes in the natural forests, shrubs, perennial grasslands and terophytic herbs, favouring several nitrophilous communities. In the temporary river channels, the potentiality goes to *Tamarix africana* and *Nerio oleander* formations. By identical motifs, serial substitution communities are very common (*e.g.* rushy pastures, meadows, anthropogenic riparian grasslands), with sub-cosmopolitan chorology.

The work that has been developed through the plant collection and elaboration of phytosociological inventories, detected several plants typical of places with high levels of edaphic salinity. Some floral examples are *Tamarix africana, Juncus acutus, Juncus subulatus, Hordeum geniculatum* and *Parapholis incurva*, *taxa* included with *Saginetea maritimae* and *Juncetalia maritimi*. These plants and vegetables communities, in the ecologic aspect, are not linked with the round-leafed oak potentiality. These are very special situations, promoted by local and very specific ecological factors.

These plants are specific in halophytic and hyper- halophytic habitats, as salt-marshes, dunes, rocks and coastal cliffs, where the salt concentrations are significant. In these cases, the contribution comes from the sea winds, the seasonal water dynamics (dunes and salt-marshes) and the organic and mineral deficit of the soils.

In the studied area, their occurrence seems to be strictly associated with the high values of salts, basically in areas with temporary flooding (winter and springtime), around hand dug wells and in the margins of torrential water lines on very plain topography with reduced flow velocity.

As a result, their presence in the inner part of Alentejo has to be considered an alert signal from the hydrogeological, ecological (*e.g.* edaphic chemical/physical degradation) and economic (*e.g.* farming limitations and deep changes in soil use) point of view.

This specific plant association can also be used as a bioindicator in order to map the Na-Cl waters present in the area, avoiding much of the expensive chemical analysis and laboratory control.

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Keywords: Ecosystems, semi-arid area, Na-Cl mineralised groundwater, plant communities, phytosociology

Groundwater dependent ecosystems in the Table Mountain Group sandstones and the potential impacts of large-scale groundwater abstraction

[1] David C. Le Maitre and [1] Christine A. Colvin

[1] Natural Resources and the Environment, CSIR, P O Box 320, Stellenbosch 7599, South Africa e-mail: dlmaitre@csir.co.za, ccolvin@csir.co.za

ABSTRACT

The potential abstraction of large volumes of groundwater from the fractured sandstone aquifers of the Table Mountain Group (TMG) has raised considerable concern among ecologists because of the potential impacts on ecosystems which are dependent on groundwater from these aquifers – both groundwater dependent ecosystems (GDEs) and aquifer dependent ecosystems (ADEs). Habitat types linked to aquifer flow in the TMG include springs, rivers, streams and wetlands and aquifer discharge zones are typically discrete and linear. Differentiating at surface which ecosystems are dependent on sub-surface flow from aquifers or sub-aquifer fault zones is problematic in this heterogenous secondary aquifer. The sandstone is resistant and forms the high mountains or the area (including Table Mountain) and catchment headwaters. Flow paths from high recharge areas through the steep, faulted Cape Fold Belt, are complex and occur across multiple spatial scales from 10m to 10km. They have a significant vertical component from >1000mamsl to > -2000mamsl, and some of the deep synclinal flow paths result in hot springs of >50*C. Fynbos vegetation (Mediterranean-type shrub unique to the Western Cape) is internationally renowned for its high plant biodiversity and a number of international funding agencies are investing in projects to ensure that it is effectively conserved. Little attention has been given to GDEs or other forms of wetlands in the current conservation effort which is focused on conservation planning. The ecological distinctiveness, and potentially the functional importance, of GDEs is not related to their size. There is limited evidence that the spring, wetland and associated aquatic ecosystems are more important than is generally recognised. These ecosystems that include many specialised species of both plants and animals (such as frogs and insects with aquatic larval stages), may support key pollinators and may be an indirect food source for adjacent dryland ecosystems. Many of the species associated with GDEs are relicts of ancient lineages – often called palaeo-endemics. The ecological distinctiveness of GDEs is hypothesised to be the result of a number of factors, the main ones being: the palaeoecology of the current mountain environments, the predictability of the groundwater supply and the contrast in the moisture regime between the GDE and the adjacent environment. Studies of the physiology of a number of wetland and non-wetland plant species indicate that there are at least some species that require these wetlands to survive. Further research is needed to understand the relationship between the current climatic regime, hydrogeological setting of GDEs, their structure and functioning and their vulnerability to groundwater abstraction and climate change. Effective conservation of these systems will require collaboration and interaction between specialists in terrestrial and aquatic ecology, hydrology and geohydrology, and the relevant water resource and land management agencies.

Keywords: groundwater dependent ecosystems, aquifer discharge, fynbos, biodiversity, ecosystem function.

Uncertainty propagation in aquifer vulnerability models

[1] Pascal DUMONT, [2] Michel J. ROBIN, [2] Bahram DANESHFAR

[1] Health Canada, First Nations and Inuit Health Branch, Main Statistics
Tunney's Pasture (address locator: 0302A1), Ottawa, Ontario, Canada,
E-mail: pascal_dumont@hc-sc.gc.ca
[2] Ottawa-Carleton Geoscience Centre, Department of Earth Sciences,
Ottawa, 140, Louis-Pasteur St., Ottawa, Ontario, Canada, K1N 6N5
E-mail: mrobin@science.uottawa.ca and bah@science.uottawa.ca

ABSTRACT

This study investigates the propagation of uncertainty in aquifer mapping. As a case study, we used the aquifers of Eastern Ontario, Canada, where a considerable amount of information is already available as a result of the Eastern Ontario Water Resources Management Study (EOWRMS). Municipality and county administrations within this region in partnership with the Government of Ontario sponsored the EOWRMS in recognition of the need to develop a regional water resources information system on a watershed basis. The EOWRMS and other similar studies in Ontario produce aquifer vulnerability maps that are used by municipal planners without the benefit of an estimate of the uncertainty associated with the information.

This poster and paper describes the three principal groundwater vulnerability models commonly used in Ontario (DRASTIC; SAAT and AVI), highlighting the sources of uncertainty intrinsic to geographical data sources (sources of uncertainty). The poster & paper describe the methodologies used to track the propagation of these uncertainties through each models (geographical application) and compares the final results (information products) to improve decision-making.

The first step is to identify the sources of uncertainty associated with the layers that are used in the vulnerability calculations. The principal components are uncertainty associated with measured point estimates (■measurement error•, associated with the process of abstraction or generalisation about real world phenomena) and uncertainty resulting from the interpolation (■interpolation error•, from measuring the positions and attributes of geographical entities, or in sampling). These uncertainty components are combined to give uncertainty maps, expressed as variance, for each input parameter that enters in the vulnerability calculations. The next step is to propagate the uncertainty of the input parameters through the vulnerability calculations using the Error Propagation Theorem (used in standard statistical applications). The result is a map of uncertainty, expressed as variance, associated with the vulnerability map.

While an uncertainty map is certainly valuable information from a scientific standpoint, it is difficult to use for planning purposes. Consequently, the final step for the process consists of producing vulnerability maps that are classified and that are accompanied with a map showing areas where classifications could change as a result of uncertainty, for a given confidence level. From the planner's perspective, a decision can then be made to make further field measurements in areas of high uncertainty depending on the risk assessment.

Keywords: Groundwater, Vulnerability, Uncertainty, Propagation, Risk

Vegetation and soil features mapping for hydrogeological purposes at Kelemenszék, Hungary

[1]Brigitta CZAUNER, [1] Judit MÁDL-SZŐNYI, [1]Anita ERŐSS, [1]Anna VOJNITS

[1]Department of Applied and Environmental Geology, Eötvös Loránd University, 1/c Pázmány Péter sétány 1117 Budapest, Hungary, e-mail: brigicza@gmail.com, szjudit@ludens.elte.hu, anitaeross@freemail.hu, mini107@gmail.com

ABSTRACT

The Kelemenszék Lake at the Duna-Tisza Interfluve (Pannonian Basin, Hungary) is fed partly by meteoric waters and also by rising saline fluids (Mádlné Szőnyi et al. 2005). The aim of the present study was to map the seasonally variable extent of the lake based on vegetational and soil salinization phenomena around the lake caused by flowing groundwater.

The Kelemenszék is a shallow lake situated in an up to 3 km wide topographic depression at the discharge zone of the allogenic deep origin saline water. The discharge of the gravity-driven flow-system with a considerable lower (350-400 mg/l) total dissolved solids content is found 2 kilometres to the East from the lake. The horizontal flow and mixing of this water with the ascending saline fluids results in, the 3500-4000 mg/l total dissolved solids content in the groundwater near to the Kelemenszék. Around the lake halophytic vegetation zones, soil salinization, soil-liquefaction could be identified. These features and some theoretical findings of earlier studies (Meinzer 1923, 1960; Meyboom et al. 1966, Meyboom 1967; Engelen and Kloosterman 1996; Klijn and Witte 1999) were used to assess the areal extent of the shallow lake.

The mapping was based, on: i) the delineation of the open water surface with 1cm depth; ii) vegetation zones; and iii) salty berms. Simultaneously, the depth of the lake and the position of the water level above the see level was recorded. Two vegetation zones, *Bolboschoenus maritimus* and *Puccinellia limosa* were distinguished around the lake which indicate the presence and depth of water. The *Bolboschoenus maritimus* indicates a water depth of 20-25 cm with high alkali content. The *Puccinellia limosa* prefers temporary wet conditions. The mapping was conducted in October 2006, and the mapped borders (Fig. 1) were located by 2019 GPS points.

The actual interaction between the lake and the groundwater was established by water level measurements during the mapping. The map of the lake's inferred extent was compared with military and cadastral maps (made in 1782-1785, 1860-1870, 1920-1930) and with aerial and satellite images from 2002 to demonstrate the changes of the lake's extent in the last two centuries and as well as in the last five years. The artificial drainage via Duna-valley and Kiskunsági main canal has been an influencing factor since 1930 by generating sublocal flow systems around the lake (Engelen and Kloosterman, 1995). The impact of water infiltrating from the canal on the salty groundwater was measured by Radiomagnetotellurics (RMT) along an E-W vertical section through the lake and the main canals.

As a result of the mapping the extent (2,05 km^2) and depth (30-80 cm) of the shallow lake could be approximated with theoretical and practical uncertainties. The inner berm (Fig. 1) seems to be the border of the lake at low water stand, which was characteristic during the mapping. On the other hand, the outer berm (Fig. 1) indicates the possible maximum extent of the lake (3,15 km^2). In some cases the existence of the outer berm was not recognizable. In these places the transition is continuous between the lake and groundwater. The vegetation zones with water requirement increasing from the margin to the open water surface, show strong correlation with the morphology of the lake basin.

From the known maximum extent of the lake, bed morphology and registered lake water level, the actual lake extent can be inferred. The results also give a basis for recording the seasonal, annual or even longer changes in the vegetation. The established relation between the vegetation zones and the lake extent can contribute to hydrological calculations (water budget etc.).

The groundwater level map shows that the lake is fed actually by groundwater. Based on the comparison between the military and cadastral maps, the aerial and satellite images and the mapped borders of the lake, it can be concluded that anthropogenic impacts have had no significant influence on the extent of the lake in the last two century. This indicates a stability of the recharge processes of the lake, i.e. that it is fed mainly by groundwater. The geophysical measurements pointed out that the impact distance of the canals around the lake with their freshwater lenses is not more than 250 m, so these canals have no direct influence on the lake water and the vegetation.

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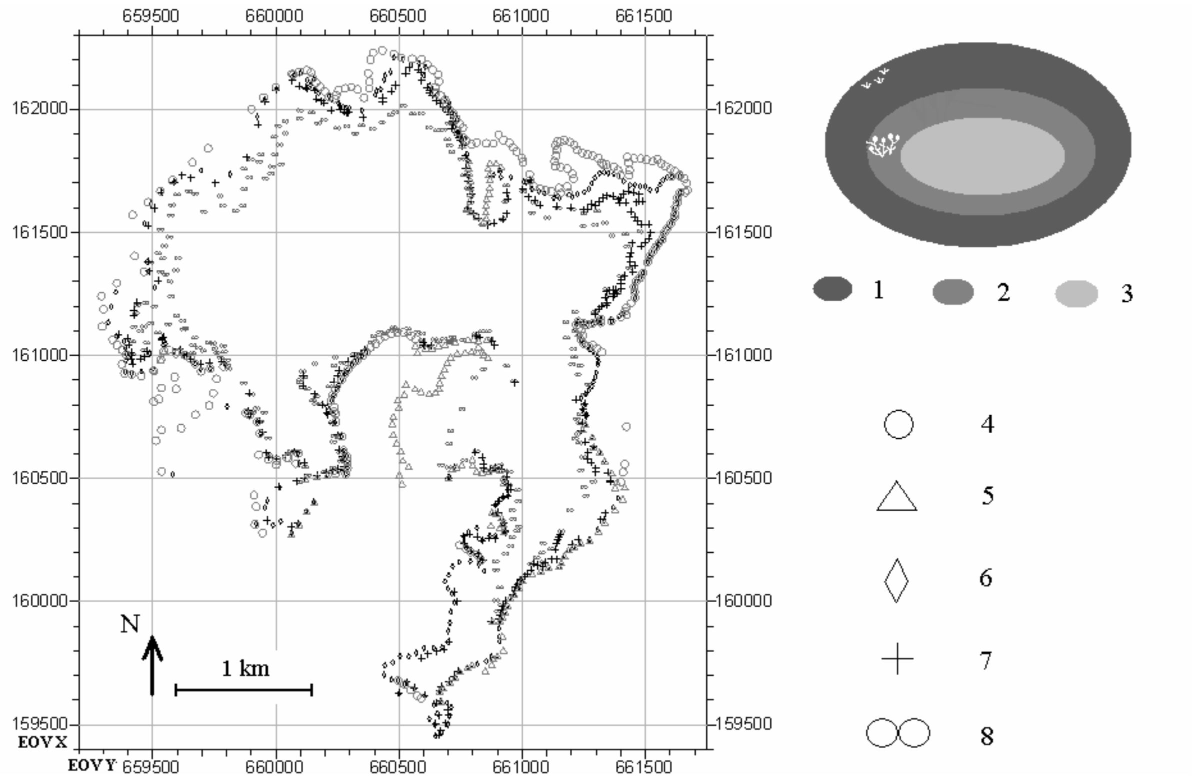

Fig. 1. Kelemenszék Lake: Theoretical zones 1: *Bolboschoenus maritimus* 2: *Puccinellia limosa* 3: open water surface; Mapped borders of zones 4: outer berm 5: inner berm 6: border of *Bolboschoenus maritimus* & *Puccinellia limosa* 7: 1 cm deep water 8: open water surface.

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Keywords: mapping, lake extent, vegetation zone, salty berm

Vulnerability Analysis of the Hundido Aquifer Valley in the Coahuila state, Mexico

[1]M. J. M RODRÍGUEZ, [1]C. J.E BERMÚDEZ, [2]B D.WOLAVER

[1]Institute of Civil Engineering, Autonomous University of Nuevo Leon, Mexico
E-mail: jmrodriguez@fic.uanl.mx, javier.bermudez@inegi.gob.mx.
[2]Brad D. Wolaver. Department of Geological Sciences, Jackson School of Geosciences.
The University of Texas at Austin. Austin, TX 78712-0254. E-mail: brad_wolaver@mail.utexas.edu

ABSTRACT

The dry climate of the Chihuahuan Desert of northern Coahuila requires the rational and effective use of water resources without adversely affecting unique groundwater-dependent ecosystems. In particular, agricultural groundwater development in the Hundido Valley threatens wetlands in the adjacent UNESCO ecological reserve of the Cuatrociénegas Valley of Coahuila, Mexico.

The Hundido Valley, due to its proximity to the Cuatrociénegas Valley is a place of great importance for México and the World due to its unique groundwater-dependent ecosystems. As a result, it is necessary to determine the vulnerability of the aquifer to contamination. The application of this methodology shows how different topographic, physical, and chemical characteristics determine the degree of vulnerability to pollutants. The method requires an extensive database in addition to field data. Also, geographic information system layers are used to handle the system properties.

Keywords: Aquifer, vulnerability, groundwater level, soils, rock.

Vulnerability assessment and groundwater management in a karst area (Banat Mountains, Romania)

[1]Cristian-Mihai MUNTEANU, [1]Marius VLAICU, [1]Constantin MARIN, [1]Alin TUDORACHE

[1]"Emil Racovita" Institute of Speleology, 13 Septembrie Road, No. 13, 050711, Bucharest, Romania, criscarst@yahoo.com, mariusv_iser@yahoo.com, constmarin@gmail.com, altudorache@yahoo.co.uk

ABSTRACT

The karst geosystems functioning frequently experiences very quick mass and energy transfers, which make them highly sensitive to any natural or anthropogenic disturbance. Therefore, the groundwater resources, threatened by agricultural and industrial pollution, should be carefully exploited, taking into account the intrinsic vulnerability of the region. This paper aims to present the results of the geological, geomorphological and hydrogeochemical studies carried out in the Banat Mountains (Romania), in order to widely assess and map the vulnerability of the most exposed karst aquifers. Following the principles of the EPIK method and using GIS, we were able to delineate upon degree 4 vulnerability classes (low, moderate, high, very high). Moreover, each unit has been assigned to a specific protection framework, comprising suitable management solutions, designed for environmental managers.

Keywords: Karst groundwater, intrinsic vulnerability, protection, EPIK, GIS

TOPIC 09

Karstic ecosystems: biological, hydrological and landscape issues

A possible important CO_2 sink by the global water cycle

[1, 2]Zaihua LIU, [3]Wolfgang DREYBRODT

[1] The State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Science, 55002 Guiyang, China, e-mail: liuzaihua@vip.gyig.ac.cn
[2] Karst Dynamics Laboratory, Ministry of Land and Resources, 541004 Guilin, China, e-mail:zliu@karst.edu.cn
[3] Institute of Experimental Physics, University of Bremen, 28334 Bremen, Germany, dreybrodt@t-online.de

ABSTRACT

One of the most important problems in the science of global change is the balancing of the global budget for atmospheric CO_2. Although anthropogenic activities have clearly altered the global carbon cycle, significant gaps exist in our understanding of this cycle. Of the CO_2 emitted into the atmosphere as a result of burning fossil fuels, roughly half remains in the atmosphere and the other half is absorbed into the oceans and the terrestrial biosphere. The partitioning between these two sinks is the subject of considerable debate. Without robust accounting for the fate of CO_2 leaving the atmosphere, predictions of future CO_2 concentrations that result from different emission scenarios will remain uncertain. This, in turn, weakens the link between energy policy and climate change.

One of the major issues surrounding carbon cycling is the apparent missing carbon that is not accounted for in the present carbon-cycle model. This is a major issue, as it may define how the atmosphere will change as emissions increase.

The balance is as follows:

Atmospheric increase = emissions from fossil fuels + net emissions from changes in land use - oceanic uptake - missing carbon sink

3.2 = 6.3 + 1.6 – 1.9 - 2.8 (all values in Pg C/a, 1 Pg =10^{15} g)

What is the possible reservoir for the missing carbon sink? Here, we show, based on theoretical calculations and evidences from field monitoring results, that there is a possible important CO_2 sink (as DIC-dissolved inorganic carbon) by the global water cycle. The sink constitutes up to 0.8013 Pg C/a (or 10.1% of the total anthropogenic CO_2 emission, or 28.6% of the missing CO_2 sink), and is formed by the CO_2 absorption of water and subsequent enhanced consumption by carbonate dissolution and aquatic plant photosynthesis. Of the sink, 0.5188 Pg C/a is to sea via precipitation over sea (0.2748 Pg C/a) and continental rivers (0.244 Pg C/a), 0.158 Pg C/a is released to the atmosphere again, and 0.1245 Pg C/a is stored in the continental aquatic ecosystem. Therefore, the net sink could be 0.6433 Pg C/a. This sink will increase with the global-warming-intensified global water cycle, the increase in CO_2 and carbonate dust in the atmosphere, and reforestation/afforestation, the latter increasing soil CO_2, and thus the concentration of dissolved inorganic carbon in water.

Keywords: CO_2 sink, global water cycle, carbonate dissolution, dissolved inorganic carbon, aquatic plant photosynthesis

Artificial maintenance of groundwater levels to protect carbonate cave fauna, Yanchep, Western Australia

Dr Cahit YESERTENER

Department of Water, PO Box K822, Perth, WA 6842, Australia, cahit.yesertener@water.wa.gov.au

Abstract The Yanchep Caves, Western Australia, Perth, contain a unique ecological system that is dependent on groundwater for its survival. Due to declining groundwater levels in the Gnangara Groundwater Mound, in the same area, since 1969 mainly from reduced rainfall, increased use of groundwater for public and private water abstraction, and pine plantations, the groundwater levels under these caves have declined. This has increased the stress on the dependent cave fauna. Despite the artificial sprinkling system for the protection of the fauna, the water levels have continued to decline since monitoring began in 1991. It has become obvious that a more robust and generous provision of water is needed. As a result, the Department of Conservation and Land Management, Water Corporation and the Department of Water have been cooperating to design and test a new emergency re-watering system for the caves, particularly those containing threatened animals. The aim of the system was to test the feasibility of rehydrating the cave system by establishing and maintaining local groundwater mounds at seven of the faunal caves. The longer-term aim is to develop a permanent artificial system to reinstate and protect the threatened ecological invertebrate communities of Stygofauna associated with Tuart tree root mats.

To evaluate the amount of groundwater required for each of the 7 caves out of 300 and to determine the effects of pumping groundwater from the superficial aquifer, a three-dimensional groundwater flow model was constructed using Visual Modflow Pro 4.1. The models estimate that a total discharge rate of up to 3.6 GL per annum would maintain water in ponds in each priority cave in both summer and winter until 2015. The effects of pumping on groundwater dependent environments have been evaluated. There are no other groundwater dependent environments (GDE) in the vicinity that may be affected by pumping from two bores, which were selected about 1km south west of the Loch McNess Lake. The cone of depression resulting from the pumping of these bores stabilize in two years and indicates that there may be a 0.5m drawdown within approximately 1 km west of the bores with no impact on the lake system towards the east after the second year of operations.

Keywords: Artificial recharge, Yanchep caves, Climate impact, Groundwater modelling

Bacteria transfer from soil to groundwater via preferential flow paths studied by means of *Ralstonia eutropha* H16

[1] Michael SINREICH, [2] Raymond FLYNN, [3] Jakob ZOPFI

[1] Centre of Hydrogeology CHYN, Neuchâtel University, Switzerland, e-mail: michael.sinreich@unine.ch
[2] Department of Civil Engineering, Queens University Belfast, Northern Ireland, e-mail: r.flynn@qub.ac.uk
[3] Laboratory of Microbiology LAMUN, Neuchâtel University, Switzerland, e-mail: jakob.zopfi@unine.ch

ABSTRACT

Matter entering from the subsurface provides an important natural nutrient source for groundwater ecosystems, while also raising the possibility of microbial exchange. Conversely, infiltrating chemical contaminants and pathogenic micro-organisms released at land surface may alter the natural state of groundwater biocenoses, while endangering groundwater quality from a human health perspective. Knowledge of mass transport rates and processes operating in the vadose zone overlying aquifers can provide information that can be critical in determining whether contaminants may be transferred to underlying groundwater. Comparative solute/particle tracer testing provides a useful means of investigating mass transfer, particularly in karstified systems where preferential flow paths can result in rates that are often orders of magnitude higher than in porous media. This study employed a new bacterial tracer, *Ralstonia eutropha* H16, and compared its response to a similarly-sized microsphere tracer, and to a conservative solute in a field-based tracer test. This has permitted the mobility of allochtonous micro-organisms entering groundwater ecosystems to be assessed, while simultaneously evaluating the degree of protection the vadose zone provides against infiltrating contaminants.

R. eutropha strain H16, is a Gram negative β-Proteobacteria that has been isolated from freshwater spring sludge; it is a ubiquitous inhabitant of soil and freshwater environments. It is a metabolically versatile organism that grows heterotrophically on a wide range of organic compounds, but also autotrophically using hydrogen and CO_2 as energy and carbon sources for biomass formation, respectively. *R. eutropha*'s motile, rod-shaped cells typically measure 0.5 µm x 1.8-2.6 µm. To date *R. eutropha* H16 has served as model organism in biochemical and genetic studies and recently the whole genome of this strain has been sequenced because of its potential for biotechnological applications. In contrast to other *Ralstonia* species, *R. eutropha* H16 has never been recognized as human, animal or plant pathogen, and therefore displays important potential as a bacterial tracing agent in hydrological studies. Because *R. eutropha* is a naturally occurring, non-pathogenic, non-genetically modified organism it offers several advantages compared to classic bacterial tracing agents: *Serratia marcescens* has been recognized as an agent for nosocomial infections in hospitals which constrains its use as a tracer. Similarly, *E. coli* strains with genes for metal-tolerance or antibiotic-resistance are not widely applicable as the introduction of antibiotic resistance genes into the environment should be avoided. Furthermore the release of genetically modified organisms is under strict legal control and currently not allowed in most countries.

Tracing experiments completed in the vadose zone at a test site in the Jura Mountains, Western Switzerland have permitted *R. eutropha*'s utility as a bacterial tracer to be evaluated at the field scale. For this study, *R. eutropha* was produced in liquid mineral medium under autotrophic conditions yielding ~10^9 cells ml^{-1}. One litre of this culture was mixed with the other particle and solute tracers in a 20 l plastic watering can just prior to injection. Application of the tracer cocktail to the ground surface followed a hiatus in irrigation with tracer-free water (at rates comparable to a moderate to heavy rainfall). This, coupled with regular sample collection from points in an unlined tunnel below thin soil and approximately 10 m of carbonate rock, permitted tracer breakthrough curves to be reconstructed following sample collection and analyses. Sample storage in chilled dark boxes prior to analyses, conducted within 24 hours of collection, permitted the concentrations of *R. eutropha* in water to be determined with minimal risk of concentration changes due to rapid growth at elevated temperatures. *R. eutropha* quantification consisted of filtration through a 0.2 µm membrane filter, which was subsequently placed onto mineral medium agar plates devoid of any organic substrates. Serial dilution in a physiological buffer prior to filtration permitted the filtration volume to be adjusted depending on the suspected cell density.

Tracer test results demonstrate *R. eutropha* to be already present in water samples collected prior to tracer injection (Fig. 1). In this case, *R. eutropha* may be regarded as a natural tracer reflecting the transfer rate of autochthonous micro organisms from soil to groundwater during recharge events. Background concentrations of iodide and microspheres recorded prior to injection reflect residues from previous *R. eutropha*-free tracer experiments at the site.

When viewed as an artificial tracer, *R. eutropha* may be regarded as a surrogate for allochthonous and potentially pathogenic bacteria. Breakthrough curves generated using the bacterium show that approximately 10 minutes after injection, it could be detected at concentrations above background level. Levels subsequently rose at a number of sampling points to a maximum concentration at between 30 and 60 minutes following injection. Simultaneously injected conservative solute tracer (iodide) had a more prolonged breakthrough curve response with consistently lower maximum relative concentrations than *R. eutropha*. Moreover, the high mass recovery of *R. eutropha* relative to iodide over the duration of the test (about 80% flow-weighted recovery for *R. eutropha*) suggested that bacterial transport occurred preferentially along faster flowing channels relative to solutes, i.e. iodide also used slower flow paths, which were not accessed by *R. eutropha*. Test results suggested that most of the iodide tracer still resided in the vadose zone above the tunnel by the time the bacterial tracer has already passed through. Fig. 1 presents breakthrough curves for *R. eutropha*, 1 µm fluorescent microspheres, iodide and turbidity for a typical sampling point in the tunnel. Comparable responses observed at other points demonstrate the consistency of bacterial analyses.

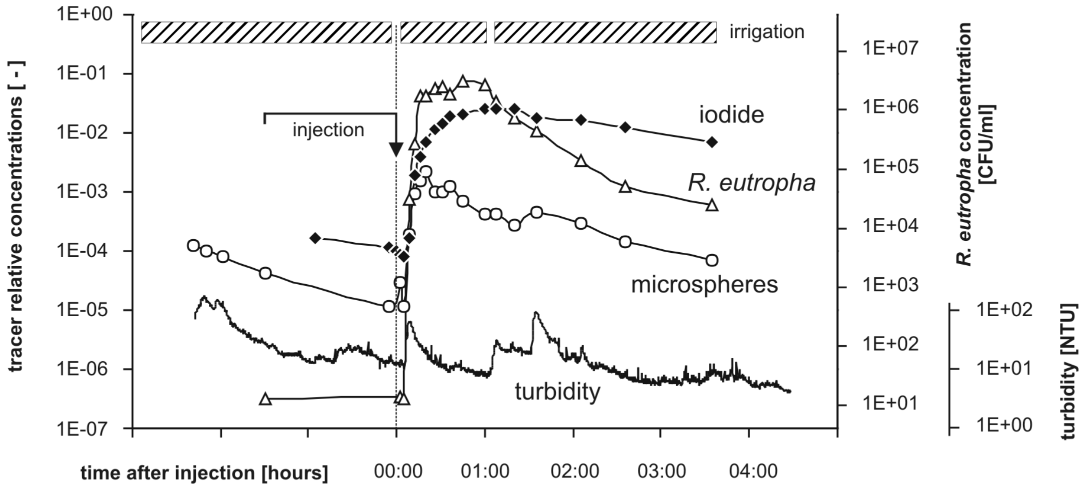

Fig. 1. Vadose zone tracing experiment results employing *R. eutropha*, 1 µm microspheres, and iodide tracer.

Comparison of *R. eutropha* breakthrough curves with those for 1 µm microspheres reflects the variable responses of comparably sized tracers. The results demonstrate that both particle tracers had the opportunity to interact with the soil and/or rock and undergo attenuation. The differing responses are assumed to reflect differing collision efficiencies resulting in variable degrees of sorption. Conversely, the differential tailing of both particle tracers is believed to be partially due to desorption processes. Overall, *R. eutropha* response cannot be adequately reproduced by employing similarly-sized microspheres.

The results of the field tracer experiment highlight the following points:

- The bacterium's intrinsic characteristics and its response during tracer testing show that *R. eutropha* may be effectively employed as a bacterial tracer in hydrological studies.
- High *R. eutropha* recovery suggests that the bacterium is relatively resilient in the subsurface over a period of hours to days.
- Breakthrough curves demonstrate that biotic and abiotic particles may be mobilised during recharge events and can be rapidly transferred to the groundwater table via preferential flow paths.
- Solutes and particle tracers (including micro-organisms) can behave differentially when being transported through the unsaturated zone. Indeed, micro-organisms may reach the water table in higher concentrations and more quickly than solutes. Consequently, solute tracer breakthrough may not necessarily reflect micro-organism responses.
- Although micro-organisms may interact with the materials overlying the water table during transport, they will not necessarily be highly attenuated (as reflected by *R. eutropha* compared to microspheres).
- Particle size alone has proved an inadequate discriminant for understanding particle fate and transport at the site, as illustrated by the comparative behaviour of microsphere tracer and similarly sized *R. eutropha* bacteria; the attenuation rate of the spheres is 30 times that of the bacteria.

Such studies demonstrate the potentially high fluxes of dissolved and particulate matter that may enter karstified groundwater ecosystems during recharge events, while simultaneously highlighting the elevated risk of potential impacts to groundwater quality resulting from anthropogenic activity in such environments.

Keywords: karst groundwater, vadose zone, bacteria, particle tracer, preferential flow

Characterization of seepage waters in a filled epikarst

[1]Benjamin LOPEZ, [1]Roland LASTENNET, [1]Philippe MALAURENT, [1]Alain DENIS

[1] Université Bordeaux1, CDGA, Centre de Développement des Géosciences Appliquées, équipe d'accueil 2970, UFR Sciences de la Terre et de la Mer, Avenue des facultés, 33405 Talence cedex, France, e-mail: b.lopez@cdga.u-bordeaux1.fr

Introduction

The understanding of karstic aquifers functioning is a real challenge (BAKALOWICZ M., 1981; LASTENNET R., 1994; EMBLANCH C., 1997). The famous prehistoric painted cave integrated in the Lascaux karstic system, offers a privileged observation point of epikarstic flows. This site belongs to one of the most important European paleolithic painted caves amalgamation. It is situated in the East of the Dordogne department (Fig. 1.a), on the northern margin of the Aquitaine sedimentary basin, in the carbonated bed formation of late Cretaceous (late Coniacian and lower Santonian, Fig. 1.b). The Lascaux site is representative of the hydrogeological environment of this area where the great carbonated sets are filled by more recent detrital spreadings (Fig. 1.c). Our work focuses on the complete understanding of this karstic system, and on the mechanisms of water and gases transfers which can affect the good conservation of the paintings on the walls of the Lascaux cave.
The main objectives of the study are as follow:

- To define the geometry and the boundaries conditions of the filled paleokarst of Lascaux.
- To determine the origins of waters and to characterize the impluvium.
- To characterize the conditions of water run-offs within the system and to compare the existing data for transfer speeds (LASTENNET and *al*., 1999) with the data gathered in transit.

Materials and methods

We carried out an in-depth study of geology and geomorphology of this site in order to specifically identify the bed formations in which waters circulate. The use of hydroclimatical analysis combined with a semi-monthly hydrochemical and isotopical follow-ups of the epikarstic emergence runing out from the cave roof (Fig 1.d), allowed the understanding of the epikarst functioning in terms of matter transfer.

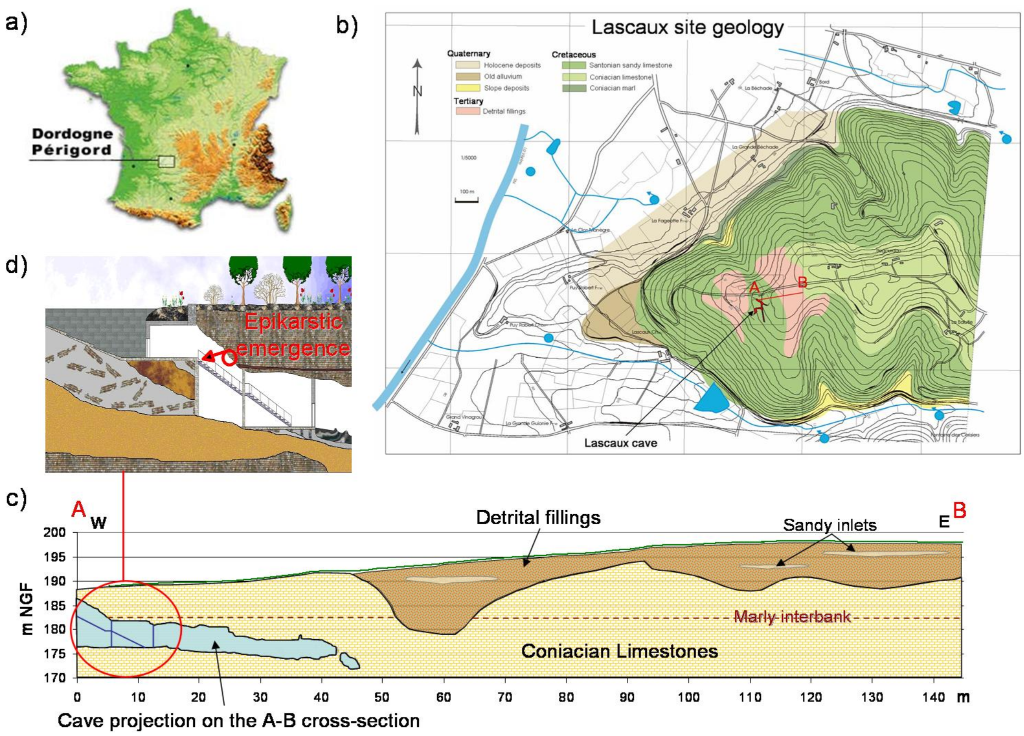

Fig. 1. The Lascaux site a) Localization of Dordogne department; b) Lascaux site geology with A-B cross-section localization; c) A-B schematic cross-section; d) Epikarstic emergence details.

Results

The rain-flow signal of the epikarstic emergence analysis shows that pressures transfers are fast in the epikarst of Lascaux when the system is recharged by rains, close to 250 mm, during autumn and winter. We notice the formation of a water table in the epikarst, and the roof emergence would work like a nonperennial overflow spring. The temperatures data indicate that this reserve is stocked at low depth, into the heterothermy zone of the basement.

The results of the physicochemical analyses show that waters drained by the epikarstic emergence result from an important water homogenisation. The minimal impact of new water arrivals on the chemical signal confirms the existence of not inconsiderable reserve. Thus, the mass transfers are slow in this system characterized by a fissured and nonkarstic behaviour type.

Waters are supersaturated with respect to calcite when they run out from the roof of the cave. This state of internal imbalance can only be explained by water degassing occuring when the partial CO_2 pressure (pCO_2) of the circulation medium becomes lower than the one where waters mineralized. The high bicarbonates and calcium concentrations show that these waters are strongly mineralized because of an important pCO_2 at saturated state (5% on average). Such values of pCO_2 do not correspond to the biogenic CO_2 production measured in the soil above the Coniacian limestones. The other supposed origin is the sandy clayey filling formations (siderolithic or old quaternary) where we measure important pCO_2 (up to more than 8% in the soil atmosphere) at the interface limestones-fillings. Moreover, the presence of water in the sandy levels of fillings suggests that the system can be partly recharged from these formations. Under this hypothesis, limestones, with less important pCO_2, would rather be involved in the water drainage and transfer towards the epikarstic emergence rather than in the reserve zone. The flows would then be degasified in the carbonated formations opened to the soil atmosphere.

The $\delta^{13}C$ data obtained at the epikarstic emergence during the cycles of study (LOPEZ and *al.*, 2006) seem to characterize the physicochemical conditions of the environments in which waters circulate during their transit in the system. They confirm the possible various origins of waters. Moreover, the increase in pressure during rising periods would disturb the waters run-off conditions in the epikarst: they would undergo degassing – precipitation phenomena, as the evolution of the signal "saturation index vs. $\delta\ ^{13}C$" highlighted. The transit of water through two physicochemicaly highly contrasted environments would be at the origin of the general flows supersaturation in the cave.

Conclusion

The chemical and isotopical analysis carried out during this study show that Lascaux epikarstic waters acquire their mineralization in the first meters of the aquifer. The flows transits are slow in this system and waters are chemically homogenized by the constitution of an epikarstic water table.

This system is compartmentalized: waters transits from confined, capacitive and rich in CO_2 horizons (fillings) to transmissive, opened to the soil atmosphere formations (limestones) and where degassing and precipitation mechanisms occur. The filling formations are involved in two aspects of the conditions of epikarstic waters run-off: (i) they homogenize them while retaining them near to the soil and (ii) give them a very high karstification potential. These "perched" and detritic spreadings filled paleokarsts are common in this area. They constitute feeding systems of large Jurassic and Turonian regional karstic aquifers. Our study shows that the recharge of the aquifers situated below filled epikarstic systems is highly controlled: its geochemical signal is homogenized, epikarstic waters and this, from the first meters of the infiltration.

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Keywords: Lascaux cave, hydrogeochemistry, epikarstic flows, seepage waters, transit

Hydrogeological and geophysical research of an island's karst aquifer – the Čarsko Polje case study

Josip TERZIĆ[1], Ante PAVIČIĆ[1] & Božo PADOVAN[2]

[1] Croatian Geological Survey, Sachsova 2, 10.000 Zagreb, Croatia, terzic@hgi-cgs.hr, pavicic@hgi-cgs.hr
[2] Civil Engineering Institute of Croatia, Rakušina 1, 10.000 Zagreb, Croatia, bozo.padovan@igh.hr

ABSTRACT

Čarsko Polje is situated in the central part of the Adriatic island of Korčula in Croatia. It is a typical karst polje covered with a few meters thick Quaternary deposits, with temporary surface streams and two major ponors (swallow holes). The rock mass below the polje, as well as outside the polje, is composed of karstified limestones and dolomites of Cretaceous age. The limestones are much more karstified, porous and more permeable, while the dolomites can represent aquifer or preferential flow direction only in tectonically extremely fractured zones. Typical karstic preferential flows occur only in such tectonic zones through the rock mass, both dolomites and limestones, and from ponors in the polje towards the vruljas on the island's southern coast (Fig. 1). Karst features outside these zones are mostly unconnected, partially infilled with fine-grained material, and should be considered as a part of the porous rock mass, where groundwater flows through the fracture networks generally towards the south, to the coast, where it springs out scattered all over the coastline. Such a phenomenon is documented as a major outflow ratio on many Adriatic islands (Terzić 2006). North from the polje is a regional reverse fault, and lower Cretaceous dolomites ascend on the northern side both tectonically and morphologically. That circumstance has mostly a positive role, because these hills (up to 555 m a.s.l.) represent the first barrier to rain clouds from the open sea on the south. Most of the precipitation comes from that side, driven by the south wind called Jugo. That causes a relatively high amount of precipitation, which averages 900 mm/m^2/year. Most of the precipitation flows on the surface and the shallow subsurface epikarst layer toward the karstified limestones and karst polje in the south. During abundant rains, torrents occur on the surface of the polje and the water flows into the ponors. That means that a relatively high amount of water does not infiltrate into the aquifer. That water flows away very fast. The water that is infiltrated in the Quaternary deposits (diffuse infiltration) is also not of interest because most of it remains in the clay and silt of the polje and very slowly evaporates from that aquitard. In any case, the terrain outside the polje has almost no fine-grained Quaternary cover; the infiltration is discrete, not through ponors but mostly through open fractures and dissolution channels. That infiltration could be considered scattered/discrete, and water immediately infiltrates the epikarst belt, than slowly flows towards fracture or fault zones to infiltrate the deeper karst underground. That groundwater is of interest to the researcher. Since dolomitic rocks in the middle of the island are not porous and permeable enough to allow the genesis of an aquifer, it is limited to a relatively narrow belt (some 2-3 km), and exposed to the influence of the sea from the south. Hydrogeological and geophysical researches began in the 1980s (Romandić 1983; Capar 1984). Several geoelectrical sounding points approximately defined the level and position of the transition zone (the sea water intrusion) in the underground. Two boreholes were drilled but the amount of groundwater that could be extracted was relatively low (below 1 l/s). No water supply was established and further researches were stopped, although the results were promising to a certain extent. Today, the eastern part of the island of Korčula is connected with the mainland by undersea pipelines. The western part covers all its needs by extracting up to 60 l/s from the Blatsko karst polje. Since this central part of the island of Korčula has not acquired a satisfactory water supply system to the present day, the researches have been continued (Terzić & Pavičić 2006; Padovan 2006) by detailed structural-geological and hydrogeological mapping, time domain electromagnetic sounding and in situ measurements in one borehole still existing from the 1980s. By defining the catchment area and approximate water balance, and understanding the functioning of this sensitive karst environment, it is possible that the required amount of groundwater could be achieved in the near future. It is also possible to extract slightly brackish water, because desalination of such water is economically much more justified than desalination of significantly mixed water or sea water itself.

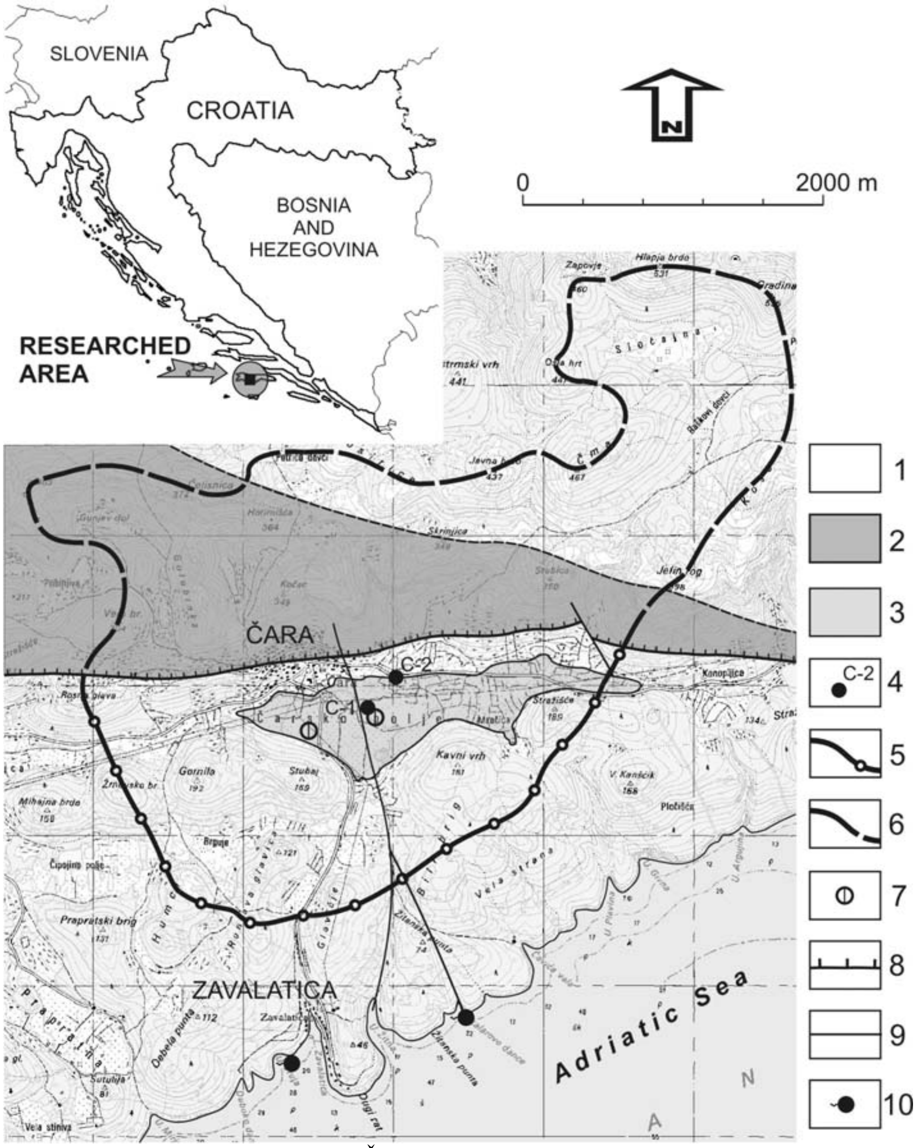

Fig. 1 Schematized hydrogeological map of the Čarsko Polje catchment and outflow area. Position sketch on small figure. 1- permeable karstified rocks; 2-dolomites of low permeability; 3-Quaternary deposits in karst poljes; 4-bore hole; 5- underground zonal water divide; 6-surface water divide; 7-ponor (swallow hole); 8-reverse fault; 9-fault; 10-vrulja (submarine spring).

Keywords karst hydrogeology, salt/fresh water relations, geophysical sounding, the island of Korčula, Croatia

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Hydrological and hydrochemical functioning of the Rançon springs

[1]Abdelkabir MAQSOUD

[1] University of Québec in Abitibi-Témiscamingue, 445 University Bd., Rouyn-Noranda, QC, Canada, J9X 5E4

ABSTRACT

The Superior Cretaceous chalk deposits of the Paris Basin, which extend over more than 110000 km^2, constitute with those of the London Basin the most bulk carbonates of Western Europe. The theories concerning this chalk aquifer started at the beginning of the twenty century; among these theories we quote: Simple aquifer, cracked aquifer and mixed aquifer. A mixed aquifer is a system where groundwater exists in the presence of a real karstic phenomena. This last theory, which considers the chalk as a mixed aquifer, was demonstrated by numerous authors. In spite of the knowledge of chalk hydrogeology, some authors continue to consider the chalk as aquifer with dual porosity (matrix and fissure) completely neglecting karstic development.

To illustrate the presence of karstic functioning in the chalk aquifer at the same time as the groundwater, we chose an example in the Paris basin, which is the Rançon springs. The available data in the literature of these springs were analysed, on one hand, by autocorrelation and spectral analysis for the discharges and precipitations and, on the other hand, by the principal components analysis for the hydrochemical data of these springs.

The analysis of the simple autocorrelogram of both cycles permits one to distinguish two types of behaviour (Fig. 1a). The autocorrelogram of the first cycle presents a slow diminution with an important memory effect, so showing the importance of the water reserves of the system. The autocorrelogram of the second cycle decreases quickly and informs us about the importance of the rapid drainage in this aquifer. Then this autocorrelogram increases and corresponds to water arriving at springs after an important delay.

This behaviour can be explained by the existence of a paleokarst perched above the level of the groundwater. When this level increases the karst is reactivated and quickly evacuates the water which it receives.

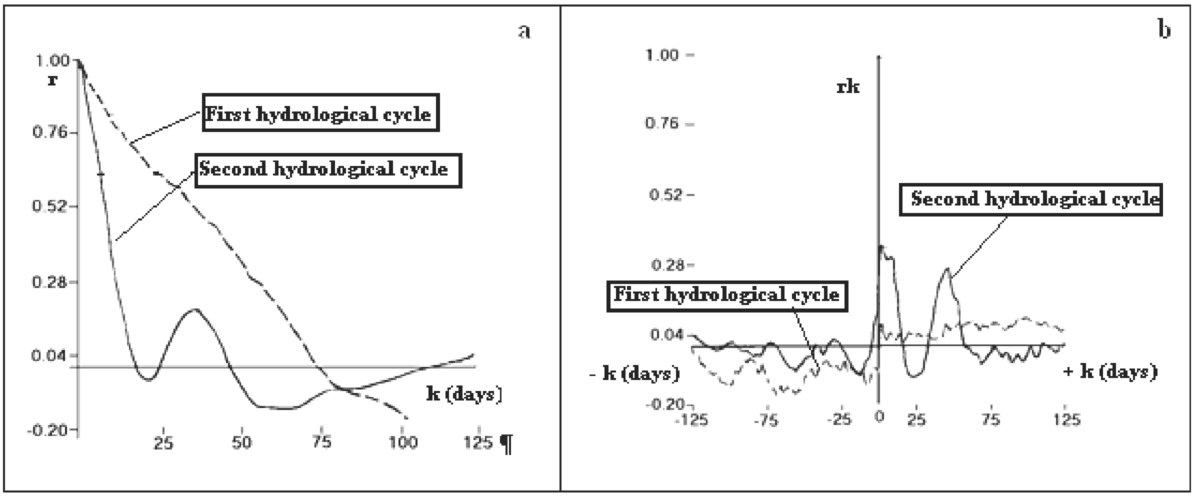


Figure 1: a) Simple correlogram of discharge of Rançon springs;

b) Crossed correlogram of Rançon spring discharges

The crossed autocorrelogram of the first cycle presents a very weak and spread response (Fig. 2a). This behaviour corresponds to a system containing groundwater with a very rudimentary drainage organization. Also, the crossed autocorrelogram of the second cycle shows a sharp response and is divided into halves (Fig. 2b). The first one, which is the more important, (r = 0.34) appears after two days and the second one after 45 days. This type of answer (doubled response) was never observed in the calcareous karstic systems but which has already been identified in the other chalk karstic systems.

As for the components analysis it shows a sharp dissociation of two types of waters:

- Water which stayed for a long time in the aquifer, confirmed by its geochemistry;
- Water which quickly passed through the chalk aquifer, always sub-saturated in bicarbonate, corresponding to water evacuated by the karstic drainage.

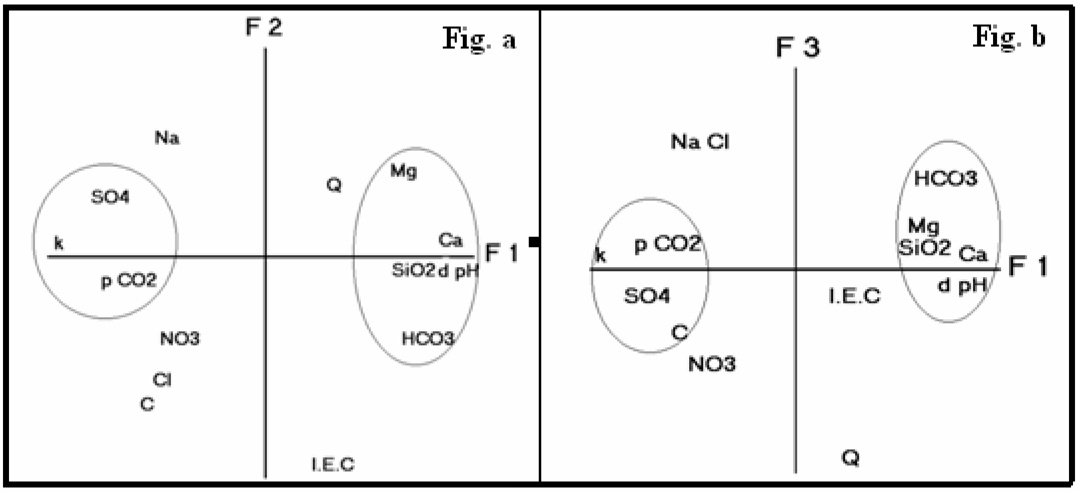


Fig 2: Principal components analysis of the hydrochemistry of Rançon springs: a) Plan F1-F2; b) plan F1-F3

In conclusion, the system of the Rançon seems to be characterized by the presence of groundwater in addition to a perched paleokarst. This paleokarst is reactivated and allows a rapid transit of waters, when the piezometric level increases. These two types of functioning must be considered during the realization of the well perimeter protections with the objective to avoid any pollution and to protect the groundwater resources.

Keywords: Chalk, Paleokarst, Autocorrelation and Spectral Analyses; Principal Components Analysis.

Identification of the Chalk Karstification Factors

[1]Abdelkabir MAQSOUD

[1] University of Québec in Abitibi-Témiscamingue, 445 University Bd., Rouyn-Noranda, QC, Canada, J9X 5E4

ABSTRACT

Chalk deposits of the superior Cretaceous of the Paris basin, which extends for more than 110000 km^2, constitute, with those of the London basin, the highest amount of carbonates deposits in Western Europe. During the twentieth century this chalk was at first considered as a porous aquifer (Gründ-Wasser theory). Then, there was a theory of the flowing in the diaclase according to which the permeability of the chalk is a consequence of fissuring. This theory was supported and then strengthened by Martel who concluded that "flowing in the diaclase" where there is chalk, into the subterranean rivers, predominate widely. The impact of this work was so strong that it was in the forties that geological studies came to change this viewpoint except in the recognized karstified areas (Pays d'Othe and the Montagne de Reims), where the chalk is fundamentally considered as an aquifer with interstice porosity. Here the karst would be present only in a accidental and limited area. The works of Mégnien led him to define the chalk as a mixed aquifer, that is a system where groundwater exists at the same time as real karstic phenomena. This functioning duality, karst and groundwater, was demonstrated by other numerous authors.

The question that now remains: How can one explain the localization and the development of the karst in chalk? To answer this question, karstic systemic approaches based on hydrodynamic and hydrochemical methods, were used. These approaches were applied to seven chalk aquifers, both located in Paris Basin. Also, the relation between fracturation, hydraulic gradient and kartic development are analysed.

Autocorrelation and spectral analysis results show that all the studied systems have an inertial behaviour thus indicating the presence of important reserves and/or the presence of filter effects due to the sedimentary cover. Also, the casement analysis between precipitations and springs discharges, show three types of behaviour:

- frank karstic response indicating a quite precise state of the system;
- negative response which indicate the captivity of the drowned zone;
- and finally a null answer due to the cover which plays a role of superficial aquifer and filter *vis-a-vis* the water infiltrations.

Principal components analysis demonstrates clearly the role played by the sedimentary cover and finally the homogenisation of the CO_2 production by the ground, in all the systems, is present.

The synthesis of all these results concludes that the karstification is mainly controlled by three factors: i) hydraulic gradient that allow the rapid water drainage from the surface to the discharge system, ii) the existence of a distensive fracturation, iii) the production of CO2 by the ground that supports the chalk dissolution; iv) and finally the absence of the superficial cover and/or the presence of sedimentary cover having a high permeability coefficient that allow water rapid infiltration to chalk aquifer.

Keywords: Chalk, Karstification, Hydraulic gradient, sedimentary cover and distensive fracturation

Investigation of bacteria-contaminated particles transfer in a karst aquifer by means of multivariate analysis

[1]Matthieu FOURNIER, [1]Nicolas MASSEI, [1]Anne MOTELAY-MASSEI, [1]Jean-Paul DUPONT

[1]University of Rouen, Department of Geology, UMR CNRS 6143, 76821 Mont Saint Aignan Cedex, FRANCE
matthieu.fournier@etu.univ-rouen.fr, nicolas.massei@univ-rouen.fr, anne.motelay@univ-rouen.fr, jean-paul.dupont@univ-rouen.fr

ABSTRACT

Relations between turbidity and bacteria are very important in the evaluation of karst water vulnerability. Turbidity, conductivity, size of the transported particles, and the enumeration of sessile and planktonic bacteria of water were monitored from their infiltration on a karst plateau to their discharge at a karstic spring. Results show that the amount of sessile bacteria is not modified at the spring whatever the turbidity values whereas a decrease in the concentration of planktonic bacteria occurred. These data highlight the fact that slightly contaminated larger particles are not recovered, whereas small-size particles which exhibited a higher bacterial contamination are directly transferred through the aquifer. The present data demonstrate that low turbidity values do not systematically exclude a risk of contamination by sessile organisms. The utilization of turbidity/bacteria relations at both swallow hole and springs might be used for simulating either sessile or planktonic bacteria time series.

Keywords: Karst aquifer, turbidity, bacteria, multivariate analysis

Karst Ecohydrology

Ognjen BONACCI

Faculty of Civil Engineering and Architecture, University of Split
21000 Split, Matice hrvatske 15, Croatia, E-mail obonacci@gradst.hr

ABSTRACT

During the last two decades the concept of ecohydrology has emerged in many scientific books, journals, workshops and conferences dealing with hydrology, hydrogeology, water resources management etc. Scientists do not agree on the details of its definition, importance, future development and role but they agree that the cooperation between hydrology and ecology could very probably help in solving many critical problems dealing with sustainable development and ecosystem management. It seems that an acceptable definition of ecohydrology could be: "Ecohydrology is the science of integrating hydrological processes with biota dynamics over varied spatial and temporal scales."

Due to the fact that the appearance, storage and circulation of water in karstified areas is specific and significantly different than in other more homogenous and isotropic terrains, karst ecohydrology should develop original methods and approaches. Karst is media specific where there exists a strong and direct interaction between the circulation of groundwater and surface water. Due to this reason, progress in karst theoretical and practical investigations as well as in ecohydrology should be based on close co-operation between hydrology and hydrogeology and many others scientific disciplines.

In this paper special attention is paid to ecohydrological functions of large karst underground morphological patterns (caves, jamas, karst conduits etc.) which play a crucial dual role: 1) Hydrological and hydrogeological for water circulation and storage; 2) Ecological as the habitat for many rare and endangered species. Large karst underground geomorphological patterns occur in many sizes and varieties, ranging from a few meters long or deep to the very large, the deepest being deeper than one kilometre and longer than tens of kilometres. Distinctions in their morphology, hydrology, hydrogeology and climate have resulted in a remarkable range of different environments, which provide the opportunity for the development of different species.

The paper presents an attempt to determine the characteristics and role of karst ecohydrology, using experience from Dinaric karst. The diversity of habitats in the particular region has resulted in great floristic diversity and richness. About 4,000 vascular flora families including high degree of endemic species, with high fauna species richness and high narrow (locally distributed) endemism show that this area is one of the ecologically richest karst regions on the Earth. One great problem is that there are many, mostly anthropological threats to cave and karst communities. The most usual and most dangerous are: 1) Engineering constructions; 2) Land development; 3) Nutrient stress; 4) Chemical pollution.

The role of the subcutaneous and aerated or vadose zones in ecohydrological processes is discussed. The importance of the flood factor in the ecology of caves is analysed. Hydrological, hydrogeological and climatological monitoring of karst cave essential for the protection of their environment and especially endangered endemic species living in them is stressed. The special case of the Vjetrenica cave (Bosnia and Herzegovina) and its ecohydrological characteristic is presented.

Keywords: karst, ecohydrology, underground karst geomorphological patterns, Vjetrenica cave, Bosnia and Herzegovina

Karstic hydrological ecosystem of Cemernica mountain, Western Serbia

[1]Dejan MILENIC, [2]Ana VRANJES, [3]Nevena SAVIC

[1] Dept. of Hydrogeology, Fac. of Mining & Geology, University of Belgrade, Serbia, dmilenic@yahoo.ie
[2] Dept. of Hydrogeology, Fac. of Mining & Geology, University of Belgrade, Serbia, vranjes_ana@yahoo.com
[3] Dept. of Hydrogeology, Fac. of Mining & Geology, University of Belgrade, Serbia, miss_nevena@yahoo.com

ABSTRACT

The territory of the Republic of Serbia is characterised by vast karst terrains (30% of its total territory). Sets of various ecosystems have been formed in such significant areas, representing almost untouched "pearls of nature". Abundance of water, hundreds of distinctive sorts of flora and fauna, fresh air and other climatic factors arouse growing interest in these terrains, not only from scientific point of view, but even more from economic, and the tourist industry view, as well. Bearing in mind that more than 70 karst springs are used for the water supply of towns in Serbia the sustainable development of karst hydrological ecosystems is a high priority in further development. One of such karst terrains is Cemernica Mountain in Western Serbia.

The complete Cemernica mountain karst aquifer is dealt with in this paper. Hydrogeological investigations and the clarification of hydrological ecosystem, water flows across and through Cemernica mountain represent a fundamental element, both in the further development of ecology and environmental protection on this mountain.

THE APPLIED METHODOLOGY. The evaluation of quantitative and qualitative features of Cemernica Mouintain groundwater, the knowledge of geological and tectonic relations on the terrain, and the sustainability of the unique karst hydrogeological Cemernica mountain ecosystem have resulted in the use of a fully complex methodological approach to the system. Cause-effect relations among investigated parameters caused the application of various methodogolical procedures, often multidisciplinary ones.The general and schematized model of the applied exploration concept is shown in Table 1

Table 1. The Applied Methodology of Hydrogeological Explorations along Cemernica Mountain

HG Recon.	Isotopic	Capacity monitoring of wells & springs	Baseflow analises + same as in flow		Balance methods	Field sampling	MAC lists	MAC standards
Geophysics	Chemistry						Chemical analyses	
Aerial ph.	Hydrology				Non-balance methods	Physical		Vulnerab. mapping
GIS	Climate					Chemical	Temperature	
Methods					methods			
Delineation	**Recharge**	**Flow**	**Discharge**	**Cemernica karst aquifer**	**Reserves**	**Quality**	**Use**	**Vulnerab.**
Parameters					parameters			
Horizontal	Rainfall	Transm-issivity	Natural discharge		Aq. volume	Bacteriolog.	Water supply	Illegal dumping
Vertical	Percolation				GW storage	Physical		
Depth of Karstificat.	Other aq. inflow	Effective porosity	Artficial discharge		Reserved	Chemical	GW bottling	Farming
					Av. yield	Isotopic	Wellness	Fertilisation
Volume	Surf. water interaction	Groundwat. direction	Baseflow calculation		Max. yield	GW origin	Recreation	Diary industry
Geometry					Min. yield	Gen. coeff.	Sport	

BASIC GEOLOGY AND TECTONICS. The Cemernica montain massif is made of limestone mass of Triassic age (karst aquifer) surrounded by Carboniferous, Permian and Jurassic deposits (hydrogeological barrier). From spatial pont of view, as the height grows, from periferial to central, heighest parts of the massif, the age of geological units goes from older to younger ones. Triassic rock masses-collectors occupy central parts of the massif and like a limestone "island" rise above water impermeable parts of the terrain. Rock formations of Lower Cretaceous of Seis and Campil beds as aureoles close the limestones of Anisian and farther grade into the oldest geological formations on the terrain- of the Carboiferous and Permian ages. The Triassic island is made of massive limestones of a complex rupture composition with abrupt changes of the terrain inclination.Young tectonic movements occurring at the end of the Tertiary and in the Quarternary affected significantly the forming of faults and joints. Neotectonic activity has been recorded through morphologic forms of recognized ruptures. The area of Cemernica mountain is intensively faulted, where two fault systems of hectameter and kilometer dimensions, with clear marks in the relief in the form of elongation of corries and dry valleys, dominate. The Tectonic setting, the systems of fault formations, their orientation, size and mutual intersections cause groundwater movement and their discharge.

AQUIFER DELINEATION. The northern part of the Cemernica area differs in height from the southern part with highly pronounced hypsometric difference pointing out the block structure of the terrain. The depths of occurence of Triassic formations can be followed from west to east, the change of which is directed to the reducing of thickness of Anisian sediments, which corresponds to the direction of the terrain inclination. The central part of the massif is singled out by height as elongation hearth west-east, with differently oriented line distribution of plate and well shape corries. The total area of the karst aquifer amounts 21km^2.

RECHARGE, FLOW AND DISCHARGE. The aquifer recharges through precipitation, open hydrogeological structure and the high level of karstification of the terrain intensify the process additionally. The complexity of the geological setting and tectonic features hinder the delineation of the watershed for all four springs, while the disagreement.of topografic drainage divide with the hydrogeological one, makes the process of delineation of the recharge area for all four springs even more complex (Fig.1). Mutual relations of groundwater collectors and their communication and quantitative relations in case of karst system are caused by hydrogeological barriers, fault zones with an active function or without it. The mountain massif is drained in four main springs, of different yield, distributed in an arrow from south west to south east part of the terrain. The yield drops from west to east, as well as the thickness of Middle Triassic limestones. The uniqueness of Cemernica karst ecosystem water balance is caused additionally by mountain climate, relief, the area covered by forest and unequal degree of karstification of the terrain.

WATER QUALITY AND PROTECTION. The groundwaters of the Cemernica karst massif are of an exceptional quality. Similar chemical composition characterises are found in all four springs with minor fluctuating in mineralization and pH value. The groundwaters are hydrocarbonate-calcium type (HCO_3-Ca), the mineralization of 225-290mg/l, and pH values 7.5-7.7, while temperatures fluctuate between 8 and 10^o C. The muddiness of water has the value lower than 5°Co-Pt scale during the whole hydrologic cycle on three springs but not the one where periodical muddiness occur in the period of high waters. The openness of the hydrogeological structure increases vulnerability of groundwaters and opens the way to bacterial and other pollutions. The emphasis is on the protection of the natural regime of the Cemernica environment, with established zones of sanitary protection as safety measures for insurance from undesirable consequences of pollution and disturbance of natural balance.

GROUNDWATER USE. The possibility of the utilization of the Cemernica karst system for groundwater exploiting is varied. First of all, the possibility for the water supply of surrounding towns, groundwater bottling, for the needs of sports and wellness centres,etc. can be seen.

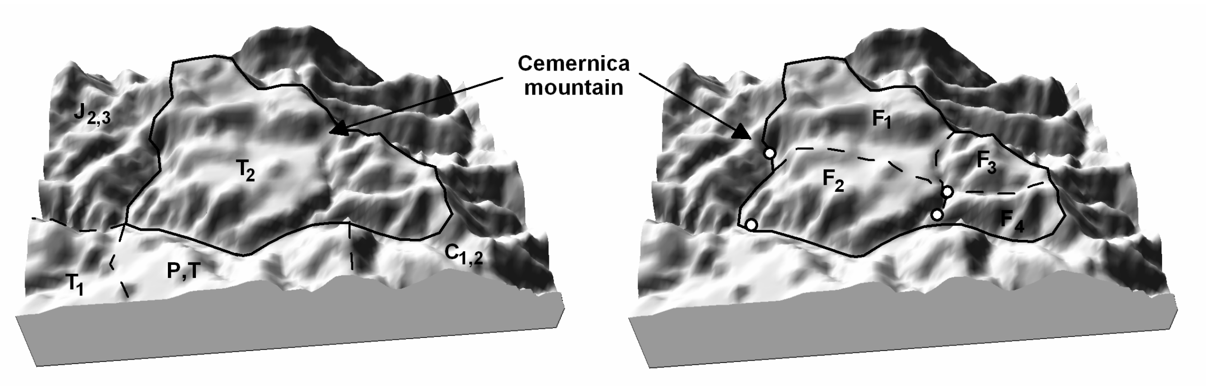


Fig.1. Investigated model of Cemernica Mountain, western Serbia
Legend to left model: geological setting – $C_{1,2}$-Carboniferous graywacke;
P,T-Perm-Triassic quartz conglomerate;T_1-Marl and shale;T_2-Massive limestone;$J_{2,3}$-Ophiolithes
Legend to right model – the surface catchment areas of the investigated springs:
F_1-Curcica spring; F_2-Stitkovo spring; F_3-Bursac spring; F_1-Kusica spring

Table 2. Calculated water balance parameters of the Cemernica Mountain karst aquifer

Area No.	Spring Name	Min/Max Yield	Average yield	Precipi-tation	Surface catchment	Evapo transpiration	Surface run-off	Effective infiltration
		$Q_{max}/Q_{min.}$	$Q_{av.}$	P	F	E	Q	$i_{ef.}$
		m^3/s	m^3/s	mm/a	km^2	mm/a	%	mm/%P
F_1	Curcica spring	0.05-0.35	0.120	1009	12.3	342	36	300/30
F_2	Stitkovo spring	0.02-0.11	0.048	1009	5.2	342	37	293/29
F_3	Bursac spring	0.004-0.02	0.008	1009	2.3	342	56	101/10
F_4	Kusica spring	0.008-0.03	0.011	1009	1.5	342	43	232/23

Keywords: hydrogeoecology, water balance, water quality, karst

Long-term recharge, groundwater extraction, and aquifer/spring interactions in a regional karst aquifer

[1]Hugo A. LOAICIGA, [1]James WOLF

[1]Department of Geography, University of California, Santa Barbara, California 93106 USA

ABSTRACT

The Edwards Balcones Fault Zone Aquifer (the Edwards Aquifer) is one of the largest and most productive karst aquifers in the United States, and in the world. It features recharge predominantly from stream seepage through its outcrop area. From there, groundwater flows mostly confined in a general south and easterly direction to discharge in a series of fault-controlled springs. Some of the groundwater discharge is captured by wells, which diminish spring flow and ecosystems. The impact of wells on spring flow is exacerbated during droughts, which recur with irregular frequency in the Edwards region. This paper presents (1) a statistical analysis and fitted probability density function to annual recharge in the Edwards Aquifer for the period 1934-2005; (2) relative impacts of groundwater extraction and changes in recharge induced by climate change on the aquifer's water resources; (3) theoretical principles for the sustainable extraction of groundwater. Recommended rates of extraction as a function of climatic conditions in the Edwards Aquifer are identified and explained.

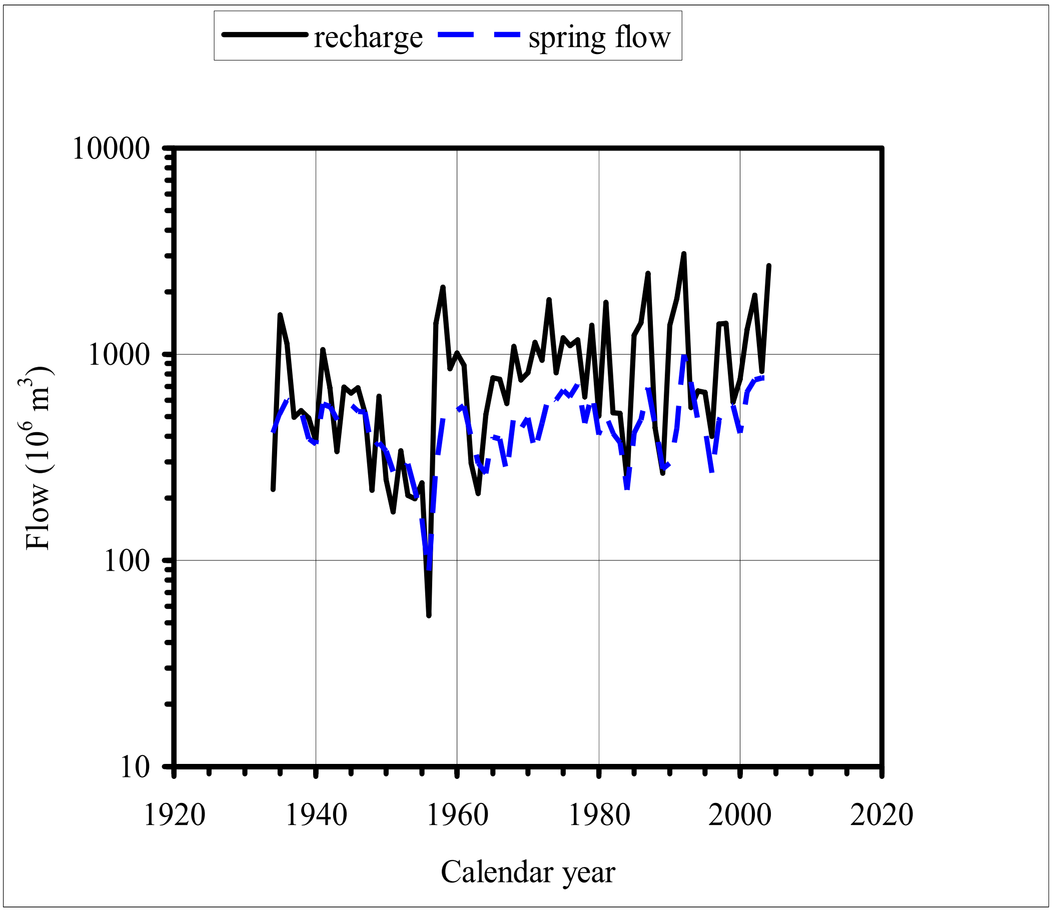


Fig. 1. Recharge and spring flow in the Edwards Aquifer, 1934-2004.

Keywords: karst aquifer, climate change, groundwater flow, spring flow, ecosystems.

Regulating variable karstic spring flow with high capacity wells.

A. SAHUQUILLO

Universidad Politécnica de Valencia. Grupo de Investigación de Hidrogeología.
Dep. Ingeniería Hidráulica y Medio Ambiente. C de Vera s/n 46071 Valencia SPAIN asahuq@hma.upv.es

ABSTRACT

Karstic aquifers in Spain are usually exploited with wells distributed all over the aquifer. In many cases it is difficult to site the wells owing to the often complicated topography of karstic terrain. In some cases the only, or most convenient, possibility available has been to locate wells near the spring, in the vicinity of existing canals or aqueducts used to transport the spring flow. In such cases, pumping has a rapid effect on aquifer flow. As pumping is carried out to augment the spring flow when natural flow is below existing water demand, the spring dries out and all the water required must be pumped once pumping starts. Operating in this way means that supply can be increased well over the natural flow of the spring during the irrigating season, or used for urban or industrial purposes. Consequently, the usually large variation of flow in many of these karstic springs has been accommodated to water demand. The use of an aquifer as a subsurface reservoir is very intuitive when the spring dries out. In many cases very high flows have been obtained in wells - up to 1200 liters per second in two wells in the Los Santos River spring in Valencia, Spain. In the Deifontes Spring near Granada in southern Spain, more than two cubic meters per second was provided for five 100-m deep wells. In other cases, the spring constitutes a component of more complex schemes. An example of this is the most interesting Marina Baja water supply scheme in Alicante Province some 100 km south of Valencia. The components involved are two dams and two aquifers, one of which feeds the El Algar Spring, with reclaimed treated waste water used for irrigation purposes that is exchanged for fresh water for urban use. Alternate use of groundwater and surface water and the regulation of the El Algar Spring by wells solved the acute supply problem suffered by a very important tourist area near Alicante on the Mediterranean coast of Spain. The two wells near the spring can pump up to 400 liters per second each and are used exclusively during dry periods. The underground storage provided by the aquifer during the extended drought of 1980-86 was estimated to be in the order of 40 million cubic meters, three times the existing surface storage. There are interesting additional possibilities in karstic areas in Spain for regulating springs that have being included in more complex conjunctive use schemes. No major environmental problems were detected except the use of the spring area for recreational use, although in a case this use was enhanced. A simulation method of the aquifer state and spring flow during and after pumping is provided for karstic aquifers.

Keywords: Karstic spring, aquifer storage, karst, modeling

Spatial and temporal assessment of groundwater quality indicators and hydrogeological characterization of a karstic aquifer in Western Turkey

[1]Alper ELCI, [1]Orhan GUNDUZ, [2]Celalettin SIMSEK

[1]Dokuz Eylul University, Dept. of Environmental Eng., Tinaztepe Campus, 35160 Buca-Izmir, TURKEY, e-mail: alper.elci@deu.edu.tr, orhan.gunduz@deu.edu.tr
[2] Dokuz Eylul University, Torbali Vocational School, Dept. of Drilling, 35860 Torbali-Izmir, TURKEY, e-mail: celalettin@deu.edu.tr

ABSTRACT

A case study is presented that characterizes the hydrogeology of a karstic aquifer system nearby the city of Izmir, Turkey. The main objective of this study is to provide an assessment of the spatial distribution of specific groundwater quality parameters, and to gain insight into their temporal evolution. The study area is the Nif Mountain karstic aquifer system located to the southeast of the city of Izmir that is an important recharge source for the densely populated surrounding area. The 1000 km2 study area is within the boundaries of the third largest city, and in the vicinity of one of the most industrialized areas of Turkey. Therefore, it is under significant environmental stresses due to residential, industrial and agricultural activities. Field work was conducted as a series of field excursions to study the hydrogeology, and to mark sampling points for consecutive groundwater sampling. A total of 59 sampling points were selected constituting of 25 wells and 34 springs. Sampling was performed in April and September 2006, during the wet and dry season of the year to assess possible temporal changes in water quality and isotopic composition. Samples were analyzed for several groundwater quality parameters including major ions, arsenic, boron, heavy metals and isotopic composition. In addition to geochemical characterization, discharge rates of some springs were measured.

It is found that the hydrogeological structure is fairly complex, with springs having a wide range of discharge rates. High-discharge springs originate from allochthonous limestone units and surface outcrops of conglomerate and sandstone units. On the other hand, low-discharge springs are formed at the contacts of claystone and limestone units, and at the contact zones of allochthonous limestone and flysch units. High-discharge springs typically have rates higher than 200 L/s in the winter months, with a maximum of about 1000 L/s. However, a 65% decrease was observed for the summer months. Based on stable isotope analysis data, an oxygen18-deuterium relationship is obtained that lies somewhere between the Mediterranean meteoric and mean global lines. Tritium analyses confirm that low-discharge springs originating from contact zones have longer circulation times compared to high-discharge karstic springs. Isotopic composition of groundwater does not change throughout the year, except for tritium. Furthermore, spatial assessment of geochemical data revealed a correlation of sampling elevation with nitrate, chloride and electrical conductivity (EC). This result implies that groundwater quality significantly deteriorates as water moves from the mountain to the plains. The same “elevation effect” was also observed for the CaCO3 concentrations, therefore indicating continuous rock dissolution as groundwater flows through the system. Heavy metal, arsenic and boron concentration are generally below drinking water quality standards, with a few exceptions occurring in residential and industrial areas located at the foothills of the mountain. Comparative evaluation of winter and summer quality data shows an overall increase in electrical conductivity values. Nitrate contamination was more sporadic and concentration changes in time were less predictable. Although lower contaminant concentrations due to dilution effects were expected for the winter months, the internal hydrodynamics and the ongoing dissolution processes in the karstic aquifer system are suspected to seclude any temporal trends.

It is concluded that the Nif Mountain overall has a significant potential to provide high quality water, although the available groundwater quantity is expected to drop significantly in the summer months due to a decrease in discharge and also because of deterioration of groundwater quality. From a water quality point of view, direct consequences of anthropogenic activities were observed, which requires close monitoring of Nif Mountain’s pristine water resources. The study revealed that less groundwater recharge in the dry period of the year does not always translate to higher concentrations of all groundwater quality parameters. It was also evident from the study results that water circulation times, lithology, quality and extent of recharge also play an important role on the alteration of groundwater quality.

Keywords: stable isotopes, groundwater quality, nitrate, boron, arsenic

Spatial and Temporal Heterogeneity in the Flux of Organic Carbon in Caves

[1]Kevin S. SIMON, [2]Tanja PIPAN, [3]David C. CULVER

[1]Department of Biological Sciences, University of Maine, Orono ME 04469-5751,U.S.A., email: ksimon@maine.edu
[2]Karst Research Institute—ZRC-SAZU, Titov trg 2, SI-6230 Postojna, Slovenia, email: pipan@zrc-sazu.si
[3]Department of Biology, American University, 4400 Massachusetts Ave. NW, Washington, D.C., U.S.A., email: dculver@american.edu

ABSTRACT

We present a conceptual model for the movement of organic carbon through a cave. There are three main inputs—(1) localized flow of particulate organic carbon (POC) and dissolved organic carbon (DOC) through sinks and shafts, (2) diffuse flow of POC and DOC from soils and epikarst, and (3) deep groundwater inputs. We estimated carbon fluxes for the first two inputs for two caves—Organ Cave in West Virginia and Postojna-Planina Cave System (PPCS) in Slovenia. Both caves have streams entering the cave from the surface as well as many active epikarst drips. The model is shown in Fig. 1.

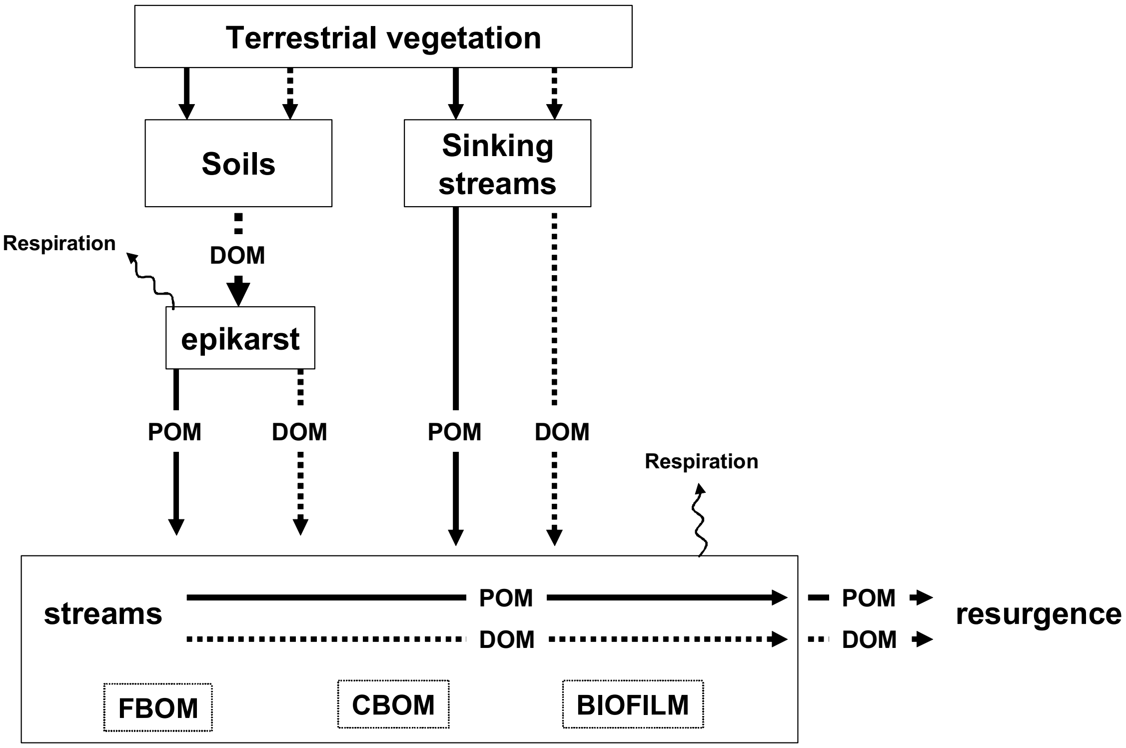


Fig. 1. A conceptual model of energy flux (as organic carbon) in a kast basin. Solid and dashed arrows represent the flux of particulate (POC) and dissolved (DOC) organic carbon. Standing stocks of organic carbon in cave streams include fine (FBOC) and coarse (CBOC) benthic organic carbon and biofilms on rocks.

We made a series of measurements of organic carbon, especially DOC in epikarst drip water, cave streams, surface streams sinking into the cave, and at resurgences. In both caves most of the organic carbon entering through the epikarst was DOC, at concentrations averaging around 1 mg C/L (Table 1). Most DOC entered both caves through sinking streams where concentrations averaged 4 to 7 times higher than epikarst concentrations, but DOC in epikarst water is more generally distributed and appears to play an important role in subterranean food webs. It is likely that considerable processing of organic carbon occurs within both caves, resulting in reduced DOC concentrations at the resurgences of the caves.

Table 1. Estimates of dissolved organic carbon from Organ Cave and PPCS.

	Organ Cave			**PPCS**		
	n	**Mean (mg C/L)**	**S.E.**	**n**	**Mean (mg C/L)**	**S.E.**
Sinking streams	3	7.67	1.03	2	4.36	0.46
Epikarst drips	20	1.10	0.15	99	0.70	0.04
Cave streams	6	1.08	0.32	3	4.75	1.57
Resurgence	3	0.90	0.17	2	2.67	0.80

Keywords: carbon flux, ecosystems, epikarst, karst, organic carbon

Spectral and wavelet analyses of hydrodynamics and mass transport in a karst aquifer

Nicolas MASSEI, Jean-Paul DUPONT, Barbara J. MAHLER, Benoît LAIGNEL, Matthieu FOURNIER, Danièle VALDÉS and Sylvie OGIER

Contact* : nicolas.massei@univ-rouen.fr
Department of Geology, UMR CNRS 6143 M2C « Morphodynamique Continentale et Côtière», IRESE A, 76821 Mont-Saint-Aignan Cedex.

ABSTRACT

In order to investigate the relation between particle and dissolved species transport and hydrodynamics in karst systems, spectral and wavelet analyses were done on rainfall water level, electrical conductivity, and turbidity time series at a karst spring system in the chalk aquifer of the lower Seine valley (France). Autocorrelation functions for water level, electrical conductivity and turbidity were compared in terms of memory effect, and these results revealed a much longer memory effect for the latter variable. The rapid reactivity of the spring to rain events, typical of karst patterns and a storage of water in the fissured chalk explaining the longer memory effect for electrical conductivity were interpreted. Energy spectra computed by fast Fourier transform of autocorrelation functions showed a strong structure in the output signals (water level, electrical conductivity, and turbidity), whereas the input signal (rainfall) was random, thus allowing assessment and comparison of the system's behavior regarding dissolved and solid transport. Cross-correlation functions displayed one main peak followed by two smaller ones suggesting the existence of additional flowpaths that might involve the contribution of other point-source recharge and/or delayed infiltration through the clayey surficial formation and solution pipes, which could act as epikarst. Continuous wavelet analysis and filtering allowed a better investigation of the rainfall signal structure and highlighted the strong relationship between turbidity and rainfall. Characteristic spectral components in the water level were isolated and time-domain reconstruction using inverse wavelet transform allowed separation of quick-flow and slow-flow components.

Keywords: karst, correlation and spectral analysis, wavelet analysis, turbidity, specific conductance.

The estimation of groundwater recharge from karst spring hydrograph (Bulaž, Croatia)

[1]Jelena PARLOV, [1]Kristijan POSAVEC & [1]Andrea BAČANI

[1] University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Pierottijeva 6, Zagreb, Croatia, e-mail: jelena.parlov@rgn.hr

ABSTRACT

This paper presents the results of the recession analysis of the karst spring hydrograph for a period of 8 years (1994 – 2001). The Bulaž spring is a typical karst well of the rising type. The water appears at the contact of the limestone and Quaternary sediments. The catchment area of the spring (105 km^2) is built up of highly fractured carbonate rocks (permeable rocks), and flysch sediments (impermeable medium). The recession analysis of karst spring hydrograph was performed manually (Maillet, 1905) and with automated technique (Posavec, 2006). The results were compared, and used to predict a minimum spring discharge, to estimate groundwater recharge with the adapted method, applied by Meyboom (1961), and to the structural adjustment of the karst aquifer system. The results of recession analysis indicate significant and rapid changes of outflow, with fast stabilization on a relatively small and steady volume of the baseflow. The calculated recession coefficient refers to a quick drainage, large drainable porosity, large transmissivity and small water storage. In the case of the Bulaž spring, the applied analysis is considered reliable and highly accurate for practical purposes in water supply.

Keywords: groundwater recharge, recession analysis, karst spring

Using Borehole Data to Assess the Dynamics of the Epikarst Zone in a Mantled Karst Area, Lagoa Santa, Brazil

[1]Paulo Fernando Pereira PESSOA, [2]Celso Oliveira LOUREIRO, [3]Augusto AULER

[1] Rua do Ouro, 1875 / 103, Belo Horizonte / MG, CEP.30-210-590, Brasil, e-mail: ppessoa@hidrovia.com.br
[2] Av. Contorno 842, 7º andar. Belo Horizonte / MG, CEP. 30.110-060, Brasil, e-mail: celso@desa.ufmg.br
[3] Rua Keppler, 385 / 04, Belo Horizonte / MG, CEP. 30.360-240, Brasil, e-mail: aauler@terra.com.br

ABSTRACT

Hydrogeological investigation using borehole data to assess the dynamics of the epikarst zone has demonstrated that the epikarst zone in the Lagoa Santa mantled karst aquifer behaves as a temporary aquifer system, controlling ground water flow in different directions. This depends on the structural bedrock agents involved and soil covering situations, and shows a compartmentalization between the carbonate-rich karst aquifer and the poor ones. Hydrogeological monitoring during an 18 month period has allowed the discrimination of three types of water level oscillations zones with marked seasonality of water levels. These separate the boundaries of convergence and divergence flows alternately, between distinct hydraulic conductivity and aquifer conditions at mantled porous media and in the epikarst zone.

Keywords: Epikarst, Hydrogeology, Water level oscillations.

Water management scenarios of a karstic system – The Cent Fonts karstic system (Hérault, South France)

N. DÖRFLIGER, B. LADOUCHE, P. LACHASSAGNE

Brgm, 1039 rue de Pinville, 34000 Montpellier, France, tél. +33 4 67 15 79 65,
n.dorfliger@brgm.fr, b.ladouche@brgm.fr, p.lachassagne@brgm.fr

ABSTRACT

Aware of the necessity of leading a sustainable policy on water resources management, the Conseil Général of Hérault in close scientific collaboration with BRGM and CNRS is running a research project on the characterisation of the structure and functioning of the Cent Fonts karst aquifer. This system, located in Hérault River basin, area being identified in deficit on drinking water resources in 2015, belongs to one of the main karst aquifers of the Rhône Méditerranée & Corse basin; it was classified by the Water Agency among the aquifers to be studied as a priority.

Studies were carried out into 4 successive phases since 1996, according to karst aquifer characterisation methodology (Bakalowicz, 1999). The first phases allowed the identification and characterization of the structure and the hydraulic behaviour of the Cent Fonts karst system. The third phase of the project included pumping tests on the major karst conduit of the karstic network, just upstream of the major outlet of the Cent Fonts karst system. The interpretation of the pumping tests was done using a specific mathematical model combining a “reservoir” model and an analytical solution for the groundwater flow from the fissured surrounding blocks (Ladouche *et al*., 2007; Maréchal *et al*., 2007).

The fourth phase concerns the assessment phase. This one is specifically dedicated to defining water management scenarios of the Cent Fonts karst system. So, the aim of this paper is to present water management scenarios of the Cent Fonts water resource karst system, considering water needs on one hand and, on the other hand, the water discharges to return to the Hérault River, as well as hydrogeological boundary conditions based on simulation models previously fitted on experimental data.

Thirty scenarios were established, on the basis of water needs and considered a graduated increase of water consumption between May and September and during the high tourist summer months (between 14th July and 15th August); four safety yields for the water supply were taken into consideration: 100l/s, 125 l/s, 150 l/s and 200 l/s.

Three hundreds and twenty simulations were carried out, considering the hydraulic behaviour of the Cent Fonts karst system under pumping, using two numeric simulation models with 30 various hydrologic cycles for 2006-2016 period. The hydrologic period of these 30 years was characterized using a stochastic process with 500 random drawing for rainfall and evapo-transpiration based on 1995-2005 time span, within a rainfall-discharge model. The discharge time series were analysed and are presented in terms of occurrence probability.

Water management forecasts for the Cent Fonts karst system are given considering results of various scenarios for different hydrological conditions. These scenarios include discharges to return to the Hérault River, between 200 and 300 l /s as well as water needs for the water supply. Different results will be presented. For example, considering an occurrence probability of more than 30 « dry » years, the system could be exploited with deeper capture work with 400 l/s as safety yield during high water demand period. Within a very water short hydrological framework, the water supply discharge could reach 200 l/s during high water demand periods in summer, and with in addition 200 l/s to return to the Hérault River. The annual pumped water volume for this type of scenario would be 5.3 MCM.

TOPIC 09

Karstic ecosystems: biological, hydrological and landscape issues

Golija biosphere reserve (Serbia) - management and natural resources protection during the investigations of karstic groundwater in the outer protection zone

[1]Vlade CANIC, [2]Sibela NUHOVIC, [1]Ivan DJOKIC, [2]Gordana LETIC, [2]Mirko CEKIC

[1]Faculty of Mining and Geology, Djusina 7, 11000 Belgrade, Serbia, e-mail: vlade.canic@eunet.yu
[2]Faculty of Mining and Geology, Djusina 7, 11000 Belgrade, Serbia, e-mail: n.sibela@gmail.com

ABSTRACT

Golija biosphere reserve is situated in south-western Serbia, 250 km away from the capital of Serbia - Belgrade. Study area covers the karstic aquifer with a surface of about 25 sq km within the Gradacka river catchment. The climate of this area is characterized by warm summers and cold winters, with distinguished difference between the seasons.

The study area belongs to the Golija Mt's region. Golija is the highest mountain in south-western Serbia (1833 masl.). It is one of the most beautiful mountains in Serbia and is characterized by an illustrious beauty and a variety of landscapes, as well as preserved nature and cultural and historical monuments. It is rich in water and a variety of life forms, where some parts of widespread forests have a character of the ancient forests. The biodiversity of Golija Mt. consists of about 900 taxons of floral species: 729 species of vascular mushrooms, 40 moss species, 117 species and varieties of algae. Of great importance are the endemic species that have become endangered (Acer heldreichi). Up until now it has been recorded 45 species of birds and 22 species of mammals belong to the group that have been declared rare.

Due to the all abovementioned Golija Mt was proclaimed as a Natural Park by the Government of the Republic of Serbia on September, 21st 2001. Within the Natural Park the biosphere reserve has been proclaimed by the MAB/UNESCO committee on October 2001. In the Natural Park there are numerous significant cultural-historical monuments related to the Serbian state in the middle ages. Near the monitored springs, there is the Monastery Gradac that was built in 1268 AD, founded by Jelena of Anjou, the wife of the Serbian king Uros.

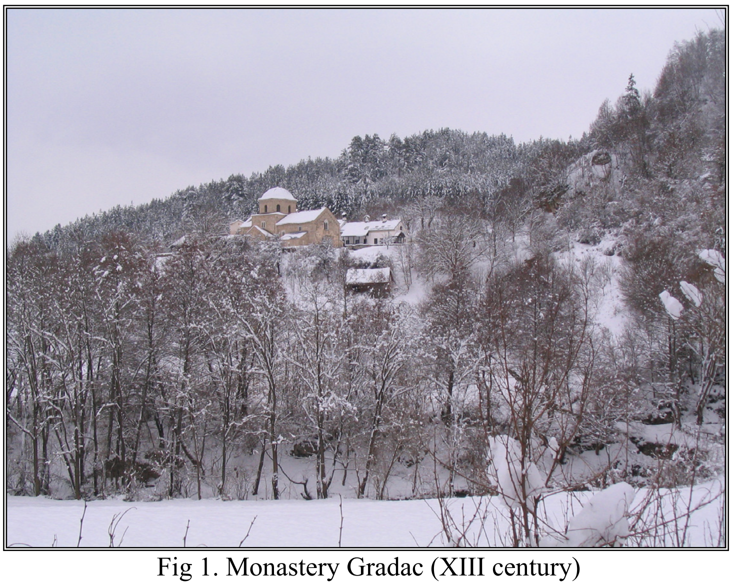


Fig 1. Monastery Gradac (XIII century)

The quality of the environment was assessed to be very high regarding of preservation of numerous environmental issues in almost original their state. Nevertheless, for a long period this area had been exposed to depopulation, which caused the diminishing of the traditional way of resources use. This led to the low standard of life of the rest of population. However, the great natural potential of the Golija Mt. should be developed and used in ways that would not endanger the existing preserved natural resources and quality of the environment. On the other hand it should provide the population with decent living conditions and economic development. As the one of the possible ways of sustainable development, the possibility of karstic groundwater natural resources use for bottling purpose has been established, since the bottling technology is environmentally friendly.

Hydrogeological investigations of karstic groundwater in this area started in the late 70's of 20th century with the observation of groundwater discharge and quality regime on two karstic springs and with a borehole drilling. These investigations were conducted within the regional hydrogeological investigations in south-western Serbia, but obtained data did not have any valorisation. New investigations started in 2001. The problem that stopped the ongoing investigations occurred due to the Natural Park proclamation. This happened later the same year. The solution to the problem of existing natural values preservation and needed development of the area was found in the sustainable development. The hydrogeological investigations were allowed to continue but under the strict and harsh demands that have been proscribed by the Department of Natural protection and the Department for historical heritage protection of the Republic of Serbia. The fact that site was in the outer protection zone made it easier. Within the zone with the 3rd degree of protection the selective use of natural resources and controlled intervention are allowed. The activities are allowed if they are in accordance with function of protecting the natural environmental well or if they are connected to the inherited traditional ways of renovation of the economics categories and living.

In order to protect the existing ecosystem, the Natural protection Department of Serbia has prescribed:

- all objects that are used in hydrogeological investigations and are not made of natural materials and in accordance to the existing surround after the end of investigations are to be removed and the area has to be put into the state that it was before the investigations took place;
- the influence of observed springs on the surface water and other springs balance is to be determined and the quantity of tapped groundwater should not be over 30% of determined yield;
- all objects on the surface are to be incorporated in to the existing surround and landscape;
- all objects for production must be placed out of the protection zones and incorporated into the existing environment;
- energy source has to be environmentally friendly;
- The waste from the investigations process and future production has to be collected and deposited at the site proscribed by the authorized service.

Hydrogeological observation has been conducted on 3 karstic springs: Ocna voda, Grabovicka banja i Ljubivoda. In order to observe discharge rate, a concrete weir was constructed on Ocna voda spring, and weirs of natural materials: wood and rock on the springs Ljubivoda and Grabovicka banja (Fig 2). The river flow on the Gradacka river is measured by a hydrometric wing.

Fig 2. Weir of natural material-spring Ljubivoda

The existing borehole which was made in 70's was closed and the terrain was left in accordance to the proscribed conditions. The new well was drilled near this site. Hydrogeological investigations are permanently controlled by the Authority and local population in order to maintain the proscribed conditions.

As the result of the conducted investigations the new well gave a free outflow of 5,5 l/s, with a water temperature of $T=18^{o}C$. Discharge rate and average temperature were determined as Q=5-8 l/s and $T=21.3\ ^{o}C$ (Ocna voda spring), Q=15-20 l/s and $T=16\ ^{o}C$ (Grabovicka banja) and Q=10-15 l/s and $T=10,8\ ^{o}C$. Referring to the chemical composition the water belongs to the hydrocarbonate-calcium-magnesium group. The environment has not been endangered in any way. These are just preliminary results, and more investigations are to be conducted in the future.

Keywords: Biosphere reserve, sustainable development, groundwater monitoring

Gravimetric and electrical-IP methods applied to water resources and risk management in karstic areas: a case study in Paraná State, Brazil

[1]Francisco José Fonseca FERREIRA, [2]Jair Silveira da SILVA JUNIOR

[1]Laboratório de Pesquisas em Geofísica Aplicada/LPGA-UFPR, Centro Poltécnico, Jardim das Américas, Caixa Postal 19045, CEP 81531-980, Curitiba-PR, Brasil, e-mail: francisco.ferreira@ufpr.br
[2]*In memoriam*

ABSTRACT

This paper presents a geophysical study of a karstic region that supplies a great part of the drinking water consumed in Curitiba, the capital city of Paraná in southern Brazil. The region studied presents, in almost 80 percent of its extension, elements of a complete karstic aquifer system, such as caves, underground water flow, dolines and sinkholes. From a geotechnical point of view, however, karstic systems correspond to unstable areas whose proper occupation and exploitation require previous geophysical and structural knowledge. In fact, many cases of subsidence and collapse have occurred in that region due to irregular occupation and inappropriate groundwater exploitation. Geophysical methods were applied around the Ambrosio Bini School. This structure collapsed, most probably because it was constructed over a risk area where there are two water exploitation wells. Microgravimetrical, resistivity, and induced polarization (IP) methods were applied to an approximately 11,200 m^2 collapsed area that surrounds Ambrosio Bini Scholl, in order to investigate qualitatively and quantitatively the hydrogeological and geotechnical conditions of geological structures revealed by geophysical maps. Collapse probably occurred because the school was built in a risk area where two groundwater wells are present. Four hundred and seventeen gravimetric stations in a square 5m x 5m spacing grid were located. Ten vertical electric soundings (VES) spaced by 5 meters were performed in a Schlumberger array. A total of 550 meters of electrical-IP profiling was performed in five lines separated from each other by 10 meters following the dipole-dipole array (AB=MN=10m). The gravity data, automatically corrected for earth tides and instrumental drift, were collected using a Scintrex CG-3 digital gravity meter, with 60-second readings at each point. The electrical-IP profiling data were collected with a high power transmitter (VIP 3000W) and a multichannel spectral receiver (ELREC 10), manufactured by Iris Instruments. As caves and voids present a high density-resistivity-chargeability contrast with their surrounding rocks, gravimetric and electrical-IP methods were then applied in order to identify and quantify near-surface occurrences of such structures, whether filled or not with sediments and/or water, which might compromise ground stability and cause future geotechnical problems. The resulting gravity and resistivity-chargeability maps clearly show areas of considerable mass deficiency and electrical-IP anomalies, respectively. Gravimetry and resistivity-chargeability inversion revealed how large and deep the features were presented in geophysical anomaly maps. Gravity inversion (Fig.1) was performed by using an open-code 3D algorithm developed by USGS (United States Geological Survey) and implemented Fortran programming language. The electrical-IP profiling inversion was developed by Zonge 2-D Inversion for Interactive^{TM} IP software (Interpex). In the VES (1D), electrical-IP profiling (2D) and gravity (3D) inversion process, the geometric forms of the bodies are modeled using the observed geophysical data and then, the effect caused by this model is calculated. The geophysical effects, the observed and the calculated, are compared and if they agree, the inversion was successfully done. The models allows the visualization of the mass and resistivity-chargeability distribution in the subsurface, characterizing underground structures that may constitute the fragility of the aquifer system and identifying areas that present some geotechnical risk. The results of studies like this can orientate appropriate future hydrogeological drilling and predict potential risk areas.

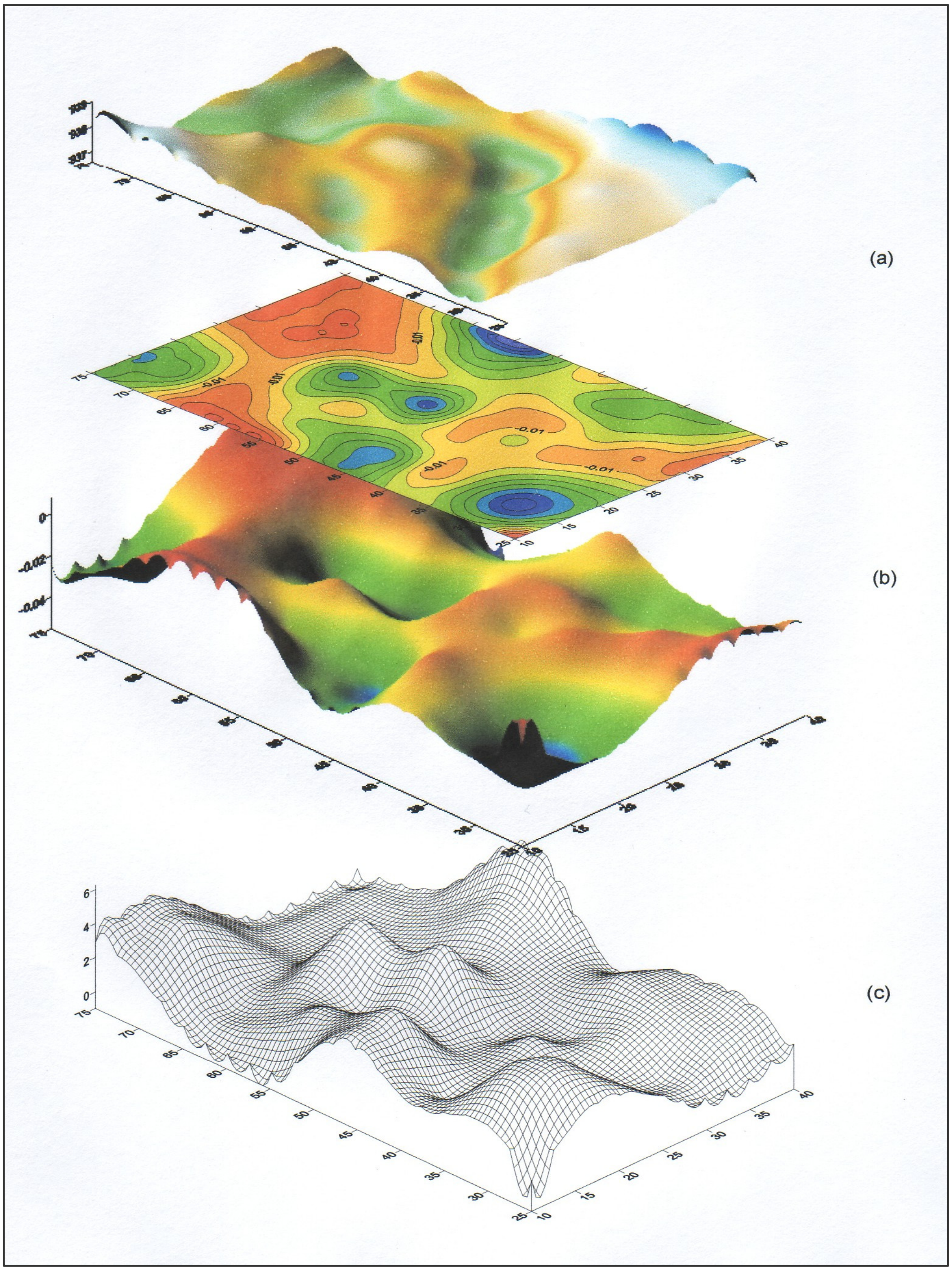


Fig. 1.Gravity inversion model: (a) relief; (b) residual anomalies in plane and 3D view; (c) model surface.

Keywords: Karstic aquifer system, cavity, risk management, gravity and resistivity-IP inversion.

Heavy metals in the Ljubljanica karst river basin (Slovenia)

[1]Branka TRCEK

[1]Geological Survey of Slovenia, Dimiceva ul. 14, SI-1000 Ljubljana, Slovenia,
e-mail: branka.trcek@geo-zs.si

ABSTRACT

In main springs and swallowholes of the Ljubljanica karst river basin the monitoring of heavy metals was established at the beginning of 2005 with the intention to study the solute transport in the water body and to analyse the risk of contamination with heavy metals.

The study region is a karstic catchment area of the Ljubljanica river, which occupies 1100-1200 km^2 (Habič, 1976). The altitude difference between the highest Mt. Snežnik (1796 m) and Ljubljanica springs near Vrhnika is 1505 m. The area is a part of Classical Dinaric Karst that is composed from Permo-carboniferous, Permian, Triassic, Jurassic, Cretaceous, and Quaternary sediments.

The altering of permeable and impermeable rocks and a tectonic structure affect the superficial and underground water flow, which is schematically illustrated in Fig. 1. Underground and superficial waters from headwater flow to karst poljes, sink there and reappear on the surface on lower karst poljes. Finally all waters, after several sinks or after underground flow, discharge in springs near Vrhnika.

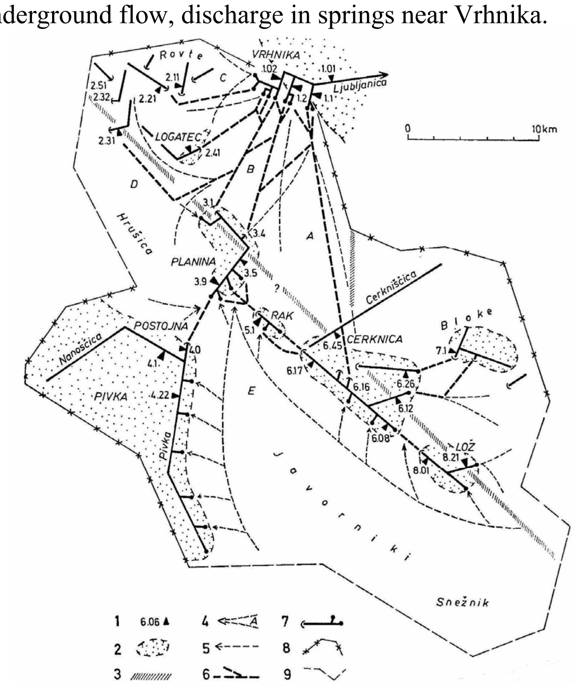


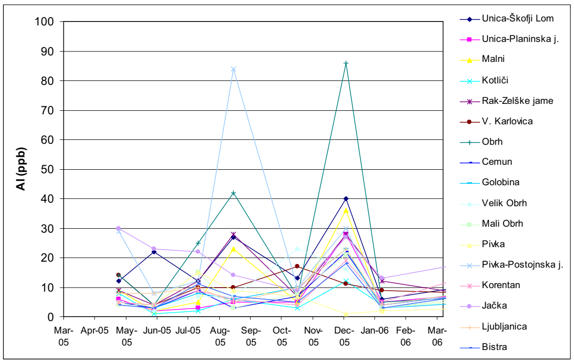
Fig. 1. Schematic review of superficial and underground waters in the Ljubljanica karst river basin (1 – important gauging stations, 2 – karst polje with sediments, 3 – central hydrogeologic relative barrier, 4 – catchment area of permanent karst springs, 5 – periodic high water discharges of karst water, 6 – underground water connections, 7 – superficial stream with springs and ponors, 8 – superficial watershed, 9 – supposed karst watershed (Habič, 1976).

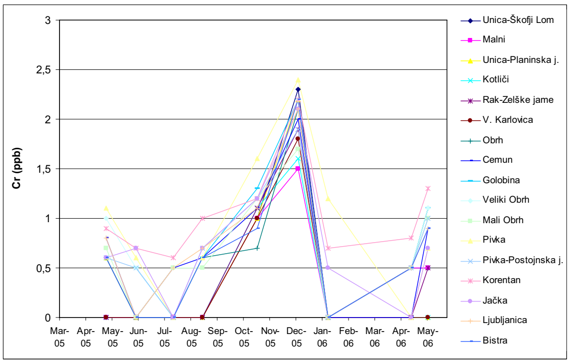
The water sampling for heavy metals was performed at 17 observation points over a period of two years. Water was sampled seasonally, under low and high water conditions. Water samples were analysed by enhanced ICP-MS for 72 elements. The results that indicate the load on the environment due to industry, traffic, agriculture and urbanization (e.g. Al, As, Cd, Cl, Cr, Cu, Mn and Pb) and solute transport processes will be presented.

Fig. 2a illustrates aluminium (Al) content in sampled waters. The critical Al value in drinking water is 200 ppb and it was not exceeded in sampled waters. However, the values indicate a general oscillation trend of this parameter. The increased values from December 2005 are indicated, during a period of very high waters after a long dry autumn season.

Fig. 2b illustrates chromium (Cr), for which the critical value in drinking water is 50 ppb. The content of this element began to increase at all observation point in autumn 2005 and reached the maximum values in December 2005, at the period of very high waters.

A lead (Pb) content in sampled waters is presented in Fig. 2c. Its critical value in drinking water is defined at 10 ppb and it was exceeded at the observation point Obrh in October 2005 that could be characterized as a wet month. In that month the highest values were recorded also at observation points of Pivka and Veliki Obrh (about 1 ppb), while at other observation points the Pb content was low (0-0.4 ppb).





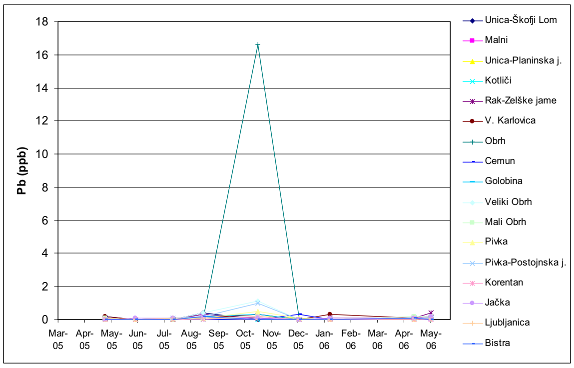


Fig. 2a-c. Aluminum, chromium and lead concentration the first monitoring phase.

It could be summarized that the results of the monitoring of heavy metals indicate that the vulnerability of karst aquifers depends on aquifer hydrodynamic conditions, infiltration conditions and development of a karst drainage system. Furthermore, they identify the local and regional geochemical and hydrogeological characteristics and distinguish the main processes and effects that impact on environmental changes.

Keywords: Ljubljanica Karst River Basin, Slovenia, springs and swallowholes, monitoring of heavy metals

Hydrogeological studies on the Buda Thermal Karst system (Budapest, Hungary)

[1]Anita Eröss, [1]Judit Mádl-Szönyi

[1]Dept. of Applied and Environmental Geology, Institute of Geography and Earth Sciences, Eötvös L. University, Pázmány P. s. 1/c, 1117 Budapest, Hungary,
e-mail: anita.eross@geology.elte.hu, szjudit@ludens.elte.hu

ABSTRACT
The capital of Hungary, Budapest, has a particular hydrogeological setting: a recently active hydrothermal system, the Buda Thermal Karst can be studied here via the lukewarm and hot karst springs and the underwater Molnár János cave. Furthermore, the evolution of the system can be traced back to Pleistocene times, by means of the already dry caves and travertines. Nevertheless our knowledge of the operation of the Buda Thermal Karst System is far from complete. The understanding of the hydraulics of the karst system is crucial here because of porosity evolution, geothermal activity, vulnerability of groundwater and protection of the caves. The knowledge of the porosity evolution acquired by hydrogeological studies may serve as an analogue for other thermal karst areas. The results may also help to set up a protection policy for caves and springs in such a densely populated urban area and to improve the use of geothermal energy.

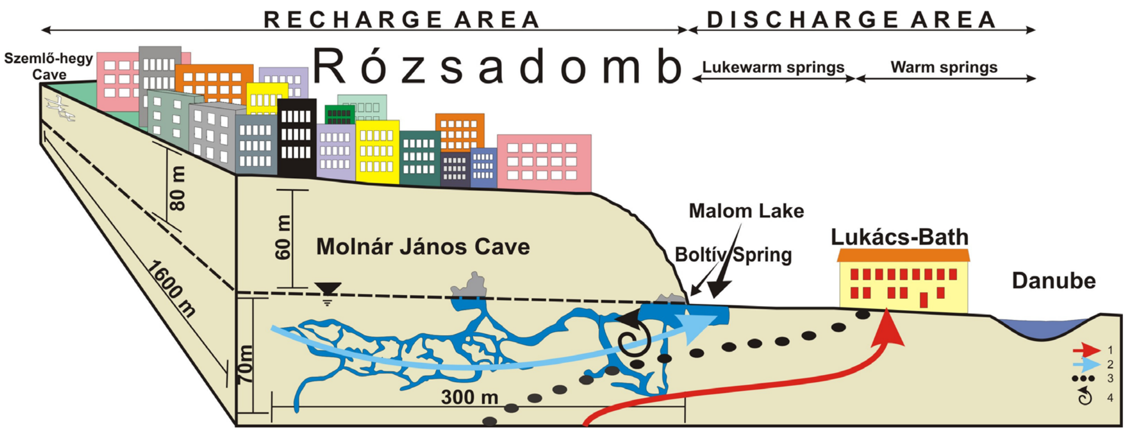


Fig. 1. Model of the discharge distribution at the Rózsadomb area (1: uprising warm water, 2: descending cold water, 3: supposed boundary of the local and regional flow path, 4: free convection)

This study focuses on the understanding of the hydraulics and the flow regime of the system. To characterize the meteoric water moving along a local flow path from the nearest recharge area to the lukewarm springs, we have studied the Rózsadomb area, one of the nearest hills to the Danube. The recharge was investigated by dripping water measurements in the already dry, Szemlö-hegy Cave. By data acquisition from the "natural research laboratory" i.e. the Molnár János underwater cave at the foothills of Rózsadomb, the mixing of meteoric and thermal water could be investigated. Because the foothills of Rózsadomb nowadays is a fully urbanized environment and the discharge artificially disturbed, the knowledge of the "original" places and features of the discharge is also crucial for understanding the system. Therefore a retrospective study was carried out, based on archive data, to localize the position and characterize the temperature and chemical properties of former lukewarm and hot springs in the area of Lukács bath.

Keywords: thermal karst, caves, dripping water, Budapest

Landfills on karst and monitoring of their impact on groundwater

[1]Metka PETRIC, [1]Janja KOGOVSEK

[1]Karst Research Institute at ZRC SAZU, Titov trg 2, SI-6230 Postojna, Slovenia, e-mail: petric@zrc-sazu.si, kogovsek@zrc-sazu.si

ABSTRACT

In the modern world, the production of waste is very intensive and the amount of waste being dumped is still increasing in many areas. This results in a serious threat to the environment, especially to groundwater due to the washing out of waste substances by precipitation and percolation of wastewater into the underground. Landfills on karst are particularly problematic due to a strong fissuration of the rock base and its very good permeability. The rainwater together with harmful substances enters quickly into the aquifer. Underground the water runs quickly through the karst channels and opened fissures. From the entrance point, the water rapidly spreads in different directions even towards the more distant karst springs. Due to the flow in the underground it is difficult to determine its directions and characteristics. The capacity of natural filtration in karst is very low, and possibility of negative influence very high. Therefore the construction of landfills on karst requires especially strict regulations and management practices to avoid pollution of karst water resources.

In the article some experiences from Slovenia are presented and discussed. Karst areas cover around 43 % of the territory and approximately one half of the population uses karst aquifers for the water supply. Therefore karst is not just a characteristics type of environment, but also a very important reservoir of drinking water and should be properly protected. According to the existing legislation of our country, it is not possible to plan new landfills on the so-called risky areas to which also the karst belongs. But in the actual transitional period in legislation in Slovenia (Fig. 1) still 9 landfills on karst are active. For all these landfills the closing as well as their further maintenance and protection are foreseen. The new regional centres for waste management placed on better locations with modern technological solutions should take over from the older landfills. In order to control the negative impacts (now and for the future) of closed landfills, operational monitoring of their impact on the environment is prescribed. One part of it is also the measurement of parameters of contamination of groundwater by hazardous substances, if they are in the area of influence of the landfill.

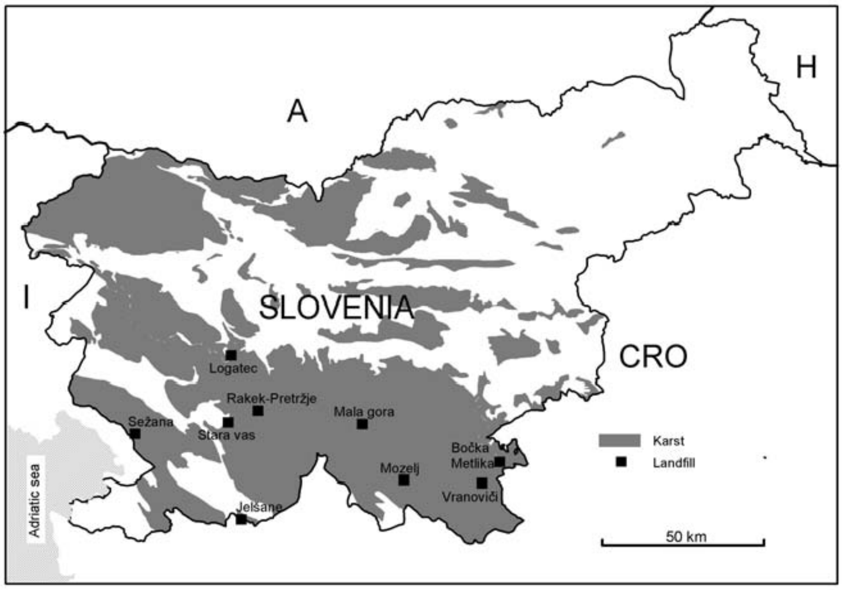


Fig. 1. Landfills on karst in Slovenia.

The plan of monitoring should be based on adequate hydrogeological research and needs to describe hydrogeological conditions and the characteristics of groundwater flow before the construction of landfill, target hydrogeological zones, characteristics of the contamination source, the description of the selection, the plan and the test of monitoring points, the definition of monitoring parameters and the frequency of their measurements. In our practice additional to the basic

hydrogeological research, the tracer tests proved an effective tool for the definition of groundwater flow directions and characteristics, on which the programme of monitoring should be based. In the article examples of the application of this method in different locations on Slovene karst are described and based on the results, some recommendations for the performance of monitoring of the impact of landfills on karst groundwater are given. In order to simulate the natural conditions the tracers were injected into well permeable fissures on the karst surface, so that the influence of the vadose zone on the transport of contaminants can be studied as well.

Obtained results indicate where and how fast the precipitation water from the landfill area runs off, how fast the transport of soluble components of the pollution is which are washed out of the waste by this water, and in which springs they will appear. All these are essential information for the preparation of the plan of monitoring the impacts of landfills on karst groundwater. Especially interesting and characteristic for karst areas are findings about the fast transport as well as longer storage within the vadose zone. One part of a soluble tracer flows rapidly through the primary drainage paths and the remainder is retained in the vadose zone and is then pushed out by newly infiltrated water in precipitation events over a long time period. In the selection of the monitoring points, the proved directions of groundwater flow should be considered, and in the definition of the period and frequency of sampling, the main emphasis should also be on findings about the characteristics of flow and storage acquired by the tracer tests.

Keywords: karst, landfills, monitoring of groundwater, Slovenia.

Methodology of hydrogeological research for the purpose of bottling of groundwater - an example of a groundwater source in karst

[1]Veselin DRAGIŠIĆ, [1]Slavko ŠPADIJER, [1]Vladimir ŽIVANOVIĆ, [1]Zoran STEVANOVIĆ

[1]Department of Hydrogeology, Faculty of Mining and Geology, Djušina 7, Belgrade, Serbia, e-mail: v.dragisic@rgf.bg.ac.yu, spaco@rgf.bg.ac.yu, v.zivanovic@rgf.bg.ac.yu, zstev@eunet.yu

ABSTRACT

The paper shows the procedure and methodology of hydrogeological researches which are necessary in order to determine the groundwater reserves, capture them and get concessions for their bottling. The amount of accomplished investigations is done according to the existing legal regulative of the Republic of Serbia which is in accordance with the standards and recommendations of the EU for groundwater bottling.

The research area consists of the catchment of the karst spring Buk, on the hillside of Rtanj Mountain in East Serbia. Ground water body as well as recharge, circulation and drainage conditions of karst aquifer are defined by detailed geological, geophysical and hydrogeological researches. The amount of regime monitoring of the groundwater quantity and quality is that which is defined by the legal regulative in Serbia.

After analyzing the possibility for groundwater capture (taking into account the quality of groundwater, their protection and economical justification for spring tapping) the idea of bottling water from natural spring Buk was abandoned. Detailed research has shown that building a well for karst ground water tapping is a much better solution, from the aspect of groundwater quality and protection. On the basis of the geophysical research done, a microlocation was chosen for two wells, which were used successful tapped the karst groundwater for the necessity of their bottling.

Keywords: karst, bottling, water quality standard

Multiparametric and tracer test study of a water resource in a contaminated karst mountain area

[1] Pauline AMEZ-DROZ, [1]Pierre-André SCHNEGG

[1] CHYN, University of Neuchatel, Switzerland,
e-mail: pauline.amez-droz@unine.ch, pierre.schnegg@unine.ch

ABSTRACT

The spring of la Puya is a karst emergence located in a highly faulted area of lower Cretaceous limestones. Part of this spring is used for the freshwater supply of the small town of Petit Bornand (France). The drinking water periodically shows bacteria of fecal origin. This study aimed at 1) locating the spots which disrupt the water quality in the catchment area, 2) evaluating local infiltration rate compared to the spring outflow and 3) proposing measures of purification.

Continuous sampling of the spring water was carried out during four months (Summer-Autumn 2006). The following parameters were recorded by a GGUN fluorometer : water temperature, electrical conductivity and turbidity, dissolved organic matter and artificial dye tracers (uranine and sulforhodamine B) during 3 tracer tests.

Tracer tests (Fig. 1) clearly showed a connection with the karst emergence. However, identified spots of obvious infiltration hardly contribute for 0.5% of the spring flowrate. Yet their influence on bacterial contamination is extremely high due to the lack of filtering soil coverage on the limestone in an area of seasonal pasture. Vulnerability assessment mapping has been proposed.

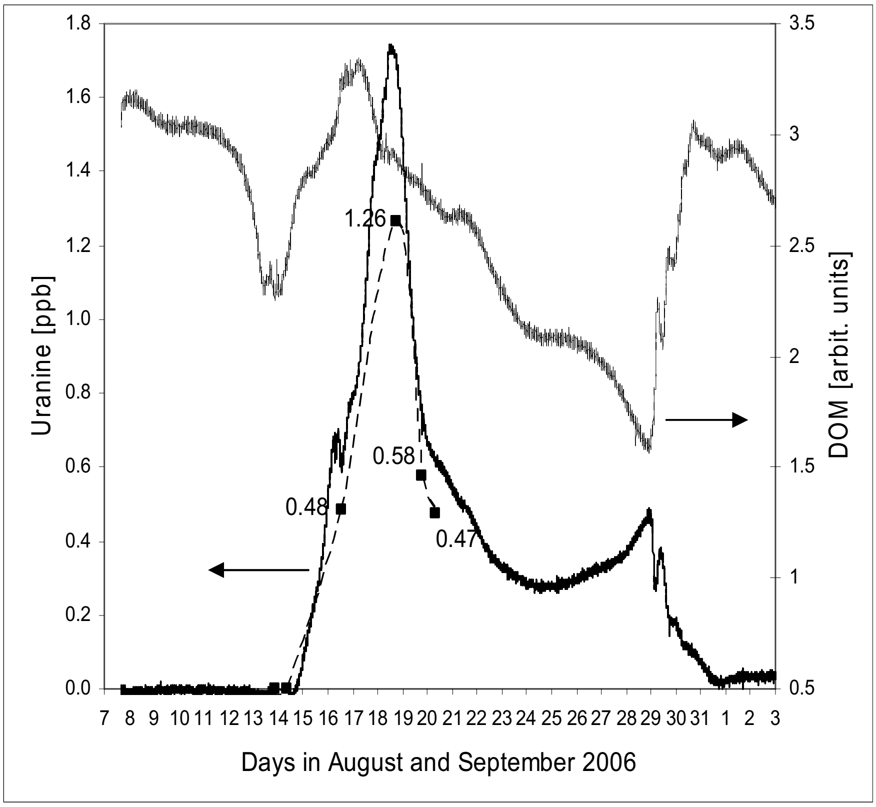


Fig. 1. Breakthrough curve of uranine measured with a flow-through field fluorometer after removal of DOM signal (upper curve). The discrete dots show comparison with samples brought to the laboratory.

Keywords: Hydrogeology, contamination, fluorometer, DOM, tracer test

Multiproxy approach to vulnerability assessment of karst ecosystems from the Ponoare test area (Mehedinti Plateau, Romania)

[1]Marius VLAICU, [1]Cristian-Mihai MUNTEANU, [1]Cristian GORAN, [1]Constantin MARIN, [1]Andrei GIURGINCA, [1]Rodica PLAIASU, [1]Raluca-Ioana BANCILA, [1]Alin TUDORACHE

[1]"Emil Racovita" Institute of Speleology, 13 Septembrie Road, No. 13, 050711, Bucharest, Romania, mariusv_iser@yahoo.com, criscarst@yahoo.com, goran_iser@yahoo.com, constmarin@gmail.com, sankao2@yahoo.com, rodica_plaiasu@yahoo.com, ioana_ralpink@yahoo.com, altudorache@yahoo.co.uk

ABSTRACT

The socio-economic pressure on karst landscapes and the remarkable dynamics of the natural processes acting within these terrains require a more general approach to a hazards inventory and vulnerability assessment. Our studies have been focused on a representative test area (Ponoare), comprising a large karst system (Zaton-Bulba), marked by many sensitive features (karren fields, sinkholes, caves, springs). The geological and geomorphological researches, guided by a working protocol similar to that of the EPIK method, highlighted the role played by the lithology, structure, tectonics, epikarst and protective cover, related to the infiltration conditions, flow parameters and impact area of a potential pollution event. The results have been improved by adding hydrogeochemical data. However, the diverse types of land use imposed the appraisal of the habitats quality. Certain taxa have been investigated in order to evaluate biotic parameters and the potential of the analyzed taxa as bioindicators, in order to obtain additional data on the area vulnerability.

Keywords: Karst ecosystems, intrinsic vulnerability, EPIK, land use, bioindicators potential

Stalactite drip rate variations of the Agua cave (Spain): an example of low discharge control inside caves?

[1]F. SÁNCHEZ- MARTOS, [2]A. FERNÁNDEZ-CORTES and [1]J.. CALAFORRA

[1]Dpto. de Hidrogeología y Química Analítica, Universidad de Almería. Campus Universitario, 04120 Almería. Spain.
[2]Dpto. Ciencias de la Tierra y del Medio Ambiente, Laboratorio de Petrología Aplicada. Universidad de Alicante. 03690 San Vicente del Raspeig – Alicante. Spain.
fmartos@ual.es, acortes@ua.es y jmcalaforra@ual.es

ABSTRACT

Introduction
Water infiltration into the Cueva del Agua (Granada, South-eastern Spain) is measured using a point monitoring system installed there. The station records electrical conductivity, water temperature and drip intensity in the Chamber of Endriagos, while a weather station outside the cave measures air temperature and precipitation. All measurements are made hourly (Fig. 1). Infiltration into the cave has been characterized based on a temporal study of these parameters over five hydrological years.

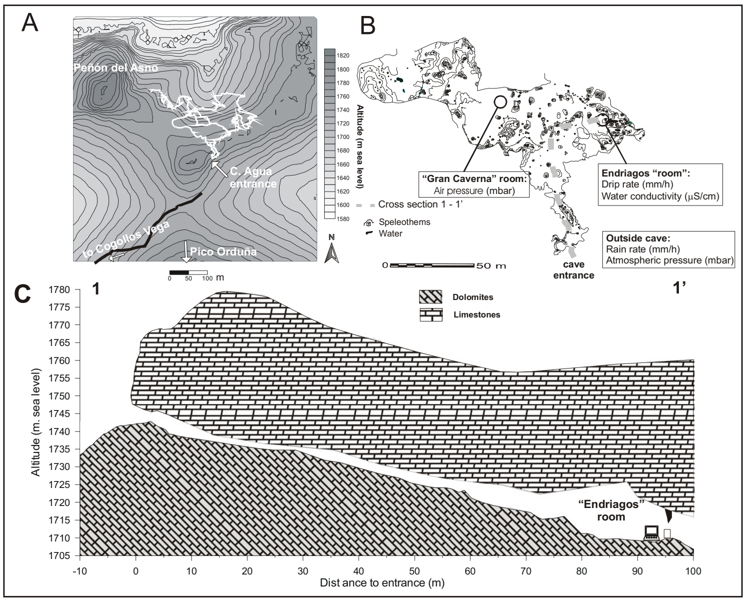


Fig. 1. A: Situation of the Cueva del Agua with respect to the surrounding topography, B: Detailed topography of the largest chambers in the cave and location of the infiltration monitoring stations, C: Cross section of the cave from the exterior to the Endriagos chamber showing the relationship to the outside surface.

Results and discussion
Mean annual precipitation over the period 1997-2002 was 952 mm and its distribution over the year shows two maxima. The absolute maximum is in autumn (177.3 mm in November) and a relative maximum occurs in the spring (104.6 mm in March). Thornthwaites method was used to calculate a daily water balance was done to calculate the periods of deficit or water surplus, shown in Fig. 2. The water deficit generally coincides with the summer months or the onset of autumn.

Mean intensity of dripping shows two relative maxima in autumn and spring, and falls to a minimum in summer, in keeping with the rainfall regime. Variations in electrical conductivity of the drip water can be related to the residence time of the infiltration water in the unsaturated zone and, therefore, with the degree of saturation of the drip water. A comparison between the sharp increases in drip intensity and the variation in electrical conductivity of the water reveals a "piston effect" that dislodges the supersaturated water. This is particularly clear for the period 2001-2002. These sudden increases in dripping into the cave usually occur during autumn (September-November) and at the beginning of spring (March-April). During this evacuation of supersaturated water driven by the "piston effect" two intervals can be distinguished (Fig. 2):

t_d: Duration of the rain water deficit outside the cave prior to the first rainfall excesses. For the period analysed (1997-2002) this lasted approximately through the summer months.

t_1: filling time of the water in the microfissures and pores within the vadose zones, necessary for the onset of the piston effect. This equates to the time lag between the start of the period of excess rainfall and the onset of the sudden increases in drip intensity and electrical conductivity of the drip water. Its duration shows a random element, which mainly depends on the character of the precipitation and the mode of the infiltration of surpluses into the ground.

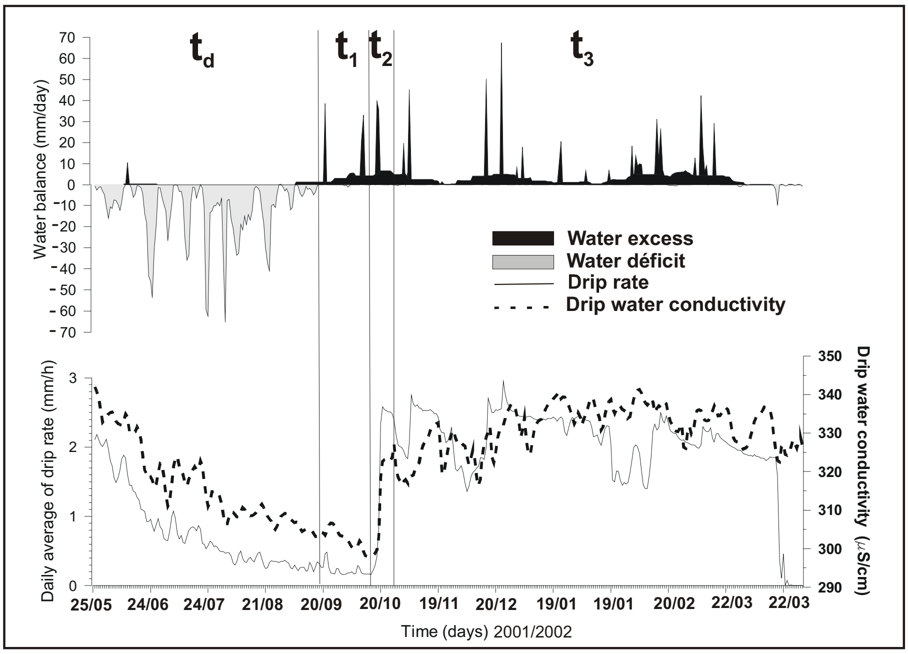


Fig. 2. Example of the increase in dripping intensity due to the "piston effect" inside the Endriagos chamber for the hydrological year 2001/2002. (t_d: duration of the water deficit on the ground surface; t_1; filling time of water in the system of microfissures and pores; t_2: duration of the "piston effect " and t_3: "emptying" of the vadose zone).

t_2: **evacuation** time of the supersaturated water by dripping. This is the period running from the end of the filling of the vadose zone (t_1) to the onset of a fall in the conductivity of the drip water. This is the time required to dislodge the mass of supersaturated water from the vadose zone and is indicative of the length of the "piston effect". For the series under study, (1997-2002) this varied from 5 to 10 days.

t_3: **emptying** time of the infiltration water derived from the last rainfall surplus since the previous deficit period. Graphically, t_3 would be the period between the onset of the drop in conductivity of the drip water and the onset of the base level of minimum drip intensity, characteristic of a state of minimum recharge and marking the beginning of a period of water deficit. The value of t_3 is approximately the same as the succession of numerous peaks in the rainfall surpluses following the end of the first "piston effect".

Water infiltration into the cave via the piston effect must be preceded by the filling of the system of pores and fissures. In addition, excess rainwater infiltrates the epikarst, filling the conduits and increasing the hydraulic pressure of the vadose zone on the supersaturated water. Lastly, this water reserve will leave the microfissures and pores by flowing along the preferential flow paths and entering the cavity through drips, fractures and curtains, etc. From a hydrogeochemical point of view, there is a sudden increase during the recharge via the piston effect, followed by a gradual decline of the electrical conductivity of the infiltration water.

Year to year, dripping intensity depends on seasonal rainfall. Within this pattern, the piston mechanism causes sudden changes in the drip regime of the infiltration water flowing along the preferential conduits and due to the evacuation of the stored, supersaturated water. Gradual and seasonal changes in the drip intensity are further extended through time, as is clear from the recession periods, which lasted for an average of 172 days for the period under study (1977-2002). In contrast, the sudden changes in the infiltration regime due to mobilisation of the water stored in the system of microfissures and pores can last for 5 to 10 days (the time taken to evacuate the supersaturated water in the Endriagos chamber by dripping). Both types of oscillation in drip intensity in the Endriagos chamber are linked to rainfall excesses or with the type of infiltration in the unsaturated zone.

This study reveals new conclusions about the process of water infiltration in cavities due to drip flow. Comparison of the results with those from studies in other cavities at different depths, in different geology, structure or other climatic regions would be of great interest in the characterization of the lack of linearity over time of the infiltration process in karstic terrain, and particularly those associated with caves.

Acknowledgements
We are sincerely grateful for all the help given by the Diputación Provincial de Granada and especially to Manuel González Ríos, who is responsible for the management of the Cueva del Agua. A. Fernandez-Cortes benefits from a postdoctoral grant supported by the Spanish Ministry of Education and Science through the Research Programme "Juan de la Cierva" .This study has been undertaken within the framework of Project "Gypsum Speleothems and Paleoclimatic Records" CGL2006-01707/BTE supported by the Spanish Ministry of Education and Science.

Keywords: Drip discharge, speleothems, karst, cave, non-linearities

Surveying and flow velocity measurements in a karstic and coastal aquifer (Bari, southern Italy)

M. POLEMIO [1], P.P. LIMONI [1]

[1] CNR-IRPI, via Amendola, 122/I, Bari, Italy

ABSTRACT

The study area is located in the Murgia plateau which constitutes a large and deep coastal karstic aquifer (of Mesozoic age); the predominant rock material of which is either limestone or limestone-dolomite. The aquifer is affected by karst and fracturing phenomena, also well below the sea level, whereas intruded seawater underlies fresh groundwater owing to a difference in density.

The groundwater flow is confined except on a restricted coastline strip. A strong connection between the increase in salt contamination and the lowering of piezometric levels, which can be ascribed to groundwater overdraft and/or a natural decrease in groundwater recharge, has been recognised in the coastal area.

The fluctuations of the transition zone, in the absence of human influences, are closely related to alternating periods of recharge and depletion of the aquifer, though a certain unbalance is likely to occur between recharge due to rainfall infiltration and the discharge due tapping by wells.

To contribute to the study of these phenomena on the basis of affordable and long-lasting data, a surveying station was realised in a well bored for this purpose in the urban area of Bari.

The monitoring started in 2004; collecting data on piezometric level, water temperature and rainfall. The groundwater data are stored every two hours. Multi-parameter logs are executed every six month along the well, using probes equipped with sensors of temperature, specific electrical conductivity, pH, dissolved oxygen and Eh.

The detailed characterisation of vertical flow variability has been realised with tracer tests realised in the well.

The time series and whole data are anyalised highlighting the peculiarities of the selected karstic aquifer.

Keywords: karst aquifer, surveying, flow velocity

The Problems of Water Supply in Holokarst terrains - The Example of Karst Area of the Town of Bileca, the Republic of Srpska

[1]Veselin DRAGIŠIĆ, [1]Slavko ŠPADIJER, [1]Vladimir ŽIVANOVIĆ, [1]Miroslav KRMPOTIĆ,

[1]Department of Hydrogeology, Faculty of Mining and Geology, Djušina 7, Belgrade, Serbia, e-mail: v.dragisic@rgf.bg.ac.yu, spaco@rgf.bg.ac.yu, v.zivanovic@rgf.bg.ac.yu, kornat@eunet.yu

ABSTRACT

The most important results of hydrogeological researches of karstic massif of Bileca in eastern Herzegovina- the Republic of Srpska performed during 2006 are presented in this work. The research was done for the purpose of water supply of town of Bileca and surrounding villages. The lack of drinking water was the reason for a comprehensive analysis of potential sources of ground water situated near the town of Bileca, as well as surrounding villages, determining groundwater quality and possibilities of groundwater capturing.

Given the extremely complex problems to be solved, this research could not be approached in a stereotypical way, so multidisciplinary approach was applied and all modern analytical means of karst researches were used.

In that sense, apart from analysis and reinterpretation of the results of earlier researches, detailed morphological analysis of broader investigation area was done, together with appropriate digital elevation models of ground. Production of these digital maps and their correlation with analysis of satellite imagery, structural relationships, geological structure (building) and hydrogeological characteristics, gave new picture, regarding the quantity and quality of karstification development in the plan and profile. This was of great importance for the design of future researches that is intended in an attempt to resolve the problem of water supply.

As regards the ground research, detailed hydrogeological ground investigations (mapping) of potentially perspective grounds were done. Based on the mapping, locations were defined on which geoelectrical researches should be done.

The analysis of all research undoubtedly showed that ground water circulation is very deep in relation to ground surface. However, karstification process and noticeable heterogeneity in lithological structure in carbonate formations suggested the possibility of formation of so-called “perched” aquifers. The existence of these aquifers was also discovered by means of geoelectrical research. On the basis of this research, a certain number of exploratory boreholes of 80 to 120 meters were designed with the aim of establishing the existence of ground waters formed in the frame of “perched” aquifers. However, the existence of “perched” aquifers was not proved due to the insufficient amount of research. Therefore, further research on these locations should be approached extremely carefully; the principle of phasing in research should be strictly respected as well as the concept defined by researches. Three exploratory boreholes of 200 to 250 meters are foreseen, by means of which regulation of karst aquifer from so-called “base run-off” will be done. Exploratory boreholes are just one phase in resolving the problem of water supply of this region. Regime observations during rainless period will give the genuine information on the quantity of ground waters and economical justification of the construction of deep wells.

Keywords: holokarst, water supply, multidisciplinary approach

Use of integrated methods to investigate interaction of tributary conduits and karstic springs that discharge in Lake Shkodra, Albania

Nexhip MASKA

Water Supply Department, SFWMD, West Palm Beach, FL 33406. E-mail: nmaska@sfwmd.gov

ABSTRACT

Geophysical, hydrogeochemical and tracer methods were carried out in a karstic sedimentary rock aquifer system, partially covered by a thin layer of argillaceous terra rossa for the investigation of interconnection of the aquifer's tributary conduits and the interrelations between rainfall infiltrations and karstic waters that discharge in Lake Shkodra (Albania) through a group of karstic springs. The spontaneous polarization method was utilized to delineate the underground pathway of the main conduit, its depth and flow direction while geochemistry and tritium content of spring waters during both low and high flow conditions were used to select the less polluted spring from argillaceous terra rossa load, a contamination that was more evident after heavy rainfalls. The study demonstrates that the spring and its underground tributary selected for agricultural and husbandry application, had little to no change in flow yield, geochemical and tritium content in both low and high seasonal flow conditions compared to the neighboring springs. A dye tracer (Rhodamine B) was used to visually verify the results of the above methods findings.

TOPIC 10

Groundwater impact on coastal, estuarine and near shore marine ecosystems

Development of geochemical sensors for real-time management of groundwater resources in coastal regions

[1]Paul THORN, [1]John MORTENSEN, [1]Niels SCHRØDER

[1]Roskilde University, Universitetsvej 1, 4000 Roskilde, Denmark,
e-mail: pthorn@ruc.dk, john@ruc.dk, schroder@ruc.dk

ABSTRACT

The steadily increasing pressure on the freshwater resources and potential future climate change has put focus on water resource management. Over-exploitation and inefficient management of groundwater resources has led to a number of water quality and related health problems worldwide. With a limited and shrinking supply of unpolluted groundwater resources, there is a growing need to develop techniques to maximize the available groundwater, while protecting it from contamination and preventing over-exploitation. Optimization in groundwater management has focused mainly on remediation design problems. However, real-time, adaptive control can allow for interactive management of the water resources, providing the ability to respond before groundwater becomes contaminated.

Saltwater intrusion is a pressing threat to groundwater supplies in coastal regions. In areas where saltwater intrusion has occurred, technical solutions, such as freshwater injection on the coastal side of the aquifer, have been employed to prevent the intrusion. Alternatively, the wells have been abandoned, forcing an alternative source of water such as surface water or even desalinisation plants. However these solutions are often expensive and cannot be employed in every situation. In other cases, the fear of saltwater intrusion has led to groundwater abstraction being moved away from the coastal areas further inland. The movement of abstraction sites further inland has its problems, as it can result in a reduction of baseflow to streams and wetlands, significantly affecting the fresh-water ecosystems. This has been observed on the island of Zealand in Denmark.

Improvements in groundwater modelling technologies have allowed us to begin to tackle the problem of sea-water intrusion at least in part. However, many parameters in these models, such as recharge, are not constant and can vary both seasonally and annually. Therefore, when determining the amount of groundwater that can be utilized while maintaining its quality, a wide margin of safety must be used. The result of this is that a significant amount of water is lost to the sea, particularly during periods of high recharge. The development of groundwater monitoring technologies that can monitor for seawater intrusion in coastal regions could provide for a more efficient utilization of the groundwater resource.

At Roskilde University, Denmark, geochemical sensors for use in groundwater abstraction wells are currently being developed. These sensors will provide constant, "real-time" data on the concentration of Cl-, Ca++, K+ and Na+ ions within the groundwater. Changes in the concentrations of these ions will provide an early warning on impending seawater encroachment into the well-field. This information will be integrated into an adaptive well-field management model, allowing the resource managers to assess the information and immediately react to observed water quality changes (Fig. 1). With the ability to proactively react to changes in the system, one can maximize the amount of groundwater one can sustainably utilize, while safely maintaining groundwater quality.

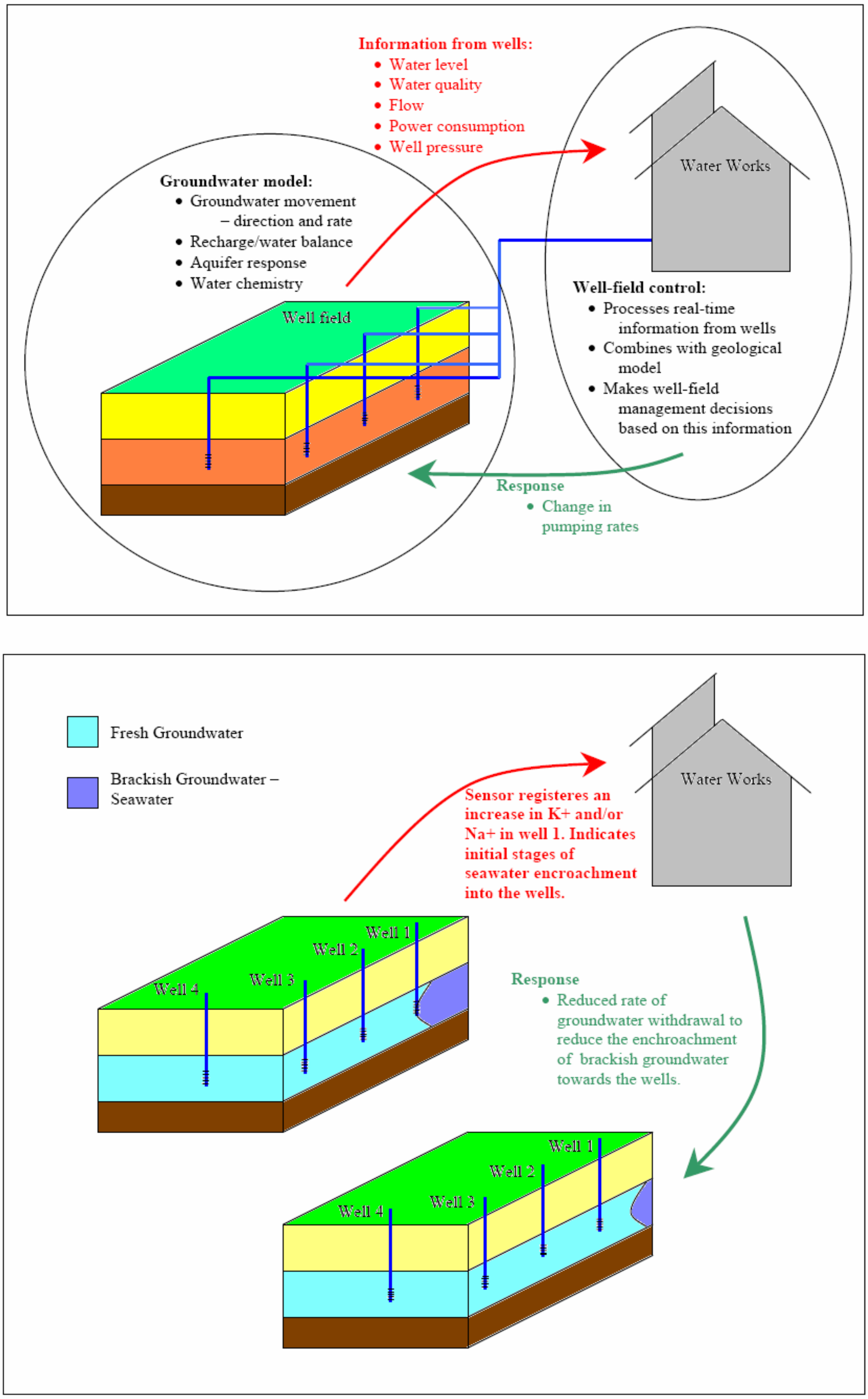


Fig. 1. Illustration of the well-field management process (top) and the sensor recognition/response (bottom). The geochemical sensor in well one registers the initial encroachment of seawater into the well field. Using a response model developed for the well-field, a proper response is determined, and pumping rates are adjusted. The salt water/fresh water interface subsequently moves away from the water wells.

Keywords: Groundwater, saltwater intrusion, sensors, monitoring

Evaluation, management and protection of groundwater resources in semi-arid zones: Application of hydrochemical methodologies to Essaouira synclinal basin (Morocco)

[1] Paula GALEGO FERNANDES, [1] Paula CARREIRA, [2] Mohammed BAHIR,

[1]Instituto Tecnologico e Nuclear, Estrada Nacional nº102686-953 Sacavém, Portugal, e-mail: paulagf@itn.pt
[2] Laboratoire d'Hydrogeologie, Faculté des Sciences Semlalia, Marrakech, e-mail: bahir@ucam.ac.ma

ABSTRACT

The water resources of the Essaouira basin are characteristic of a semi-arid climate, and are severely impacted by the climate (quantity and quality). Considering the importance of the Essaouira aquifer in the groundwater supply of the region, a study was conducted in order to comprehend the groundwater evolution of this aquifer. It is a coastal aquifer located on the Atlantic coastline, southern Morocco, corresponding to a sedimentary basin with an area of near 200 km^2.Covering the Palaeozoic bedrock, the sedimentary series range from the Triassic to the Quaternary. The sedimentary sequence begins with Triassic deposits having the same lithology as in Sines basin, outcropping in the E and S of the region. The Carbonate rocks compose the Jurassic and marly sediments of lower Cretaceous to Cenomanian dominate the Cretaceous. The dolomitic limestones of the Turonian are covered by Senonian gypsy marls (Duffaud et al. 1966), which appear below the Plioquaternary detrital deposits of sands, sandstone and conglomerates. The geological structures delineate a syncline bordered by the Tidzi diapir of Triassic age which outcrops to the E and S (Fig.1).

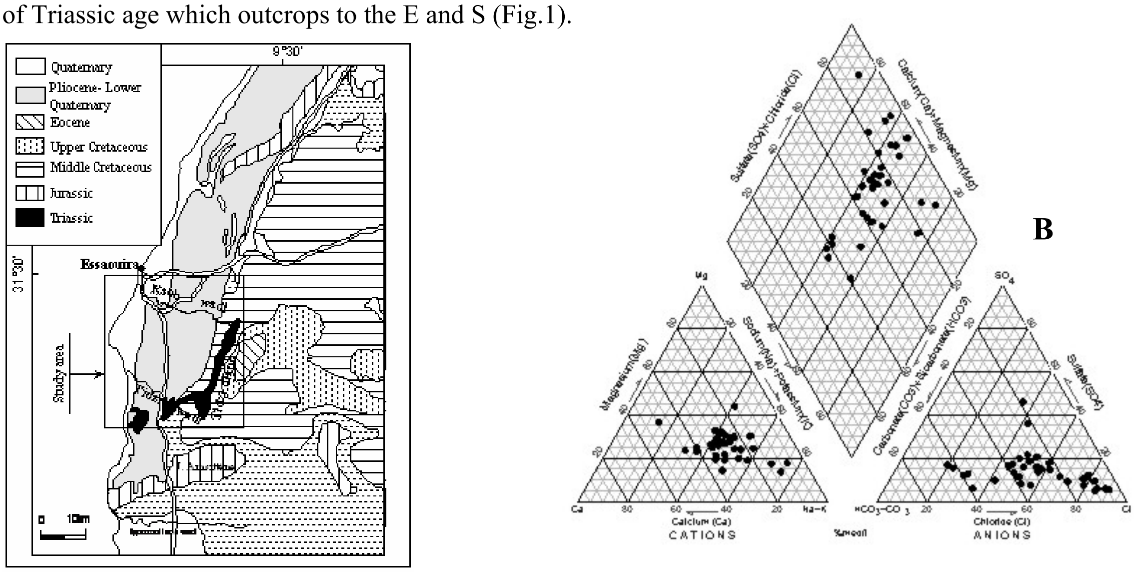


Fig.1 – A- Geological map; B- Piper Diagram

In the Essaouira basin a multi-aquifer was identified constituted by detrital deposits of the Plioquaternary and dolomitic limestones of the Turonian. The Plioquaternary is unconfined below the Senonian marls. However, in some places it can be in direct contact with the other Cretaceous and Triassic units. The Plioquaternary is generally up to 60 m thick. The Turonian is confined by the Senonian marls and in direct contact with the Plioquaternary on the edges of the syncline structure.

For a few years, water has been withdrawn through drilling wells to supply the Essaouira tcity. At present, the Plioquaternary provides 47% of drinking water for Essaouira with about 64000 inhabitants and a rural population. The total rate of extraction in this system is around 97 L/s (Agoumi 1999).

The piezometric levels in the Essaouira multi-aquifer present a general standardization through time (1990/2000). However, locally some piezometric variations can be identified. As a consequence of the weak thickness the sensitivity to drought has an important impact on the water reservoir, as widespread drought periods, have affected Morocco since 1978 (Agoumi 1999).

Morocco has a wide range of climate conditions: the coastal regions generally have a mild climate; the Atlas Mountains can be cold and wet during spring or even in summer, while the desert is hot and dry nearly all year. The Essaouira basin can be considered a semi-arid area with annual rainfall up to 300 mm/year and a very high potential evapotranspiration of about 920 mm/year (Agoumi 1999).

The main flow direction is from SE to NW towards the Atlantic Ocean, being the recharge area located near the Tidzi diapir. The piezometric maps, since 1990 to 2000, show, in the N, a line deviation to the NE, indicating a possible contribution of the Oued to the aquifer recharge.

In the Essouaira basin, in spite of the occurrence of calcareous and dolomitic levels, all waters are of Na-Cl-type. The chemical signature of these waters could be the result of the preferential recharge area that is located in the Tidzi diapir. A high correlation coefficient was found between electrical conductivity, chlorides and sodium contents, suggesting the large contribution of these elements to the groundwater chemical load. Nevertheless, occulted by chloride the groundwater is highly bicarbonate as a result of the presence of carbonate compounds in the reservoirs matrix.

Analysing the dispersion of the values of the parameters it is probable that the difference between the maximum values and the average is a result of a timely increase. However, the present range is mostly a result of the Oued contribution into groundwater recharge, leading to a dilution of the water mineralization. Another hypothesis to explain the range in mineralization could be the available time in the water rock interaction with the diapir that constitutes the basin.

If we assume that sample 27 is representative of the water, it is expected that waters progressively increase the concentrations of chemical constituents. The higher Na and Cl concentration could be explained by the calcite and halite dissolution. Calculated saturation index (S.I.) indicates that the majority of groundwaters are near equilibrium with respect to calcite and strongly undersaturated relatively with halite. The progressively increasing EC values, Cl and Na concentrations due to increased water rock interaction would ultimately result in higher saturation index values with respect to the referred minerals.

Using a simple mass balance model through the PHREEQC program this scenario was tested. The reaction path was assumed to be such that waters observed at shallow depths evolved to more mineralised waters. We considered a path that initiated in sample 27 (Table 1) and that was calculated the behaviour of groundwater mineralisation with different percentages of halite dissolution.

Figure 1 shows the results of modelling, with halite dissolution at open system. Were also projected all the samples analysed to evaluate the behaviour of groundwater from the aquifer. It is possible to notice that the waters are projected along the line that represents the waters evolution in open system, indicating that these waters have an important contribution of water-rock interaction in groundwater mineralisation. This corroborates the fact that chemical signature of these waters could be the result of the preferential recharge area that is located in the Tidzi diapir.

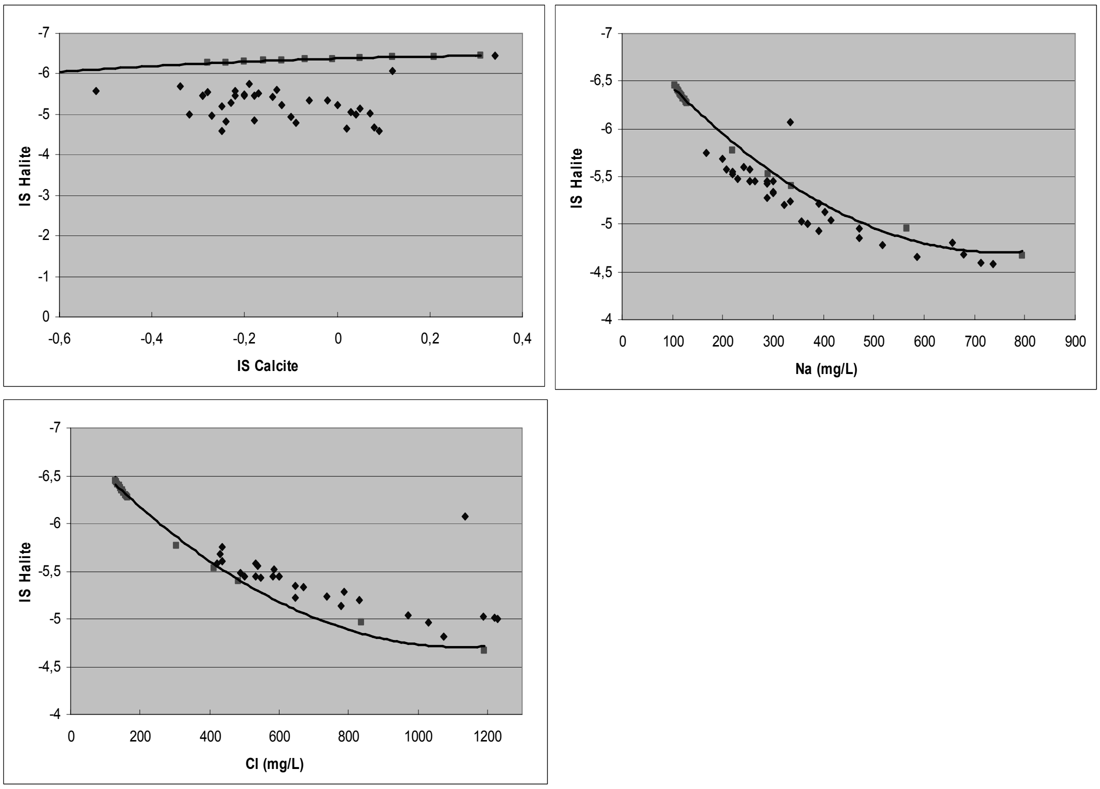


Fig.1 – Halite Saturation Index *versus* Calcite Saturation Index; Sodium and Chloride contents.

Keywords: Essaouira Basin Aquifer, hydrogeochemistry, mass balance model

Geo-environmental approach of Tinos's wetlands (Aegean Sea, Hellas)

[1] George STOURNARAS, [1]Dimitra LEONIDOPOULOU, [1]Gerasimos YOXAS

[1]University of Athens, Faculty of Geology and Geo-environment, Panepistimioupolis, Zografou, 15784, Greece, e-mail: stournaras@geol.uoa.gr

ABSTRACT

The paper is an overview of the three main wetlands (Panormos, Kolympithra and Livada) of Tinos Island from its geological, hydrogeological and environmental point of view. Tinos Island presents a surface of 197 km^2. Its geologic formations belong to a certain geotectonic unit, known as Atticocycladic complex. According to Melidonis (1980), three groups or sequences of rocks participate in the geological structure of Tinos, the sequence of metamorphic rocks, the sequence of igneous rocks and the quaternary sediments. The existence of three main categories of folds, with axes of NW-SE, NE-SW and N-S directions respectively and two groups of faults with SE-NW and NNE-SSW directions respectively, complete the geotectonic structure of the island. The basic factors which affect and form the hydrological and hydrogeological character of the island are the discontinuous media character (secondary porosity), due to the tectonic and microtectonic activity on the geologic formations and the degree of weathering of the given formations.

The morphology is mainly controlled by the extent of lithologic formations and the tectonics, together with the climatic characteristics. The high humidity and the strong NNE winds cause intense chemical and aeolian alteration and weathering on schist and granite. Human activity is another important factor that affects the morphology of the island. This activity consists of the construction of artificial support dry stone walls, which cover a large part of the island's surface, keeping the soil in place, and thus protecting it from erosion phenomena. The island has been characterized as semi-mountainous, because of the area between the contour line of 100 and 400 m which takes up 61% of the island while the rest (29%) represents the flat area.

According to the map (Fig. 1) the Livada wetland belongs to medium to high erosivity, but the catchment and Kolympithra wetland belong to the low to medium degree of erosion. Finally in Panormos wetland which consists of marbles, no remarkable erosion phenomena are manifested (Alexouli-Livaditi and Livaditi, 1997). The catchments basins of Livada and Kolympithra belong to the same areas of erosion, as their corresponding wetlands. On the other hand, Panormos catchment basin belongs to the low to high degree of erosion contrary to Panormos wetland.

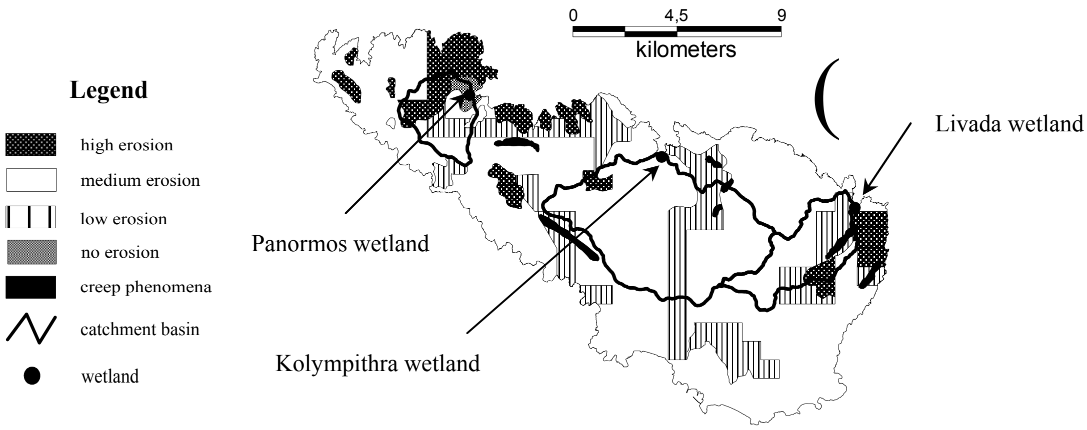


Fig. 1. Map of erosivity (Alexouli-Livaditi and Livaditi, 1997; with modifications)

In order to determine the characteristics of the three main catchments areas of Tinos Island in correlation with the wetlands drainage, network analysis was applied (Table 1). The three wetlands under consideration are formed at the lower part of a torrent, where the drainage slopes are very gentle, with values less than 10^o. The catchments basins of the three torrents are developed mainly on schists, lithologic formations that are considered to be impermeable and help the surface flow, explaining the thin drainage texture in all three torrents. Livada's catchment area is developed on two different lithologies, which are responsible for the different drainage texture between the eastern and the western part/side. All three torrents are dentritic type with channels oriented in a wide variety of directions, with little structural influence, expect for the Livada torrent which is developed along the lithologic contact of granite and schist, leading to an elongated denritic type. Surface flow, on the other hand, produces through weathering and erosion processes sediments, which are transported at the lower part of each torrent. This transported material, which is finer at the lower parts, makes the drain of the weak groundwater aquifers difficult, due to the above wetlands formation.

Table 1: Wetland characteristics

		PANORMOS	**KOLYMPITHRA**	**LIVADA**
WETLAND CHARACT ERISTICS	NATURALNESS DEGREE OF WETLAND*	2	7	9
	AREA WETLAND	7 Km^2	100 Km^2	no data
	TYPE OF WETLAND	Coastal	Coastal	Coastal
BEACH CHARACTERISTICS	DIRECTION	N-S	E-W	E-W
	MORPHOLOGICAL SLOPE	low to middle	low to medium	gentle
	SHORELINE MATERIAL	Mixed	Sandy	Coarse sands and pebbles
	WAVE ENERGY	Low energy waves	Affected by intense wave energy and strong winds	Affected by intense wave energy
	LITHOLOGIC TEXTURE	Schistolithic fragments and mainly (80%) carbonate rocks	Schistolithic, quartzite, quartz and a lot of mica fragments	Coarse sediments: mainly schist (90%) but also quartzite and granite. Fine sediments: more granitic than schist components

*According to Katsadorakis *et al* (2007) the naturalness grade for these wetlands is in a scale of 1-10 (1 = artificial wetland or very degraded)

In order to determine the size and shape of the coastal and fluvial sediments, morphometric analysis of coarse sediment and grain size distribution of the fine sediments was evaluated. According to grain size analysis on Livada beach, the coastal deposits are transported and deposited by the waves and the wind are of a certain grain sizes. The fluvial sediments, on the other hand, which correspond with the size of coarse sand, are not selected according to size like the coastal ones. In the fine sediment more granitic than schist components were found in the coastal material, and roughly the same percentage of granitic and schist components, in the fluvial material. This means that schists and granite follow a different weathering and erosional procedure through coastal and fluvial processes.

In order to determine the size and shape of the coastal and fluvial sediments, morphometric analysis of coarse sediment, and grain size distribution of the fine sediments was evaluated. According to grain analysis of coastal and aeolian deposits of Kolympithra, wave energy is bigger in the centre of the beach, while in west becomes less intense. The waves approach the coast vertically, resulting in bigger wave energy in the central part. Therefore, in the central part of the beach coarser sediments are deposited, having poorly graded distribution, while in the external part fine sediments, have well graded distribution. The study of aeolian deposits showed that the dune material is fine sand. The cumulative curve has negative asymmetry, which means that the aeolian deposits have bigger percentage of coarse sediments, hence very probably is deposited by strong winds. The aeolian lithologic texture was the same as the coastal one, but with different contribution of each mineral.

The wetlands (or water biotopes) play the most important role, either in the maintenance and development of geological environment or in the development of biological environment. The importance of the wetlands is established by its significant functions (enrichment of underground water, absorption of CO_2, storage and heat liberation, engagement of solar radiation and support of trophic meshes). On the other hand these ecosystems are of great environmental, hydrological, social-economical and scientific value (irrigation, agricultural, flood-preventing, water quality improvement, climatic).

The basic problems, resulting from the land use at the vicinity of the wetlands and furthermore at the totality of their catchment areas are: the unverifiable opening of private boreholes that affects the water management and facilitates sea water intrusion, the disposal of urban waste in the valleys that affects the basic aquifers of the island and thus the wetlands themselves and results in the destruction of wetlands due to extensive urbanisation.

Keywords: Hydrogeology, ecosystems, fissured rocks, Tinos Island.

Nutrient sources for green macroalgae in the Ria Formosa lagoon – assessing the role of groundwater

[1]Tibor Y STIGTER, [1]Amélia MM Carvalho Dill, [2]Erik-jan Malta, [2]Rui Santos

[1]IMAR – FCMA, Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal, tstigter@ualg.pt, amelia.dill@ineti.pt
[2]ALGAE – Marine Plant Ecology Research Group, CCMAR, Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal, emalta@ualg.pt, rosantos@ualg.pt

ABSTRACT

Human activities, particularly those related to agricultural practices, have highly increased the nutrient load on groundwater and caused its contamination in many areas of the Algarve, in the south of Portugal. Currently, the highest nitrate concentrations are observed in the area corresponding to the drainage basin of the Ria Formosa lagoon, as shown in Fig. 1. In fact, this area comprises the only two nitrate vulnerable zones (NVZ) designated in the Algarve, in compliance with the Nitrates Directive 91/676/EEC. Moreover, groundwater monitoring in the NVZ of Faro provides clear evidence that the diffuse, well-defined nitrate contaminant plume (with concentrations exceeding 300 mg/l) is moving towards the lagoon.

The Ria Formosa is a mesotidal lagoon located in the south of Portugal that is recognised both on a national and an international level as an extremely valuable and sensitive ecosystem. Every winter, blooms of green ulvoid algae develop in the intertidal zone, forming thick mats on the mud flats, while in summer free-floating ulvoid blooms develop as well on the sandy beaches of the adjacent coastal zone. A further increase of the nutrient load on the lagoon may cause denser populations of algal blooms and the development of new bloom sites, with potentially serious impacts on biodiversity, seagrass meadows, shellfish and fish populations and tourism development. In 2004 a scientific research project was initiated that seeks to identify the species-specific nitrogen (N) metabolism of the blooms both within and outside the lagoon and to relate them with the N mass balance between the lagoon and the adjacent terrestrial and coastal zones.

A fundamental task in this project is the determination and quantification of the main sources of nutrients in the Ria Formosa, particularly N, as this element is considered to limit primary production in most shallow ecosystems and thus to be one of the driving forces in ulvoid growth rates. The input of N from coastal groundwater discharge (CGD) is difficult to assess, as several discharge mechanisms are known to exist: i) "diffuse" outflow along the fresh/saltwater interface near the coast; ii) "preferential" outflow along geological faults that form water conduits and iii) deep groundwater circulation that may extend beyond the limits of the Ria Formosa, leading to submarine groundwater discharge (SGD). The yearly average groundwater discharge from land is estimated in this work by setting up a regional water balance. Effective recharge is estimated on the basis of infiltration capacities, which may reach 50% in the highly karstified carbonate aquifer systems. The total annual recharge is estimated around 70 hm^3 ($x10^6$ m^3), of which a large fraction is consumed by irrigation. In fact, before the connection of the western area to the surface water irrigation district in 2001, more than 65% of groundwater recharge was consumed by agriculture. This extremely high value, though prone to some uncertainty, demonstrates that coastal groundwater discharge (CGD) in some areas along the coastline must have been limited.

In order to determine the existence and location of preferential groundwater outflow along faults, geophysical surveys are being carried out nearby and inside the lagoon. The Radio Frequency-Electromagnetic Method (RF-EM) was carried out for the first time in a lagoon and produced interesting results, despite the expected attenuation from the salt-water layer. Artificial anomalies were detected at several locations, the origin of which is not clear, since there are no records of a possible existence of old pipelines or buried ruins in the lagoon. A large natural anomaly was detected, corresponding to lateral changes in lithology. The orientation of the anomaly seems roughly parallel to one of the directions of the meandering channel, possibly causing its form. This could lead to the hypothesis that tectonic structures have more to do with the morphology of the Ria Formosa than previously considered. The following surveys carried out on land, near Tavira and Olhão (see Fig. 1), also revealed the presence of several anomalies. Unfortunately, the data logger experienced some serious problems (malfunctioning), so that it was not possible to download the data. The surveys will be continued in order to obtain a comprehensive picture of possible groundwater outflow paths.

The total N load on groundwater, mainly related to fertilisation and septic tanks, was determined to be approximately 700 ton yr^{-1}, larger than other sources such as stream discharge (27 ton) and wastewater treatment plants (419 ton). However, the latter discharge directly into the lagoon, whereas for groundwater the fraction that enters the lagoon depends on a number of factors: i) the distribution of groundwater outflow among each of three referred components; ii) the dissolved N concentration, i.e the distribution of the N load among the outflow components and iii) the biogeochemical processes that occur particularly in the lagoon sediment, affecting dissolved N concentrations. It is well-known that the highest N loads exist near the coast, and that shallow groundwater has the highest nitrate concentrations. The main issue that remains to be solved is the importance and volume of shallow groundwater outflow with respect to the other outflow mechanisms.

The magnitude of N exchange with the ocean is also being analysed. An example is provided of the detection of nutrient-rich freshwater in the lagoon during significant rainfall, associated to stream discharge, thereby obtaining baseline information for the assessment of the relative importance of surface vs. groundwater outflow. Sampling campaigns were set up during spring tide and neap tide once every two months during one year (March 2006 to March 2007). Samples were taken every 2 h over a 24 h tidal cycle from the Farol inlet (see location in Fig. 1), responsible for 45-50% of the total water exchange. During the other months, samples were taken at daily high and low tide during spring tide and neap tide from the Farol as well as the Armona inlet, together representing more than 90% of the total water exchange. Though complete presentation of the exchange data with the ocean cannot be given yet, in general the results based on inorganic nutrients seem to confirm earlier studies in that, on an annual basis, there is a net export of nutrients to the ocean. It is clear however that there is large heterogeneity in time, as most export takes place in winter, whereas in summer export is limited.

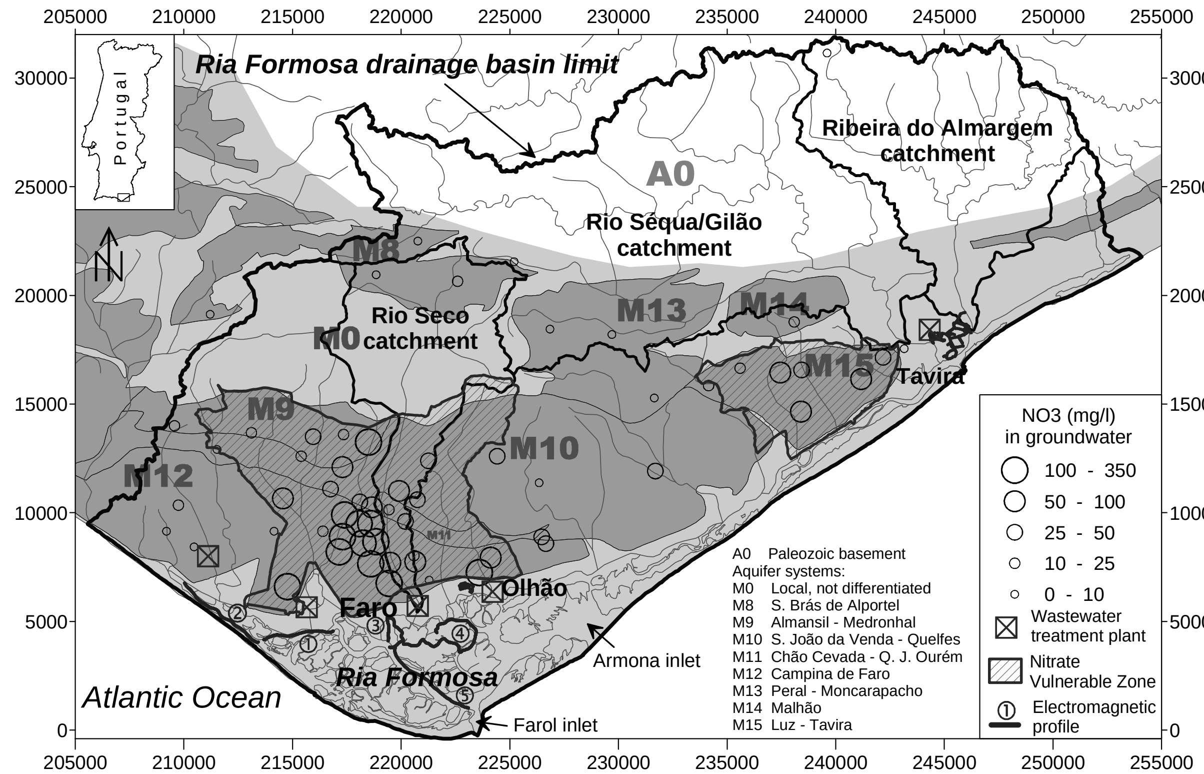


Fig. 1. Location of the Ria Formosa lagoon, its drainage basin and the three major stream catchments, defined aquifer systems, nitrate concentrations in groundwater, the designated Nitrate Vulnerable Zones, waste water treatment plants and electromagnetic profiles

Keywords: Algal blooms, Ria Formosa, nutrient sources, groundwater discharge, electromagnetic surveys

The fate of groundwater nitrate in the coastal zone

[1]Dieke POSTMA, [2]Martin S ANDERSEN, [1] Rasmus JAKOBSEN, [3]Ludovic BARON
[1]Institute of Environment & Resources, Techn. Univ. Denmark, Denmark, djp@er.dtu.dk, raj@er.dtu.dk
[2]School of Civil and Env. Eng., Univ. New South Wales, Australia, m.andersen@wrt.unsw.edu.au
[3]Institut de Geophysique, Univ. Lausanne, Switzerland, ludovic.baron@gmail.com

ABSTRACT

The discharge of nitrate-containing fresh groundwater from a sandy coastal aquifer and into the adjacent shallow marine environment was investigated near Esbjerg at the northern end of the Wadden Sea in Denmark (Fig. 1). As shown in Fig. 1 the shallow groundwater is rich in nitrate with a concentration of up to about 1 mmol/L. The groundwater potential lines indicate a groundwater flow directed towards the coast. The distribution of shoreface sediment containing freshwater was mapped using on-shore multi-electrode profiling (MEP), underwater multi-electrode profiling (UMEP) and the electrical conductivity measured on pore waters in samplers installed in the shoreface sediments. The results show that the fresh groundwater discharge is controlled by sand filled buried channels that connect the aquifer with the shoreface sediments. Nitrate is only present in the discharging groundwater at few places along the coast, indicating that nitrate removal processes must take place in the shoreface sediments.

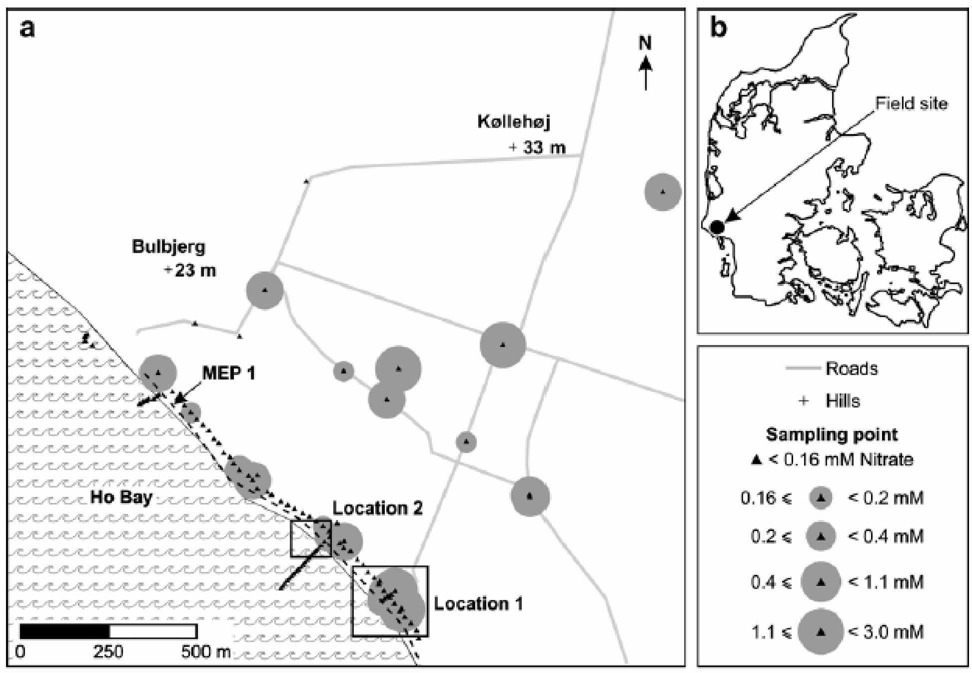


Figure 1 (a) Nitrate distribution in the shallow groundwater of the studied catchment in mmol/L. Triangles are sampling locations; (b) Location of the Ho Bay field site in Denmark;

The nitrate removal processes were studied in more detail in a vertical transect of samplers at Location 1 in Fig. 1a. The samplers were placed parallel to the groundwater flow direction as inferred from head measurements. A groundwater travel time of about 1 yr from 0 to 20 m in Fig. 2 was estimated for the flow path based on Darcy's law. Along the flow path nitrate decreases from a maximum of 1.4 mM upstream to 0 mM downstream, near the high tide line (Fig. 2a). Concurrently there is an increase in both sulphate (Fig. 2b), dissolved inorganic carbon (DIC) (Fig. 2c) and dissolved ferrous iron (Fe^{2+}) (Fig. 2d). In Figure 2 the sulphate concentration shown was corrected for the sea-salt contribution, whereas the DIC was corrected for calcite dissolution. The DIC correction is based on the assumption that excess Ca^{2+} (compared to the sea-salt contribution of Ca^{2+}) must largely come from dissolution of carbonate minerals, releasing an equivalent amount of DIC on a molar basis.

The increases in sulphate and Fe^{2+} indicate that the oxidation of pyrite (FeS_2) may play a role in reducing the nitrate according to:

$$5FeS_2 + 14NO_3^- + 4H^+ \rightarrow 7N_2 + 5Fe^{2+} + 10SO_4^{2-} + 2H_2O \qquad (1)$$

In reaction (1) the Fe^{2+} may be further oxidized to Fe^{3+} and precipitate as $Fe(OH)_3$. The increase in DIC (Fig. 2c) indicates that organic matter (CH_2O) also contributes to the reduction of nitrate according to:

$$5CH_2O + 4NO_3^- \rightarrow 2N_2 + 4HCO_3^- + CO_2 + 3H_2O \qquad (2)$$

Both reactions (1) and (2) predict that nitrate is transformed into dinitrogen (N_2). The net nitrate removal by reactions (1) and (2) can be verified by measuring excess dissolved N_2. Because the background concentration of dissolved atmospheric N_2 may vary due to different processes during groundwater recharge (temperature, excess air etc.) argon (Ar) was used as an inert tracer. Figure 2e shows the measured N_2/Ar-ratio in the transect. In the upstream nitrate rich zone the N_2/Ar-ratio varies between 70 and 90, roughly corresponding to the theoretical N_2/Ar-ratio of 81.8 in water equilibrated with the atmosphere at 8°C.

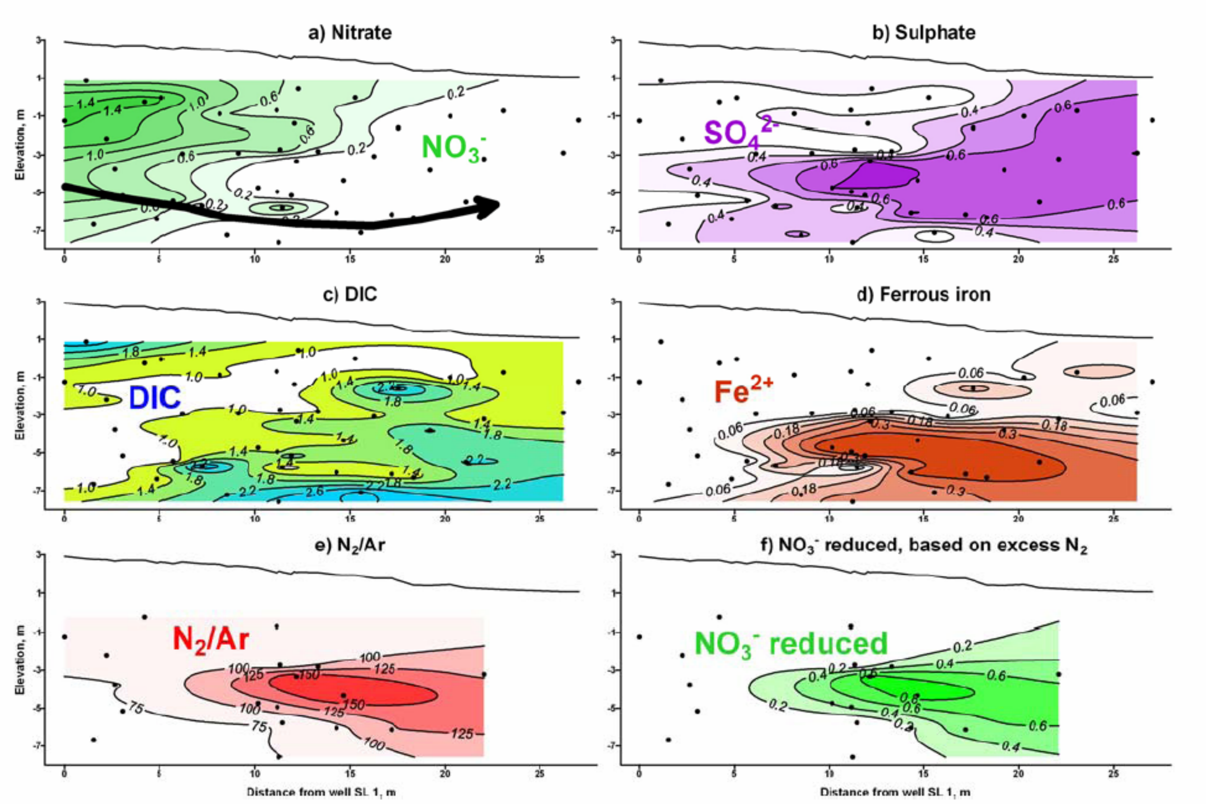


Figure 2. Vertical profiles along a transect showing distributions of a) nitrate (mM), b) sulphate (mM) corrected for sea-salt contribution, c) DIC (mM) corrected for sea-salt contribution and calcite dissolution, d) Ferrous iron (mM), e) the ratio of dissolved N_2/Ar, and f) the amount of nitrate reduced based on excess N_2 (mM). The dots are sampling points and the arrow in a) indicate a groundwater flow path.

Seawards, the zone depleted in nitrate, shows a N_2/Ar-ratio maximum of around 175 indicating ongoing nitrate reduction. The N_2/Ar data suggests that the amount of nitrate reduced is up to 0.9 mM (Fig. 2f). Electron balancing the changes in water chemistry with reactions (1) and (2) indicate that pyrite oxidation contributes with 40% to the nitrate reduction whereas organic carbon oxidation is responsible for the remaining 60% (Fig. 8). Overall our study indicates that, at our study site, a large part of the nitrate content of the groundwater is removed during passage of the shoreface sediments.

Keywords: Hydrogeology, geochemistry, nitrate, groundwater, marine.

Use of thermal imagery, hydrograph separation and numerical modelling to identify and quantify groundwater discharge in estuaries

[1]Serban DANIELESCU, [2]Kerry T.B. MACQUARRIE, and [3]Russell.N. FAUX

[1] Department of Civil Engineering, University of New Brunswick, Fredericton, NB, E3B 5A3, Canada
[2] Department of Civil Engineering, and Canadian Rivers Institute, University of New Brunswick, Fredericton, NB, E3B 5A3, Canada
[3] Watershed Sciences Inc., Corvallis, OR, 97333, USA

ABSTRACT

Previous research shows that rates of anthropogenic nutrient loading have increased in most coastal waters of the world. This increased loading is the main driving force of ecological alteration of coastal waters. While nutrient transport by surface runoff and streams has been well documented, groundwater transport of nutrients has received less attention, although it may be significant in coastal areas underlain by regional aquifers. In this research, airborne Thermal Infrared (TIR) sensing has been used to identify and assist the quantification of groundwater discharge/seepage along the shorelines of two small estuaries in Prince Edward Island (PEI), Canada. This information is used to support an evaluation of the freshwater nitrogen loading to these estuaries. Although TIR methods have been used previously for the identification of groundwater discharge locations in estuaries, only a few studies have attempted to quantify groundwater discharge based on TIR results. The study sites, McIntyre Creek Estuary (0.11 km^2 area) and Trout River Estuary (1.4 km^2 area), were surveyed in September 2005, during low tide, warm weather and clear sky conditions, by using a FLIR Systems SC-3000 TIR sensor mounted inside a Cessna 172 airplane. The conditions during the survey were near optimum for detecting thermal contrasts between the cold groundwater (approximately 10^{o}C) and the warmer estuarine water (approximately 20^{o}C). Approximately 50 line-km of images were collected during a one hour flight. The thermal images were checked against 46 temperature loggers deployed, either in the estuaries or in their tributaries, at the time of the aerial survey. Following the calibration, correction and geo-referencing of TIR images, nine springs/seeps were detected in the McIntyre Creek Estuary and 49 in the Trout River Estuary. Field verification of the springs and seeps took place in April 2006, and indicated good agreement with the TIR imagery. After removing the false positive thermal signals (i.e. cold water emanating from streams and not groundwater springs), 34 groundwater springs in Trout River Estuary and 9 in McIntyre Creek Estuary were used for further analyses. Quantification of groundwater discharge was conducted by correlating the magnitude of the thermal signal of each discharge location with the extent of its land-based contributory area, followed by the use of specific baseflow estimates to assign a groundwater discharge for each location. Contributory catchment areas for the springs were delineated from Digital Elevation Models (DEM). The thermal grid was subsampled using a rectangular polygon and the distribution of thermal values versus their cumulative area was determined. From this cumulative plot the inflection point, which indicates when the relatively warm estuarine water becomes significant compared to the cold freshwater, was chosen to define the area of each spring discharge location. The relationship between the area of cold water in the estuary and the associated contributory land area shows a good correlation (R^2=0.89). Based on continuous stream level monitoring and stream discharge measurement between July 2005 and January 2007, stage – discharge relationships were developed for selected major tributaries of both estuaries, allowing the calculation of the average specific discharge for the contributory stream watershed areas. Hydrograph separation methods were used to estimate the baseflow component of the stream discharge, and consequently to estimate the baseflow contribution to specific discharge (i.e. specific baseflow). The estimated baseflow is 82% of stream discharge, with a standard deviation of 13.5%. The specific baseflow and the contributing catchment area of the springs were used to estimate the groundwater discharge through these locations. The estimation yielded a total groundwater discharge of 0.018 m^3/s into Trout River Estuary and 0.0019 m^3/s into McIntyre Creek Estuary, which are comparable with the results from numerical modelling of groundwater flow for the catchments and the results of other studies of groundwater discharge to coastal waters. Groundwater discharge associated with each thermal grid cell (1 m^2 area) of the springs, which by extrapolation to similar sites would allow the direct estimation of groundwater discharge using thermal image alone, was estimated as 3.6x10^{-6} m^3/s/m^2, with a standard deviation of 1.5x10^{-6} m^3/s/m^2, for Trout River Estuary and 2.3x10^{-6} m^3/s/m^2, with a standard deviation of 8.7x10^{-7} m^3/s/m^2, for McIntyre Creek Estuary, respectively.

Keywords: Airborne thermal infrared (TIR) sensing, groundwater discharge, estuaries, hydrograph separation, numerical modelling

TOPIC 10

Groundwater impact on coastal, estuarine and near shore marine ecosystems

A multidisciplinary approach to groundwater systems characterisation at Santiago Island (Cabo Verde)

[1]Paula M CARREIRA, [2]José M MARQUES, [3]António PINA, [3]António MOTA GOMES, [4]Rui GONÇALVES, [4]Eugénio ALMEIDA, [1]Dina NUNES, [5]Fernando MONTEIRO SANTOS

[1] Instituto Tecnológico e Nuclear, Estrada Nacional nº 10, 2686 – 953 Sacavém, Portugal, carreira@itn.pt
[2] Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal, jmmarques@mail.ist.utl.pt
[3] Instituto Superior de Educação, Praia, Santiago, Cabo Verde afldp@hotmail.com
[4] Inst. Politécnico de Tomar, Quinta do Contador, Estrada da Serra, 2300 Tomar, Portugal, rui.goncalves@ipt.pt
[5] Univ. Lisboa, Centro de Geofísica, Campo Grande, 1749-016 Lisboa, Portugal, fasantos@fc.ul.pt

ABSTRACT

Cabo Verde is a volcanic archipelago with serious water shortage problems. Santiago Island is characterized by scarce hydrological resources due to low and irregular precipitation. This varies between 190 and 320 mm/year at low levels and in the highest mountains (Pico da Antónia or Serra Malagueta), respectively. The semi-arid to arid climate of Santiago Island, with unreliable and erratic rainfall, leads to prolonged drought periods. In fact this situation is responsible for quasi-periodic and sometimes catastrophic dryness. In this context, groundwater protection and management are of vital importance and represents the main source of fresh water resources for local population. Under the R&D Project "*HYDROARID – Evaluation of the Hydrogeological Potential and Sea Water Intrusion Monitoring in Semi-Arid Zones Using a Multitechnique approach: application to the Santiago and Maio Islands (Cabo Verde)",* groundwater sampling campaigns were carried out at Santiago Island. The aim of this study was to evaluate the application of environmental isotope, geochemical and geophysical techniques to find answers to some hydrogeological questions such as: i) the origin and mechanisms of groundwater recharge; ii) the relation between shallow and deep aquifer systems; iii) investigate the existence of salt water intrusion problems and iv) determine the apparent groundwater "age".

At Santiago Island, the main geological units (Fig.1) with strong hydrogeological significance are the following: i) the Base Unit mainly composed by the Eruptive Complex (**CA**), Flamengos formation **(ρλ)** and the Orgãos formation **(CB)**; ii) the Eruptive Complex of Pico de Antónia (**PA**) and Assomada formation **(A)** iii) the Monte das Vacas formation (**MV**) and iv) recent Quaternary sedimentary formations (**a**).

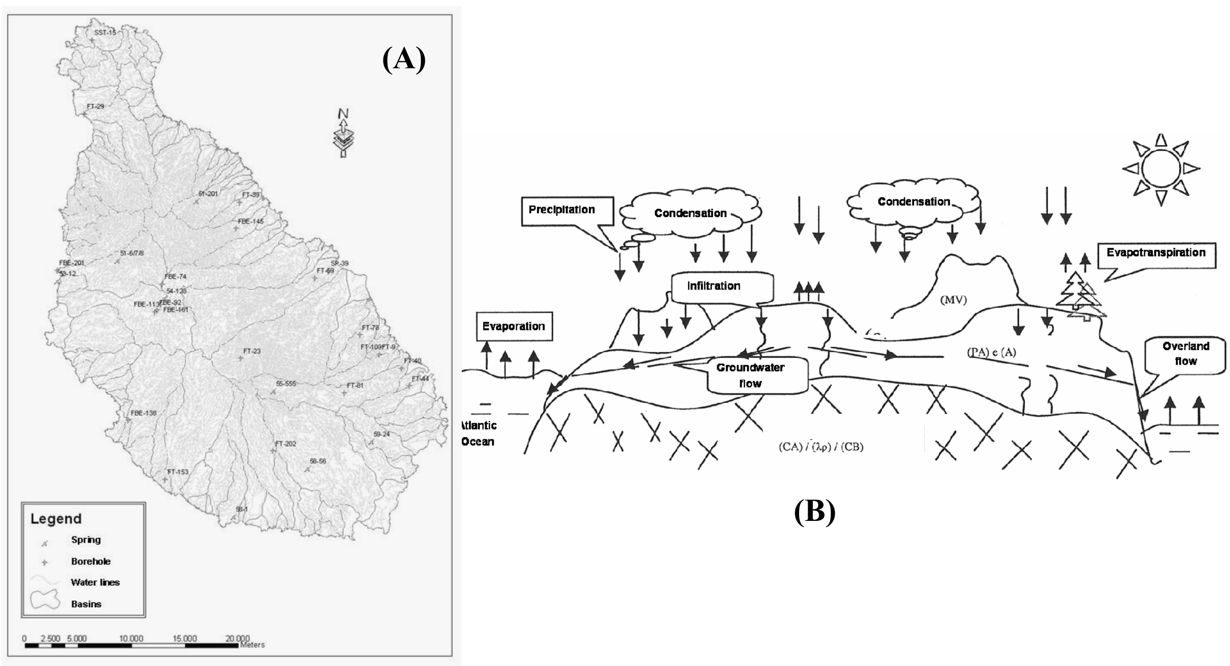


Fig. 1. (**A**) Location of groundwater sampling sites. (**B**) Schematic conceptual hydrogeological model of Santiago Island.

Several geophysical surveys comprising magnetotelluric soundings (MT), very low frequency profiles (VLF) and time domain electromagnetic soundings (TDEM) was carried out in different parts of Santiago Island (Cabo Verde) between 2004 and 2006. The main purpose of the MT soundings was to study the tectonic structures correlated to groundwater reservoir inside the island. The VLF and TDEM methods were used inside the valleys for investigating shallow structures and mapping of the fresh water/seawater interface.

Different methodological approaches have been applied in Santiago Island with the main goal of monitoring fresh-water - salt water interaction. The groundwater samples collected in high mountain areas, located in the central part of the island, belong to the Na-HCO_3 type and reveal the influence of the marine aerosol in the recently infiltrated groundwaters. The groundwaters with higher salt content were sampled near the coast line and show an Mg-Cl and Na-Cl *facies*. The Na-Cl *facies* is mainly ascribed to groundwaters sampled in valley zones, revealing the effects of the salt water intrusion phenomena. The groundwater's temperature ranges between 19.8 and 29.2 ºC, with an average of about 24.9 ºC, and is certainly consistent with the long-term mean annual temperature of the region. A plot of the electrical conductivity *versus* the altitude of the sampling sites (Fig 2A) show i) that the more dilute groundwaters are found at high-altitude sites and ii) that groundwater's mineralization increases towards lower elevations, near the coast. In addition, the low conductivity values can be the result of a short residence time (Fig 2B; see ^{3}H content). The higher mineralization of the groundwaters sampled near the coast, could represent the "mixture" of a longer flow path (residence time), higher water-rock interaction and seawater intrusion.

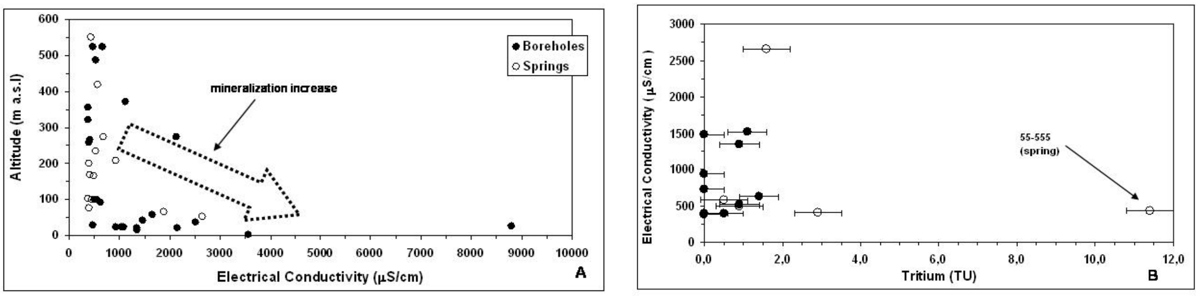


Fig. 2. (A) Altitude *versus* electrical conductivity of the groundwater samples. (B) Electrical conductivity *versus* tritium content determined in the groundwater samples.

About 60 groundwater samples were collected for isotopic analysis along two transects of Santiago Island. The isotopic composition of the water samples were used in the identification and characterization of the recharge areas (Fig. 3A) and to the quantification of the amount (%) of mixture between seawater and fresh water (Fig.3B). Based on the δ^{18}O and δ^2H values, two groups of groundwater samples were recognized: one group includes the groundwaters from sampling sites located in the eastern part of Santiago Island (near the coast line). The other group of groundwaters is ascribed to high-altitude sampling sites. From the isotopic point of view, these two groups can be distinguished by the deuterium excess (Fig. 3A). The mean stable (δ^{18}O; δ^2H) isotope content of the groundwater systems in Santiago Island is -3.80 ± 0.53 and -26.6 ± 5.8 $^o/_{oo}$ *vs* V-SMOW respectively. These values are close to the average long-term isotopic composition of rain fall over the Island. The values obtained suggest that the infiltrated meteoric waters were not subjected to previous evaporation. The recharge seems to occur by direct infiltration of rainfall in the most permeable geological formations of the Island.

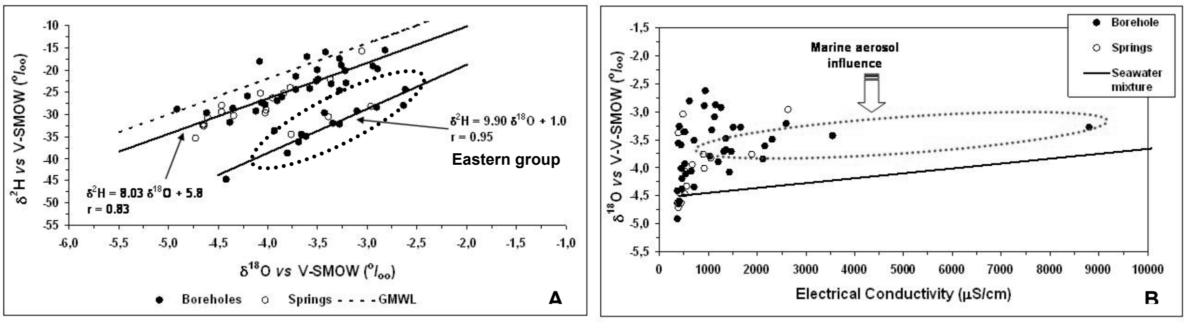


Fig. 3. δ^{18}O *versus* δ^2H (A) and ^{18}O *versus* electrical conductivity (B) diagrams for the sampled groundwaters. The theoretical seawater-groundwater mixing line was plotted. Symbols as in Fig. 2.

***Keywords**:* Stable isotopes, semi-arid region, groundwater evolution, seawater intrusion, Cabo Verde.

Acid sulphate soils and water pollution

[1] Bennett C.T. MACDONALD, [1] Ian WHITE, [2] Mats E. ÅSTRÖM, [3] Annabelle F. KEENE,
[4] Mike D. MELVILLE, [4] Jason K. REYNOLDS

[1] Centre for Resource and Environmental Studies, Australian National University, Canberra 0200
[2] Department of Biology and Environmental Science, Kalmar University, 39182 Kalmar, Sweden
[3] School of Environmental Science and Management, Southern Cross University, New South Wales, Australia,
[4] Biological, Earth and Environmental Science, University of New South Wales, Australia 2052

ABSTRACT

The world's coastal regions are under intense population and developmental pressure and the continuing development of acid sulfate soil areas poses a significant threat to coastal ecosystems. The inherent risk of these soils is the oxidation of pyrite which generates excess acid within the soil profile and can cause the weathering of soil minerals and the release of acidified, metal-rich groundwater into coastal streams and rivers throughout the world. Metal ions, in the soil solution, are released from floodplains following the flood peak, when ground water inputs are likely to be at a maximum. At the two study areas on the Tweed River in eastern Australia, the metal flux from the soil respectively was approximately 3.0 kg Al/ha, 1 kg Mn/ha, 2 kg Fe/ha following an 82 mm rainfall event. These broad floodplain areas of eastern Australian are a diffuse pollution source of metals and acidity due to the process of soil profile acidification due to sulfide oxidation. Coastal acid sulfate soils behave in a similar way to acid mine leaching. Sulfuric acid, produced by pyrite oxidation, causes the dissolution of soil minerals. The dissolved metal ions in groundwater are released into adjacent streams following rainfall. It is clear from this study and other research that the inputs of ground water and sediments from acid sulfate soil areas can radically change surface water geochemistry. The management of these soils require careful planning and evaluation of rehabilitation and production techniques.

Keywords: pyrite; sulfide; management; trace metal; heavy metal

Application of geophysical methods to study seawater intrusion in coastal aquifers

[1]Lener SEQUEIRA, [2] Sandra TORRES y [3] Oscar ESCOLERO

[1] Centro de Investigaciones Geocientíficas (CIGEO/UNAN-Managua). Nicaragua. lenersequeira@cigeo.edu.ni.
[2] Posgrado de Ciencias de la Tierra, Instituto de Geología, Universidad Nacional Autónoma de México, Ciudad Universitaria, C.P. 04510, México, D.F., <osandra_13@yahoo.com.mx>
[3] Departamento de Geología Regional, Instituto de Geología, Universidad Nacional Autónoma de México. Ciudad Universitaria. 04510 México, D.F., <escolero@geologia.unam.mx>

ABSTRACT

Worldwide, many aquifers are located in coastal environments where they are in contact with seawater, resulting in the risk of saline intrusion (contamination of the freshwater aquifer by seawater) in cases of excessive aquifer exploitation. Many of these aquifers are used for drinking water supply and for the irrigation of agriculture. This is also the case in many coastal regions of Mexico and Nicaragua. This necessitates for the study of the saline intrusion process to safeguard the use of water resources from those aquifers. Three case studies are presented, from the coastal environments in Mexico and Nicaragua, with the principal objective being to apply geophysical methods to the study of marine intrusion. The study cases are located in Tola, León-Chinandega (both in Nicaragua, Fig. 1) and in La Paz, Baja California Sur (Mexico, Fig. 2). In Nicaragua, electrical geophysical methods were applied (resistivity images), whereas Transient Electromagnetic Soundings (TEMs) were used in Baja California Sur.

Fig. 1. Study sites in Nicaragua.

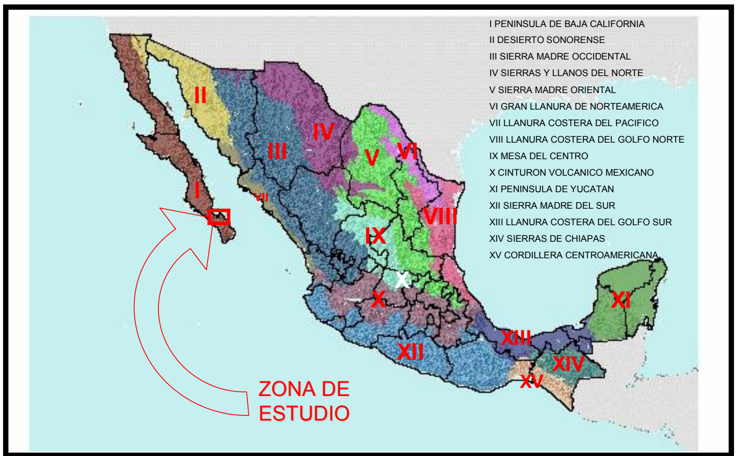


Fig. 2. La Paz. Baja California in Mexico

In Nicaragua, the geophysical method in site 1 (León-Chinandega) was applied above quaternary sedimentary deposits and tertiary rocks of the Tamarindo Formation. A profile (Fig. 3) was obtained in 2004, approximately in a south-north direction. From the resulting image, the existence of saltwater as far as 1300m inland can be inferred, characterized by resistivities of 3 ohms-m. Additionally, the existence of two vertical structures can be observed at 1450 and 1750 m on the profile, which might possibly be related to faulting parallel to the Mesoamerican Depression. The brackish water can be associated with resistivities between 3-10 ohms-m, whereas the aquifer is characterized by a resistivity between 10-22 ohms-m.

On the second site (Tola), in the south-east of Nicaragua, twelve resistivity profiles have been obtained in 2005, with the objective to identify locations that are not affected by seawater contamination. At this site, the aquifer contamination occurs due to marine water intrusion or by seawater migration through faulting perpendicular to the Mesoamerican depression. The site's geology is characterized by the Rivas Formation from the Cretacious, composed of sandstones, sandstone-tuff, siltstone, lutites, conglomerates and marl. The results indicate aquifer contamination, not from actual saline intrusion, but from the conduction of saltwater through the vertical geological structures associated with faults. The electric resistivities associated to the formations with saltwater are less than 10 ohms-m, whereas freshwater corresponds to resistivities in the range of 12-22 ohms-m.

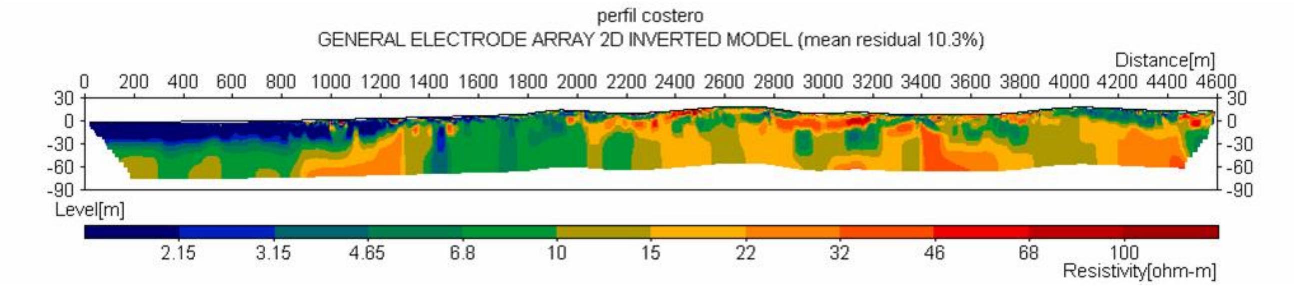


Fig. 3. Perfil Costa (León-Chinandega)

In La Paz, located in Baja California in the north-east of Mexico, 8 profiles have been elaborated, integrating 19 TEMS. The objective was to delimit the geological formations of the zone in the vertical sense within the first 600m of depth, and to define areas affected by seawater intrusion. The study area is a valley limited by the two regional normal faults: La Giganta in the West, and La Paz in the east. The valley's geology is dominated by Mesozoic intrusive rocks, tertiary sedimentary rocks of the Comondú Formation, and quaternary materials. The results from the geophysical study propose that in the south the saline intrusion has advanced 9 km. In the center of the valley a thickness of up to 200 m was defined for the Comondú Formation, 150 m for the Tepetate Formation and 100 m for the Formations San Isidro and San Gregorio.

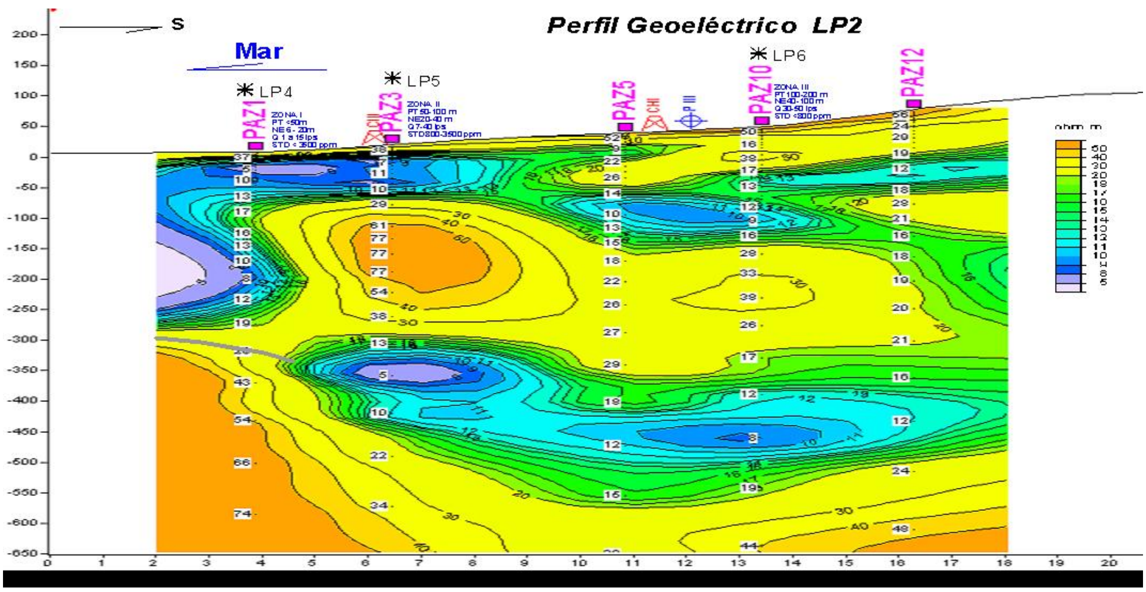


Fig. 4. Perfil LP2 Verical NS.

Keywords: Seawater intrusion, Transient Electromagnetic Soundings, Coastal Environments

Prediction of salinization effects in a shallow coastal aquifer due to sands quarry excavation: monitoring and modelling dual-density flow (Ferrara, Italy)

[1]Leonardo PICCININI, [1]Valentina VINCENZI, [1]Alessandro GARGINI

[1] Earth Sciences Department, Univ. Ferrara, via Saragat 1, Ferrara, Italy, e-mail: pcr@unife.it, vncvnt@unife.it, gga@unife.it

ABSTRACT

In Italy, mining licences for riverbed sands are no longer allowed, so the search for sands quarries in lowland alluvial coastal plains addresses paleo-channels as the main targets of exploitation. At the same time these geological bodies are fresh groundwater reservoirs and control the dynamics of local dual-density flow, being the main location of direct recharge (higher relative permeability and susceptibility to infiltration) and lateral recharge (main irrigation and navigation canals often follow the trace of paleo-river beds). Sand mining in below sea level territories affects shallow aquifers and creates artificial lakes: so it can induce undesired effects on shallow groundwater flow system as local mounding of interface or changing groundwater flow inside the sandy lithosomes with risk of increasing the overall salinity of a fragile ecosystem.

Inside shallow aquifers of the coastal Po plain, where ground level is at or below sea level, as a consequence of land reclamation in historical times, fresh/salty groundwater interface is not Ghyben-Hertzberg shaped but is a sub-horizontal surface, located at variable depth in relationship to the fresh water hydraulic loading coming from direct recharge or from irrigation canals.

For sand quarrying schemes to be developed in Ferrara province (Emilia-Romagna region, Northern Italy) local environmental regulatory agencies prescribe an hydrogeological study in order to size the maximum excavation depth so minimizing shallow groundwater salinization risk. This paper deals with a site located in the municipality of Ostellato along a paleo-channel formed by fine to coarse sands and pertaining to the Holocenic delta of the Po river (*Padòa-Eridano* branch). Maximum sands thickness is about 25 m (from 2 m b.g.l., underneath about 2 m of silts, down to 27 m b.g.l.); grey clays aquiclude occurs at the bottom. Laterally the sandy lithosome changes gradually to sandy coastal dunes deposits and silty-clayey transitional lagoonal deposits, both brackish in nature.

A monitoring system has been set-up in order to clarify the hydrogeologic system conceptual model and to acquire input parameters and calibration data for a dual-density groundwater flow model: it includes both electrical conductivity profiling inside long-screened piezometers and a borehole-based continuous monitoring of hydraulic head, groundwater temperature and specific electrical conductance (EC). The continuous monitoring system is made up of a total of 9 boreholes and 27 sensors and has recorded each parameter on a hourly basis from September 2005 to September 2006; inside one long-screened piezometer, completed along the total aquifer thickness, a vertical EC profile has been continuously recorded at 4 different vertical positions.

The monitoring over a whole hydrological year has demonstrated the key role of the irrigation canal located along the paleo-riverbed: its constant water level assures a constant lateral recharge to the shallow aquifer through the permeable sands and its specific conductance behaves like a physical tracer, influencing groundwater conductance in the nearest piezometers. Near the canal the fresh/brackish water interface reaches its maximum depth b.g.l. and rises progressively, going far away from it; both freshwater and deep salt water conductance increasingly move away from the canal. The conceptual model is so that a unique strip shaped groundwater lens located along paleo-channel/canal axis, floating over original brackish groundwater. The lens shape and dimension is affected by lateral recharge rate from the canal, by direct recharge supply from the top and by the permeability and storage parameters of the aquifer. The top of the interface is located at a depth varying between 12 and 16 m b.g.l.

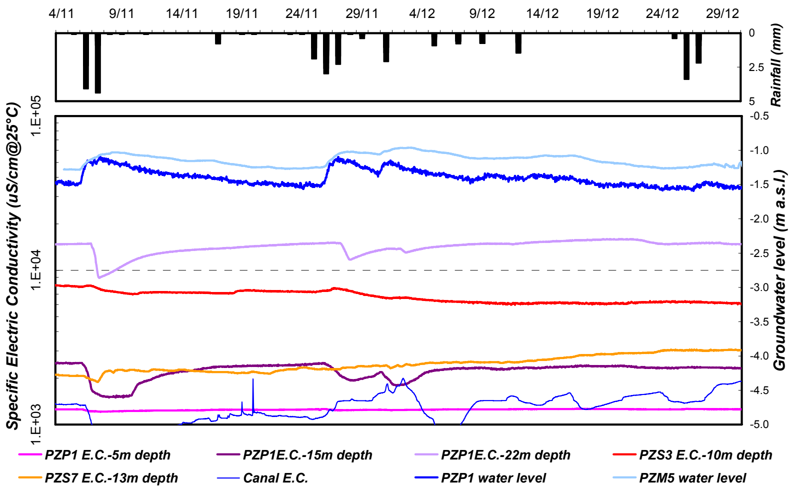


Fig. 1. An example of monitoring data: groundwater level and specific conductance variations compared with rainfall events. At every groundwater level raising, after a rainfall event, corresponds a conductance decrease.

Double-density 3D groundwater flow model has been set-up with Visual MODFLOW 4.1 (©Waterloo Hydrogeologic Inc.): 39 boreholes allowing a good representation of 3D geometry; an irregular grid made of 21 layers has been used; hydraulic conductivity of the aquifer has been calculated from 9 slug tests; storage and dispersion parameters have been taken from literature and previous studies and then adjusted through calibration; temporal discretization in 24 stress periods took into account piezometric monitoring data in relationship with rainfall events. Initial conditions for flow were obtained from a piezometric survey, and for transport, were inferred from vertical conductivity profiles through a 3-D interpolation of salinities. All conductivity data have been converted in solute concentrations (TDS, mg/L). In addition for recharge, a 3rd type boundary condition was used to simulate the canal feeding the aquifer.

The numerical code used is SEAWAT-2000 (Langevin, Shoemaker & Guo, 2003); PCG2 and TVD solver have been chosen respectively for flow and for transport. A first transient simulation over 1 hydrogeologic year was performed, to compare model results with monitoring data. Through PEST a good calibration was achieved for hydraulic heads. Regarding salt concentrations, results were hard to reproduce sudden conductance variations in response to recharge events.

A second transient simulation over five years has been realized in order to predict groundwater levels and salinity changes caused by the quarry sands: the excavation of sands and the resulting lake were simulated assigning huge values of K and storage parameters. At the end of the 5 years the groundwater level in the aquifer decreased some centimetres and the interface rose about 2 m in the excavation area.

Monitoring and modelling results represent a contribution to understanding of dual-density dynamics in shallow aquifer located in coastal alluvial low-lands of the Po plain, with hydraulic heads always located below sea level.

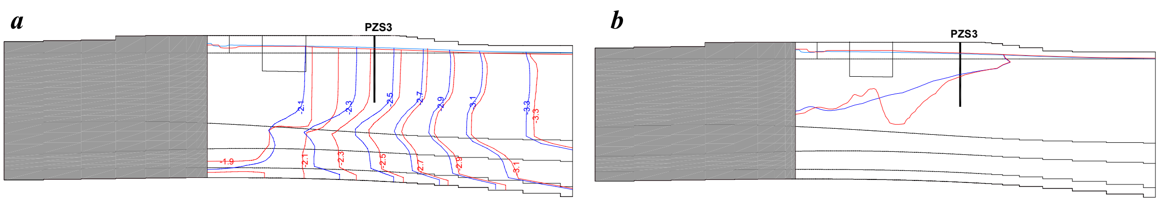


Fig. 2. SEAWAT results: 7 m deep quarry lake modifies hydraulic heads (a) and causes the upwelling of brackish waters below the excavation (b).

Reference

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Keywords: coastal aquifer, monitoring, double-density model, salinization, quarry

Using GIS and modeling to assess groundwater discharge to Santos Estuary, Brazil

[1] Malva A MANCUSO, [2]João Paulo L FERREIRA, [1] José Luiz A FILHO

[1]Instituto de Pesquisas Tecnológicas S.A.-IPT, Av. Prof. Almeida Prado, 532, Prédio 59, Cidade Universitária, 05508-901, Butantã, São Paulo, SP, Brazil, e-mail: mancuso@ipt.br, albuzelu@ipt.br.
[2]Laboratório Nacional de Engenharia Civil – LNEC, Av. do Brasil, 101, 1700-066, Lisboa, Portugal, e-mail: lferreira@lnec.pt

ABSTRACT

This work was developed on the scope of ECOMANAGE project (Integrated Ecological Coastal Zone Management System). The study seeks to develop integrated tools to help decision makers in the task of integrated coastal zone management. Santos Estuary basin is 834.6 km^2 area located in the coast of São Paulo State, Brazil (Fig. 1). The total drainage basin is composed by 9 watersheds and several small islands that contribute with fresh water (that flows in surface and underground) to the estuarine system.

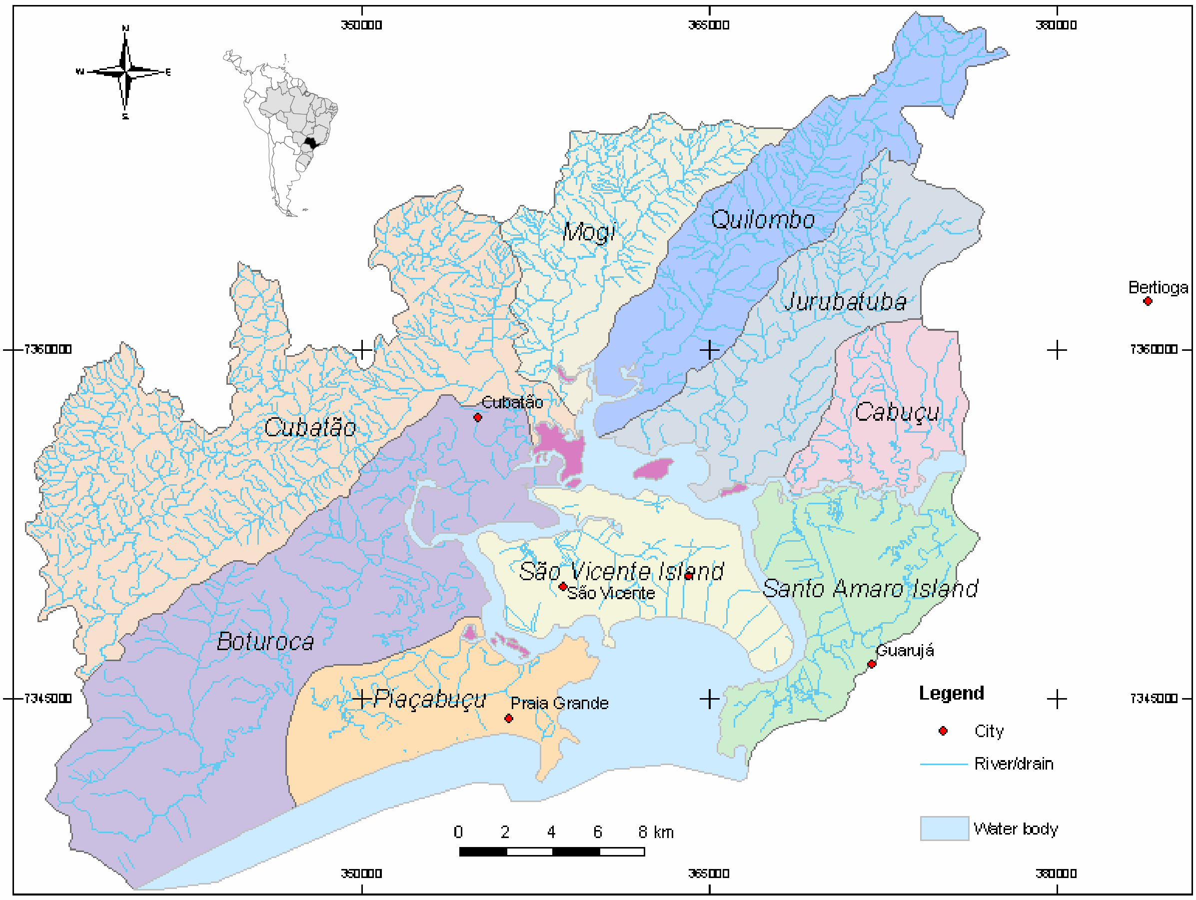

Fig. 1 – The watersheds in land Santos Estuary area.

To calculate fresh water contribution from the sedimentary aquifer to Santos Estuary it was developed a groundwater flow modeling for Santos Estuary basin. The model allowed evaluating groundwater discharge from the aquifer system to the Estuary on a steady state condition. The objective was also to provide an initial condition on a watershed scale, for a monthly flow simulation (transient condition) and for a critical condition simulation (extreme recharge data).

The modeling works included the analysis of geological, hydrogeological and climate data. The groundwater model was developed using the following software: ArcView, ArcInfo and Ground Water Modeling System – GMS, with the modules BOREHOLES, TIN, SOLIDS, MAP and MODFLOW. The conceptualization was based on the physical system, its geometry, geology, hydrogeology. The conceptual model also comprises groundwater recharge estimation and water budget understanding. The study was based on the 1:500 000 scale maps.
The area for modeling was defined in ArcView, using geological map to delimitate the Cenozoic sediments (alluvium, marine and mixed sediments, undifferentiated continental sediments and Cananéia formation). In the Cenozoic, the main events may be summarized in topography modeling, tropical humid climate, sea transgression and deposition of the sedimentary sequences. The total modeled area was 448 Km^2 (406 Km^2 of land area approximately).
According with collected information, the bottom of the aquifer (top of cristaline rock) varies from -25 m close to the hard rock, disappearing where the hard rock formations outcrop, and increase up to -230 m at the southwest part of the basin, close to the ocean. The sediments thickness close to the ocean is mostly around 100 m, going from 30 m to 230 m at southwest. For better understanding the hydraulic characterization of the aquifer media was build a 3D view of the sediments in the porous media to be modeled, based on geological maps, geological cross sections, well logs and geophysical logs. The hydraulic conductivity values were assigned for each formation, varies from 1 to 0.5 m/d on the sediment. The precipitation in the plain area is 2131 mm and up to 3000 mm close to the escarpment.
The flow model was developed considering flow as a steady state, with lakes and the channel considered as constant head cells. Rivers were simulated as drains. For modeling purpose the total recharge was estimate as 28,2% from precipitation, considering urban areas and mangrove. Mean recharge value was then 0.0019 m/d at start for modeling condition. The piezometric regional level was collected from existing data.
It was build a two layers model on porous aquifer, with 250 by 250 m cell. The first one is an unconfined layer and the second one a confined/unconfined layer. This division intended to evaluate the real groundwater flow rate discharge to the estuary, considering a total penetrating channel on the first layer.
Results show that total discharge from groundwater is $877x10^3$ m^3/d, $208x10^3$ m^3/d direct to the estuary, and $493x10^3$ m^3/d to the drains, part of the groundwater flows to the Atlantic Ocean.
Total discharge directly to the Estuary is approximately 8% of the total precipitation .

Keywords: estuarine ecosystem, groundwater, GIS, modeling.

Using seaborne TDEM measurements to detect the offshore extension of fresh groundwater systems

[1]Vincent POST, [1]Michel GROEN, [1]Jacobus GROEN, [1]Henk Kooi

[1]Vrije Universiteit, Faculty of Earth and Life Sciences, Department of Hydrology and Geo-Environmental Sciences, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands, e-mail: vincent.post@falw.vu.nl

ABSTRACT

Submarine groundwater discharge (SGD) represents an important, yet poorly quantified, pathway for nutrient delivery to coastal waters. Groundwater contaminated with fertilizer and sewage contributes to eutrophication and hypoxia in littoral ecosystems around the world. Accurate quantification of the nutrient delivery to coastal waters by SGD is essential for the proper management of these systems. This requires a thorough understanding of the hydrogeology and groundwater flow dynamics. Several methods are being used to measure groundwater outflow through the seabed, which yield point measurements of discharge rates. Upscaling of these measurements is often difficult due to the heterogeneity of the seafloor sediments and the limited data of the offshore continuation of the fresh groundwater flow systems.

To overcome the latter, a seaborne geophysical measurement system was developed to map the occurrence of fresh groundwater below the seafloor using Time Domain Electromagnetics (TDEM). The system used in this study consists of a boat-towed, coincident circular antennae/receiver loop, 50 m in diameter with a Zonge NT-20 transmitter and GDP-32 receiver.

The system was used along the western coast of the Netherlands which is bordered by a belt of dunes several kilometers wide and tens of meters high. A fresh water lens below the dunes penetrates most of the underlying Pleistocene aquifer system to a depth of over 100 m below mean sea level (MSL). A phreatic and semi-confined aquifer can be distinguished, separated by a Holocene clay-rich unit at a depth of about 20 m below MSL. It is suspected that the fresh water lens extends offshore in the semi-confined aquifer.

Evidence for the offshore presence of relatively fresh groundwater is provided by old measurements near the city of IJmuiden. A water sample taken from a depth of 27 m below MSL from a borehole 1400 m offshore that was drilled in 1964 had an EC of 8 mS/cm and a Cl concentration of 79 mmol/l. Local seawater has an EC of 40 mS/cm and a Cl concentration of approximately 400 mmol/l. Additionally, in a nearby borehole log from 1987, a layer of fresh water was found that had a maximum formation resistivity of 20 Ωm, corresponding to an estimated groundwater EC of approximately 1.5 mS/cm. The borehole was drilled on a recently deposited stretch of beach that formed after the construction of a >2 km long pier and the data are considered to still reflect the offshore conditions when the borehole location was still situated 0.6 km off the former coastline.

Based on these data, 2 different layered resistivity models (I and II) were constructed for which synthetic TDEM decay curves were calculated using the TEMIX software package by Interpex (Fig. 1). A layer of seawater at the top was included. The thickness of this layer was increased progressively from 1 to 10 m in order to investigate the ability of the equipment to detect the assumed fresh-water layers with increasing seawater-depth. The outcome is depicted in Fig. 1 and shows that for model I, the presence of fresh groundwater can still be detected with the chosen measurement configuration for seawater depths up to 5 m. Layers of brackish groundwater below the seafloor, as in model II, are much harder to detect because already at a seawater depth of 1 m, the curve starts to resemble the curve of a seawater-filled sediment.

Prior to conducting the seaborne TDEM measurements, onshore vertical electrical soundings (VES) and TDEM measurements were conducted along shore-perpendicular transects to characterize the fresh groundwater lens geometry. Cone penetration tests for electrical conductivity (CPCT) were conducted on the beach down to the mean low water line. The measurements display a considerable heterogeneity in the lateral distribution of fresh and saline groundwater especially in the upper 15 m of the soil. In general, the phreatic aquifer and confining layer contain saline groundwater. Within the confining layer, layers with relatively-fresh groundwater are intercalated between more saline layers which is due to differences in permeability. The semi-confined aquifer contains fresh groundwater up to a depth between 40 and 45 m below MSL. Below this depth, the groundwater is saline.

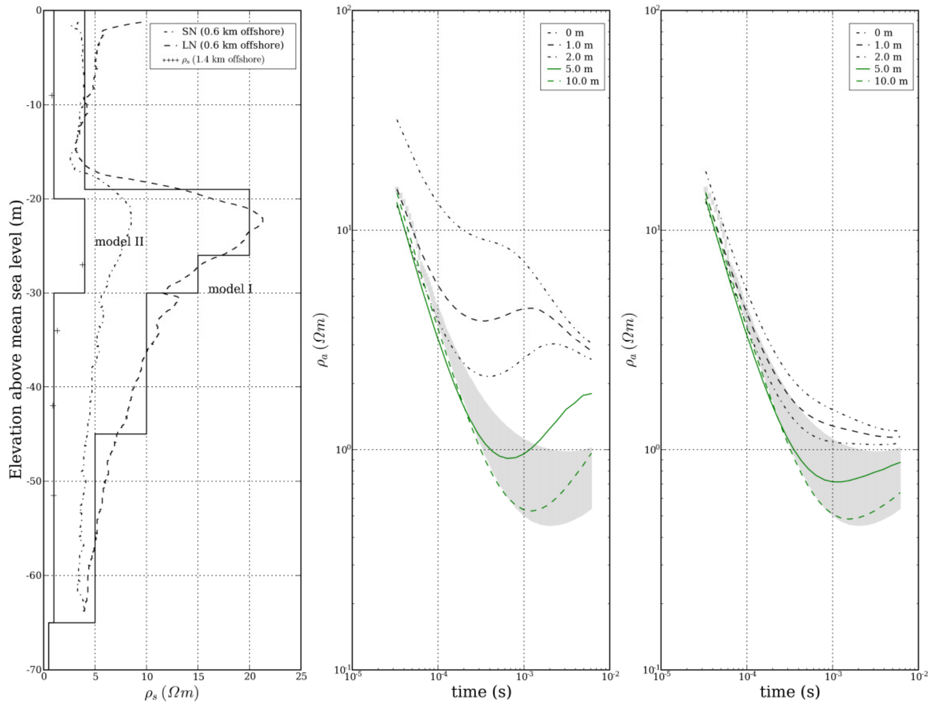

Fig.1. Panels showing the layered subsurface resistivity models representative for 0.6 and 1.4 km offshore (left) and the calculated synthetic curves of model I (middle) and model II (right) for increasing depths of seawater. The shaded area in the middle and right panels coincides with the range of synthetic curves for seawater-saturated sediment for seawater depths ranging from 1 to 10 m.

At the location of the CPCT measurement points, a TDEM sounding was conducted which served as the starting point for the interpretation of the seaborne TDEM measurements. The measurements were interpreted with increasing distance from the shore (and therefore with increasing water depth). Assuming that lateral changes in the groundwater salinity are gradual, the layered model of the subsurface resistivity of the onshore measurements was modified to fit the first offshore measurement. The same procedure was repeated for the subsequent offshore measurements, each time also accounting for the increased depth of the seawater at the measurement location. This approach was necessitated by the lack of direct measurements of the subsurface resistivity offshore.

The method proved suitable for detecting fresh water up to a depth of 5 m of seawater. As suggested by the forward models, the interpretation of the offshore TDEM measurements becomes increasingly difficult at greater seawater depths. The data showed that fresh groundwater is present below the seafloor in the first hundreds of meters from the low water line. Considerable uncertainty arises from the lack of direct measurements. Nevertheless, the results indicate that seaborne TDEM measurements are an effective method for detecting the offshore extension of fresh groundwater systems in shallow marine environments.

Keywords: time-domain electromagnetics, submarine groundwater discharge, saline groundwater, The Netherlands

TOPIC 11

Impact of climate and global changes on groundwater dependent ecosystems

A Shift in the Ecohydrological State of Groundwater Dependent Vegetation due to Climate Change and Groundwater Drawdown on the Swan Coastal Plain of Western Australia.

[1]Ray H FROEND and [1]Muriel BERTUCH

[1] Centre for Ecosystem Management, Edith Cowan University, Western Australia

ABSTRACT

The deep sand, unconfined aquifers of the Swan Coastal Plain in Western Australia support extensive open woodlands dominated by *Banksia* and other phreatophytes. During the mediterranean hot, dry summer, phreatophyte use of groundwater increases as moisture in the vadose zone is rapidly depleted. Since the mid-1970's these ecosystems have been subject to declining annual rainfall and water-tables. Groundwater abstraction for horticulture and public water supply has also increased the rate of water-table decline in parts of the Swan Coastal Plain. As a consequence there has been increasing evidence of ecological change and, in some cases, rapid degradation of groundwater dependent ecosystems.

In the summer of 1990/91, a *Banksia* woodland on the Swan Coastal Plain, was subjected to a combination of historical water-table decline due to changing rainfall patterns, and significant groundwater drawdown as a consequence of nearby abstraction. At the time, the ecohydrological state of the vegetation was typical of shallow depths to groundwater (<3m); dominated by obligate phreatophytes dependent on access to the water-table throughout the dry summer months. However, increased rates of drawdown in the summer of 1990/91 and poor aquifer recovery during the previous winter, resulted in significant degradation of the vegetation. Over 80% mortality of the phreatophytic overstorey species occurred with a corresponding loss of fauna habitat.

Over the last 16 years, the impacted *Banksia* woodland recovered with a high structural and compositional similarity to the pre-impact state. This floristic recovery is despite water-tables remaining up to 6m below pre-impact levels. Relative densities of obligate phreatophyte tree species have reduced whilst the occurrence of vadophytes has significantly increased in the understorey. Facultative phreatophyte species now dominate the overstorey, suggesting that the ecohydrological state of the site has shifted to one in which the dependence on groundwater access is reduced relative to the pre-impact state. Further groundwater drawdown, therefore, should have less or no impact on the health of the current vegetation.

To test this theory, a field experiment was performed over 3 consecutive summers, where the recovered vegetation was subjected to further drawdown and its physiological water stress, and water source partitioning compared to vegetation at control sites. This paper describes the outcomes of this experiment and discusses the relevance of a shift in ecohydrological state to phreatophyte vulnerability and reduced groundwater availability. Application of ecohydrological state theory to groundwater management is also discussed.

Keywords: ecohydrology, phreatophytic vegetation, climate change, groundwater, drawdown

Coastal Squeeze: a pilot study of potential climate change impacts on groundwater-dependent coastal ecosystems in Suffolk, UK.

[1]R Neil HUMPHRIES, [2]Nicholas J K HOWDEN, [1]Charles HUMPHRIES, [3]Roger MORRIS

[1]White Young Green Environmental, Newstead Court, Little Oak Drive, Sherwood Business Park, Annesley, Nottinghamshire NG15 0DR, UK, e-mail: neil.humphries@wyg.com

[2]School of Applied Sciences, Building 53, Cranfield University, Cranfield, Bedfordshire, MK45 0AL, UK, e-mail: n.j.k.howden@cranfield.ac.uk

[3]Natural England, Northminster House, Northminster Rd, Peterborough, PE1 1UA, UK, e-mail: roger.morris@naturalengland.org.uk

ABSTRACT

It is now accepted that sea levels will rise as average global temperatures increase, and glaciers and ice sheets melt, and present estimates of sea level rise published by the Intergovernmental Panel on Climate Change range from 9 cm to 88 cm by 2100. Given the quantity of water held in the ice caps and the estimations of a sea level 6 m higher than today's during the last interglacial period, sea levels may continue to rise above current predictions and may exceed those for the next century.

The Suffolk Coast supports one of the most important areas for wetland wildlife in the UK. It is extensive, occupying a coastline and coastal fringe of some 65 km in length, with an almost continuous semi-natural habitat coastal belt, which is connected inland by a number of river valleys. It is diverse and recognised for its international and national contribution for the conservation of birds and freshwater habitats, and is also important for invertebrates and mammals. As a consequence, large parts have been given statutory protection under UK and European legislation and international conventions. In addition, these areas, and others outside of the designated land, are significant contributors to the UK BAP for coastal and coastal floodplain habitats. The juxtaposition of the extensive freshwater habitat with the coastal and estuarine habitats, facilitated by the coastal processes of erosion and secretion of sands and gravels as bars and spits, is unparalleled elsewhere in the UK.

As a result of the predicted sea level rises there will be saline incursion and intrusion into these coastal areas with the concomitant displacement of fresh water habitats and species with saline types. This is often referred to as 'coastal squeeze'. The Living with the Sea Life Project (English Nature, 2003) has evaluated the implications of sea level rise and flood risk management issues for European designated sites in England.

The loss of habitats falling within the EU Habitats Directive, as a result of 'coastal squeeze' on the Suffolk Coast, has been defined (Posford Haskoning, 2002; Atkins, 2005). However, these do not account for all wetland habitats that may be affected within the designated areas and elsewhere along the coast. Under the UK Biodiversity Action Plan there is an obligation for the maintenance, restoration and creation of reedbed, coastal and floodplain grazing marsh, and fens. English Nature* is the lead organisation for these habitats and needs to understand the implication of the sea level rise as to the true loss and the challenge for habitat replacement.

The purpose of this study was to advise English Nature* as to the degree that the fresh water habitats may be affected and the extent of replacement habitat required to maintain the UK BAP habitats and associated species. This was achieved by: reviewing existing studies and guidance; using a GIS-framework to identify relevant habitat types and notable species within 6 study areas vulnerable to 'coastal squeeze'; specifying physical, chemical and biological factors maintaining habitats; describing preparation and management required to recreate habitats; and providing a set of generic decision rules for creating habitats in particular locations together with a GIS-model demonstrating how these may be applied.

This paper presents the preliminary conclusions of this pilot study, and suggests the likely outcome of a rise in sea level is that natural processes will, ultimately, present a completely different coastal configuration than that which currently exists. The analyses suggest the valleys and coastal strips currently of value will no longer be available for freshwater wetlands. As these habitats do not extend indefinitely inland, a way forward is to plan and influence the retreat and degree to which incursion takes place by using new approaches (such as 'roll-over' banks) which are aligned with natural processes.

The specificity and diversity of the habitats and the species assemblage hosted by the Suffolk Coastal freshwater wetlands, and their extent, is such that there can be no simple replacement elsewhere, a conclusion that is supported by preliminary modelling undertaken as part of the study. Further work is required to establish how similar the designed analogues need to be and where replacement sites should and should not be located to be certain of success.

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note: English Nature became part of Natural England in October 2006

Keywords: climate change, wetland management, saline incursion, ecosystems

Effects of elevated CO_2 concentration on photosynthesis of *Populus euphratica* grown at different groundwater depth

[1]Yapeng CHEN, [1]Yaning CHEN, [1]Weihong LI, [1]Changchun XU

[1]Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, 830011, China,
e-mail: chenyp@ms.xjb.ac.cn, chenyn@ms.xjb.ac.cn, liwh@ms.xjb.ac.cn, xcc0110@163.com

ABSTRACT

Indigenous vegetation in the lower reaches of the Tarim River between the Taklamakan Desert and the Kuluke Desert in Xinjiang, NW China, is dominated by a few riparian trees, primarily *Populus euphratica* Oliv. Due to its tolerance of severe drought and high salinity and alkalinity in soils, *P. euphratica* is very important in maintaining ecosystem function in arid and semi-arid regions. The river flow at the lower reaches of the Tarim River has been cut off since the 1970s, hence the groundwater depths in that region have decreased drastically. *P. euphratica* has never been subject to the most severe drought stress and consequently, to degradation of its natural forests. Many riparian trees are phreatophytic, relying heavily on groundwater, and the change of groundwater depths directly influences the growth, development, composition, and changes of vegetation. From our previous studies on physiological-biochemical characteristics under different groundwater depths (leaves level) and plant quadrat sampling investigation (communities level) of p. eupheritica in this area, we found that groundwater depth is a good indicator for the drought-stress condition of *P. euphratica.* Thus relationships between riparian tree growth and elevation of CO_2 must also consider tree access to groundwater.

In order to understand the effects of CO_2 enrichment on photosynthesis of *Populus euphratica*, changes in stomatal conductance (g_s), photosynthetic rates (PN) and water use efficiency (WUE) of *P. euphratica* growing in different groundwater depths (GDs) were measured under two CO_2 concentration conditions. The response of g_s in *P. euphratica* to CO_2 enrichment depends upon gd to a certain degree. The g_s of the trees with GD at 4.12m and 4.74m both decreases with increasing CO_2 concentration, the difference ($p>0.05$) between them is not obvious. The trees showed a significant difference between g_s measured at 360 and 720 μmol mol^{-1} CO_2 ($p<0.05$) when GD increased to 5.54 m or/and 7.74 m. A closer examination of the complete data set confirmed that, for all four GDs, proportional decrease in g_s did indeed increase steadily as PAR increased. However, the most important finding is that the relationship between PAR and the proportional decrease in g_s (due to measurement in CO_2 enrichment) was drastically altered by GD.The response was strongest at GD 4.74 m, followed at 4.12 m, then 5.54 m. However, at 7.74 m the response of proportional decrease in g_s to changes in PAR was disappeared. At different GDs, the effect of elevated CO_2 concentration on photosynthetic rate is different. For example, the P_N of trees with GD at 4.12 m when measured at 360 μmol mol^{-1} CO_2 was similar to that measured at 720 μmol mol^{-1} CO_2 under various PAR conditions. While at other three GDs, PN measured at 720 μmol mol^{-1} CO_2 was obviously higher than that measured at 360 μmol mol^{-1} CO_2 ($p<0.05$), and the relationship between PAR and proportional increase in PN (due to measurement in CO_2 enrichment) was altered by GD. Under the four GDs, when CO_2 concentration increased from 360 μmol mol^{-1} to 720 μmol mol^{-1}, the WUE of *P. euphratica* all increased accordingly, but the responsiveness of WUE to elevated CO_2 at different GDs varied from each other. When measured with GD at 4.12 m, the WUE of *P. euphratica* always kept increasing with increasing PAR more than 50 μmol m^{-2}s^{-1}, but the change was not significant ($p>0.05$). When measured with other three GDs, the WUE all increased for the CO_2 enrichment under various par conditions except the PAR was 50 μmol m^{-2}s^{-1}, the responsiveness of WUE to elevated CO_2 was strongest at GD 7.74 m, followed at 4.74 m, then 5.54 m. Thus, we draw a conclusion that the CO_2 enrichment can increase the WUE of *P. euphratica* grown in arid environment.

This study demonstrated great diversity in the response of gas exchange to CO_2 enrichment, assessed from the variations of g_s, P_N, WUE under different GDs, in *P. euphratica*. We observed that trees without water stress have weak responsiveness, and that trees with drought stress displayed a strong responsiveness to CO_2 enrichment. We have shown that the availability of groundwater determines the response of photosynthesis to CO_2 enrichment for *P. euphratica* in arid desert area.

Keywords: Groundwater depth, photosynthesis, elevated CO_2 concentration, *populus euphratica*

Groundwater discharge from Mediterranean karst coastal zones in the light of the global climate change

Boris MIJATOVIĆ

E-mail: borismij@eunet.yu

ABSTRACT

In the karstic areas of the Mediterranean coastal zones, vast quantities of groundwater discharge get lost in the sea through carbonate formation. This groundwater discharge and its outcrops – the coastal and submarine springs – represent the most typical and spectacular natural phenomena of littoral karst. The economic potential of these phenomena is significant: according to estimates, the annual groundwater discharging flux is between 25 km^3 and 68 km^3 per year. However, in spite of their great frequency in the Mediterranean basin, there are very few seccessfully realised freshwater tapping projects along the karst coastal zones.

The Mediterranean basin, with its main geologic structures along the coastal zones, consists of heterogeneous and disrupted perimediterranean alpine chains. It includes very well known mountain ranges, such as Dinarides, Hellenides and Taurides. These chains are particularly well known for very large development of carbonate formations (especially limestone and dolomite), responsible for the creation of the famous karst sceneries, the largest and unsurpassed in the crust of the Earth.

With the exception of this geomorphologic phenomenon, the Plio-Quaternary tectonics create a unity in the Mediterranean, through the birth of a neo-oceanic crust. Consequently, in the whole Mediterranean, it is important to emphasize the relationship between global climate change and consequent global modification of groundwater discharge in coastal zones. In this respect the Mediterranean basin is an exellent example for recording formed sea levels of low tidal amplitude and the presence of numerous indicators of ancient shorelines. Namely, the impact of global climate change affects the sea level fluctuation in the coastal zones very strongly. So, for instance, during Quaternary Periods, especially during the last two climatic extremes (LAST GLACIAL MAXIMUM 24000-18000 cal-yr BP and the HOLOCENE OPTIMUM 11500-8500 cal-yr BP), the Mediterranean sea level, first decreasing around more than 100 m during the last glacial maximum; in the subsequent Holocene optimum, the sea level had risen around 120 m, creating so the largest forms of submarine karst along the coastal zones. At present, this is confirmed by evidence of the numerous submarine springs in the wide open Mediterranean littoral, which signifies that the general erosion base of groundwater discharge in the Mediterranean is situated in the karstic belt, between 100 and 150 m below actual sea level.

This case study concerns the problems of freshwater tapping in karst coastal zones. Owing to the geological approach in the analysis and synthesis of available data, a typological classification of coastal reservoirs has been established. It identifies most of the problems arising from the process of localization and tapping facilities. Solutions suggested consist of two most important tasks: (1) the regulation of the groundwater flow, and (2) the control of salt water encroachment in the larger influence zone around the tapping facilities.

Keywords: Mediterranean, Coastal zone, Freshwater tapping.

Karstic aquifers and climatic changes
Moura-Ficalho case study

Augusto T. M. COSTA
Estrada da Portela-Zambujal, Alfragide, 2721-866 Amadora, Portugal, augusto.costa@ineti.pt

ABSTRACT

In southern Europe, decreases in mean annual precipitation and changes in its distribution associated with increases in temperature can lead to significant decrease in recharge of karstic aquifers.

Moura-Ficalho aquifer is the southern karstic aquifer of Paleozoic carbonate rocks (dolomitic rocks and marbles) in Alentejo (south of Portugal). It has 178 Km^2 and the recharge area (carbonate outcrops) is 78 Km^2. `Carbonate rocks are strongly folded by Hercynian orogeny, near NW-SE direction, making three major folds. These are, generally, dipping to NW, where the aquifer is mostly confined by schists and Tertiary overburden. Besides some springs, like Gargalão and Enfermarias, there are underground hydraulic connections with adjacent lithologies in several areas. Smaller aquifers, like "Calcários de Moura aquifer", in Moura town, are dependent on these underground water transfers.

Typical karstic aquifers can be viewed as a double hydraulic conductivity system with two connected flow networks – one characterized by high velocity flow through big karstic conducts and another characterized by low velocity flow through small fractures or openings. Storage capacity is mostly dependent on the small fractures network. The relative importance of both networks in aquifer flow is variable. In Portugal, in a general analysis on karstic aquifers behaviour, it can be stated that in aquifers of Mesozoic carbonate rocks, big conducts flow has major importance, while in those of Paleozoic carbonate rocks, flux through small fractures network is predominant.

The analysis of base flow from springs and piezometric annual amplitudes in Estremoz-Cano and Moura-Ficalho aquifer systems clearly shows the predominance of flux through small fractures system. For this reason, it was possible to calibrate a transient Modflow 2000 model of Moura-Ficalho aquifer for the period from October 2000 until December 2005. This is a two layers model with 48688 cells in each layer where all natural discharges of the aquifer were simulated by drain cells. The only input of water is recharge, assumed to be 38% of precipitation, and some cells of well type exploitation only started in 2004, to simulate new irrigation wells. Major conceptual model characteristics are represented in Fig. 1.

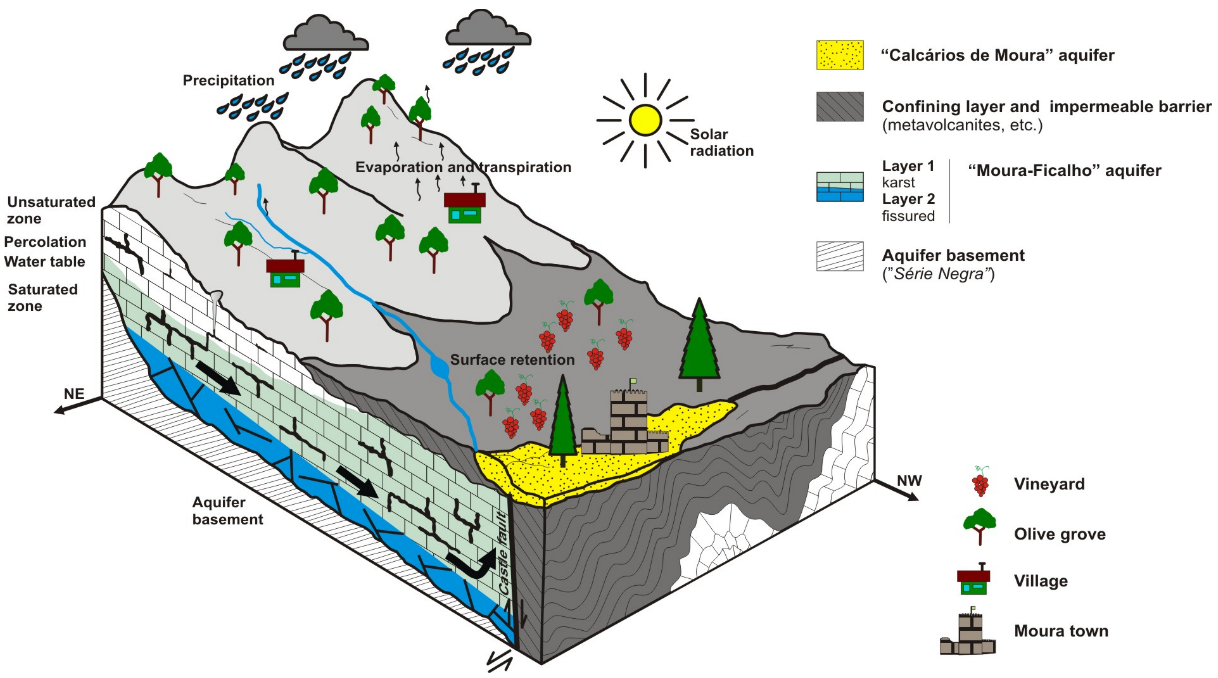

Fig. 1 – Schematic representation of Moura-Ficalho aquifer (major characteristics).

The simulation period includes one wet year (2000/01), three slightly dry years (from 2001 to 2004) and a very dry year (2004/05). The simulation clearly shows that water recharge was not enough to compensate the water lost by the aquifer. This period is considered to be abnormally dry. However, according to predicted climate changes towards dryer weather, this abnormality may well become frequent enough to be accepted as a new rule, especially in this southern part of Portugal. Therefore this scenario can be used to predict the near future behaviour of the aquifer, and can be used as a pilot study area, at least, for all karstic aquifers in the Paleozoic socle of southern Portugal.

The recharge data in this five year period (2000/05) was used to make a projection from 2000 until 2015. The results indicate a general drawdown in water levels, which should result in three major problems:

- Water supply shortage for Sobral da Adiça village (around one thousand people);
- Changes in the humid ecosystem in Gargalão area, and
- Jeopardizing of future thermal establishment, named Termas de Moura.

Water supply for Moura town (9200 people) is not at risk because, recently, new boreholes were made to replace the old system, which was highly vulnerable (two wells with 18 and 20 meters depth). The new ones are 90 and 95 meters depth and the top of the first productive aquifer level is 50 meters deep.

The first problem indicated, can be solved in a similar way as the one developed there to guarantee water supply to Moura town, but this will increase the second problem since both problems occur in Gargalão area. Water supply to Sobral da Adiça uses two wells and, one of them is an open hole well, 18 meters depth, where the productive level is between 4 and 7 meters depth. This well should be replaced by a deeper one, but this and the increasing drawdown on the area, will lead to a decrease in the natural flow rate of Gargalão spring and to turn the permanent small river called Ribeira de S. Pedro into a temporary stream flow (second problem). This will affect local ecosystem (several wild populations) and also people from Sobral da Adiça. Besides this, a new contamination problem can arise by the change of this river regime, from effluent into influent.

Concerning the 3rd mentioned problem, the predicted drawdown can affect the amount of water available by the artesian flowing well inside the castle, which supplies water for the thermal establishment. Since it is an urban area and the artesian flowing water is enough for the establishment, pumping is not used in order to avoid any possible contamination. The artesian flow rate will decrease with the predicted drawdown in piezometric levels, and contamination processes can occur~~,~~ as a result of an inversion of hydraulic potential relationship between adjacent aquifers.

There is no doubt that piezometric levels will decrease and that some natural discharges of the aquifer will dry up and that this process will go on until a new equilibrium is reached. Due to incertitude on the altitude of drains base and conductance, it is not possible to predict which natural discharges will be affected first and to what degree.

To mitigate the predicted consequences of recharge decrease it is suggested to artificially increase the natural recharge by building recharge wells, similar to the one represented in Fig. 2.

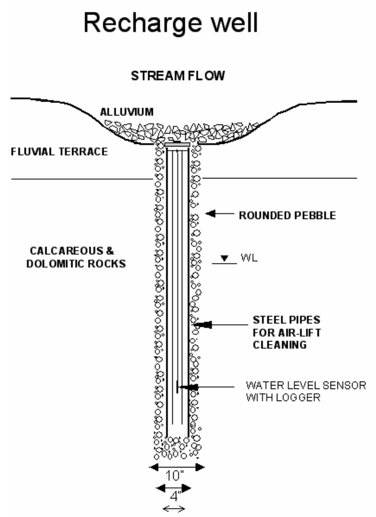

Fig. 2 – Schematic project for the recharge well.

A major problem with recharge wells is the obstruction with fine sediments. So the proposed well will have a cleaning system made of an air-lift column. This column will be closed at the top with a suspended level logger system and buried with the natural pebbles of the alluvium, being the top cover at the level of alluvium sediments basement. This way it is expected to have no problems during floods or high flow rate periods.

At least once a year, at the same time as level data is going to be collected, the top cover is opened and an air compressor will be connected to the injection pipe making the cleaning work necessary. The effectiveness of each recharge well is evaluated with the collected level data. It should be pointed out that this is not an artificial recharge well. In fact it is an artificial system to increase natural recharge as the well will be similar to natural sinkholes existing in the area, which are more or less obstructed with sediments. The major difference is that it will be equipped with an air-lift cleaning and level control system.

Four recharge wells that were added in strategic places in the flow model of the aquifer, showed results.

It is expected to mitigate consequences of climate change on this aquifer in real life as well.

Keywords: Karstic aquifer, Modflow model, double hydraulic conductivity, groundwater flow, recharge well.

Management Implications of Wetland Vegetation Response to Climatic Change and Groundwater Drawdown on the Swan Coastal Plain, Western Australia

[1]Robyn C LOOMES, [1]Ray H FROEND

[1] Centre for Ecosystem Management, Edith Cowan University, Joondalup, Western Australia, 6027, Australia.
email: r.loomes@ecu.edu.au, r.foend@ecu.edu.au

ABSTRACT

The Gnangara Groundwater Mound, a shallow unconfined aquifer, underlies 2140 km^2 of the northern Swan Coastal Plain (SCP) on the seaboard of south-western Australia. In the Mediterranean-type climate of the SCP, the aquifer is recharged during the winter and drawdown occurs during the summer. Groundwater abstraction from the aquifer has increased significantly since the 1970's in response to climate-induced rainfall decline and increased demand. The aquifer currently meets domestic, horticultural, industrial and commercial needs as well as supporting a vast array of groundwater dependent ecosystems (GDEs), including wetlands, terrestrial phreatophytic vegetation, base-flow systems and cave pool/ streams. Increased groundwater abstraction and reduced recharge (due to decreasing annual rainfall) in recent years have led to declining groundwater levels across the Gnangara Mound and increasing drought impacts on GDEs. Consequently, there has been increased evidence of ecological change and degradation in dependent ecosystems.

In the mid 1990's, in recognition of the potential for ecological impacts from reduced rainfall and increased groundwater abstraction, the Western Australian water resource management agency implemented a long-term biological monitoring program for GDEs. As some 400 wetlands occur across the Gnangara Mound, and most are direct expressions of the superficial aquifer, wetlands have become the chief focus of the program. The wetlands in the region range from shallow semi-permanent lakes to seasonally waterlogged damplands with no surface water expression. Monitoring of wetland vegetation has become a consistent indicator of wetland response with vegetation composition, abundance and condition assessed annually for up to 11 years at 19 permanent transects across 14 wetlands of differing geomorphology, hydrology, vegetation condition and disturbance regimes.

Analysis of this long-term data set has shown varying responses of wetland vegetation to groundwater drawdown. Analysis of vegetation and hydrological data considered vegetation responses recorded at sites within close proximity to abstraction bores and those further afield to determine if variations are due to differing drawdown pressures or other factors such as disturbance events. There are response patterns that appear to be the result of groundwater abstraction, reduced rainfall recharge or the cumulative impacts of both.

To-date many wetlands have shown a proportional response under which a progressive change in vegetation condition has corresponded with a progressive groundwater level decline. Progressive changes are typified by gradual alterations in species composition and structure through weed species invasion, encroachment of terrestrial species and reductions in cover and abundance of species most susceptible to water level decline, sometimes resulting in local extinction of these species. Although a smaller number of wetlands have shown little to no change, other wetlands have undergone dramatic, apparently irreversible changes once a particular threshold has been exceeded. The most notable changes have occurred where a wetland has dried gradually over a number of years and is then exposed to a disturbance event such as summer wildfires. The build up of dry plant litter in the wetland basin, combined with dried, exposed organic sediments provides a substantial fuel load which continues to smoulder for months once ignited, resulting in the complete destruction of wetland tree roots and loss of littoral and fringing species. In contrast, summer fires in wetlands that have not dried as extensively, merely provide an ash bed which enhances propagation of wetland species.

It is evident that the type and rate of vegetation response to groundwater decline will vary according to historic water regime changes, the existing ecohydrological state of the wetland and the potential for cumulative disturbance events. These factors need to be considered by water resource managers as they will influence the degree of wetland vegetation resilience, determining ecosystem capacity to recover if groundwater levels return to historic levels or if the character of the ecosystem is altered irreversibly. However, the question remains; At which point should groundwater decline-induced changes in wetland vegetation structure, composition and condition trigger a management response?

This paper describes the outcomes of eleven years of vegetation monitoring, examining the degree and rate of change of vegetation in wetlands of varying geomorphology, hydrology and disturbance regimes, and identifies ecological thresholds that, once reached, should trigger a management response.

***Keywords*:** Climate change, groundwater drawdown, wetland vegetation, ecological response, thresholds

Present-day and Holocene groundwater fluctuations in Bus de la Spia – Acquasanta karst system and their impact on the formation of hypogean calcareous tufa

[1] Andrea BORSATO, [1] Silvia FRISIA, [2] Klaas VAN DER BORG

[1] Museo Tridentino di Scienze Naturali, Via Calepina 14, I-38100 Trento, Italy; borsato@mtsn.tn.it, frisia@mtsn.tn.it, miorandi@mtsn.tn.it
[2] Department of Sub-Atomic Physics, Universiteit Utrecht, Pleinlan, Postbus 8000, Utrecht, The Netherlands; K.vanderBorg@phys.uu.nl

ABSTRACT

Bus de la Spia cave (Alps of northern Italy) is a temporary valclusian spring, and consist of a 400 m long downdipping gallery that reaches the present-day groundwater level at –55 m from the entrance. The main gallery continues several tens of meters below the groundwater level, and is hydrologically connected to the Acquasanta karst spring (mean discharge 400 $l \cdot s^{-1}$) located 1.1 km from the cave entrance.

In winter, the groundwater level in the cave oscillates cyclically several meters 3 to 12 times per days (Fig.1) due to the presence of a self-priming syphon system that controls both the groundwater level in the cave and the spring discharge. In fact, Acquasanta spring displays identical sub-daily discharge fluctuations with a delay of about 40 minutes with respect to the groundwater level in the cave. During the snowmelt, the base level of the groundwater rises about 10 m and the sub-daily cycles are replaced by daily cycles that follow the air temperature cycles at the surface (Fig.1). During this period, intense rainfall events result in the groundwater level rise of several tens of meters, and the strongest episodes cause the complete flooding of the cave, and the water flows from the cave entrance for a few days. This phenomenon at present occurs 2 to 4 times per decade.

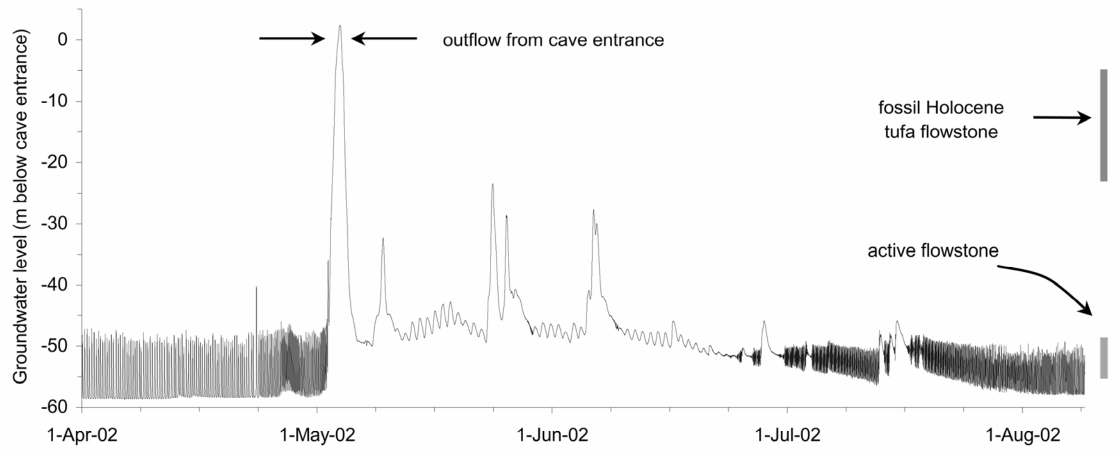

Fig. 1. Groundwater level fluctuations during the 2002 warm season with respect to the fossil and active calcareous tufa deposits.

The groundwater sub-daily fluctuations promote the formation of calcareous tufa flowstone in the inner part of the cave, within the winter groundwater level fluctuation zone (cfr. Fig.1).

Hypogean calcareous tufa is a porous speleothem that typically forms near cave' entrances, in the presence of high water discharge, and consists of calcite laminae mostly composed by inorganic layers alternated with microbially- and bio-mediated micritic layers. Another fossil calcareous tufa flowstone, 0.5 m-thick, coats almost entirely the 50 m-long downdipping entrance gallery, and is located 30 to 50 m above the present-day mean groundwater level (cfr. Fig.1).

We studied this fossil deposit along a 0.45 m long core dated between 11 kyr and 4 kyr BP by means of several ^{14}C AMS analyses complemented by annual laminae counting. Because the growth rate of the tufa flowstone depends mainly on the water availability, we utilized the growth rate calculated from the laminae thickness to gain insight on the hydrological variability during the Early and Middle Holocene. Two major depositional phases have been recognized. The first phase, from 11,000 to 8,500 cal. yrs BP, is characterized by higher rainfall and higher inter-annual variability, which indicates that complete flooding of the cave probably occurred several times during the year, thus promoting calcareous tufa deposition.

In the second phase, from 8,500 to 5,000 cal yrs BP, the rainfall diminished slightly but the inter-annual variability decreased significantly. Finally, from ca. 4900 cal. yrs BP onwards, a sudden decrease in growth rate suggests a progressive lowering of the groundwater table, followed by the near-starvation of the flowstone that occurred soon after 4,500 cal. yrs BP.

Keywords: calcareous tufa, karst spring, groundwater fluctuations, sub-daily cycles, Holocene

TOPIC 11

Impact of climate and global changes on groundwater dependent ecosystems

Evaluating the impact of climatic change on groundwater resources of the Ebre river basin using GIS and hydrologic models

[1] Javier Samper, [1] Diego Álvares, [1] Bruno Pisani,,[2] Miguel Angel García Vera

[1] Escuela de Caminos, Universidad de A Coruña, España, e-mail: jsamper@udc.es
[2]Confederación Hidrográfica del Ebro, Ministerio de Medio Ambiente, España, e-mail: mgarciave@chebro.es

ABSTRACT

This paper presents the evaluation of the impact of climate change on groundwater resources in several Ebre River basins. The calibration period runs from 1970 to 2000. Impact of climatic change was simulated for several periods: 2010-2040, 2040-2070 and 2070-2100 using predictions for scenarios A1B, A2 and B1 of IPCC and scenario Commit of Canadian Centre for Climate Modelling and Analysis. Projection outputs of Global Climate Model CGCM3 were used for each selected scenario. A routine GENBALAN was developed to perform statistical downscaling of CGCM3 monthly results for simulation periods. Downscaled monthly values were later de-aggregated into daily series.

Projected average precipitation decreases 8.9%, 15.0% and 14.2% for simulations periods of 2010-2040, 2040-2070 and 2070-2100, respectively. Projected increase in annual average temperature are 1.7ºC, 2.8ºC and 3.6ºC for each simulation period, respectively. Figure 1 shows the prediction results of changes in precipitation and temperature for each scenario and each simulation period for one of selected basins (Alcanadre).

A semi-distributed hydrologic model, GIS-BALAN, was used to perform water balance in selected basins. The model was calibrated first with measured flow rates in the calibration period from 1970 to 2000. In general, the model fits measured annual and monthly streamflows well.

Estimated average decrease in total streamflow in selected basins is 16.2%, 23.1% and 18.5% for simulation periods of 2010-2040, 2040-2070 and 2070-2100, respectively (Fig. 2). Streamflows increase in the last simulation period because precipitation predicted with CGCM3 increases in that period.

Results of the climate change impacts assessment show strong space-time variations (Fig. 3). Impact of climate change will be more severe in Southern Ebre basins which at present show more intense water shortage. Our contribution addresses the main sources of uncertainty related to climate change predictions as well.

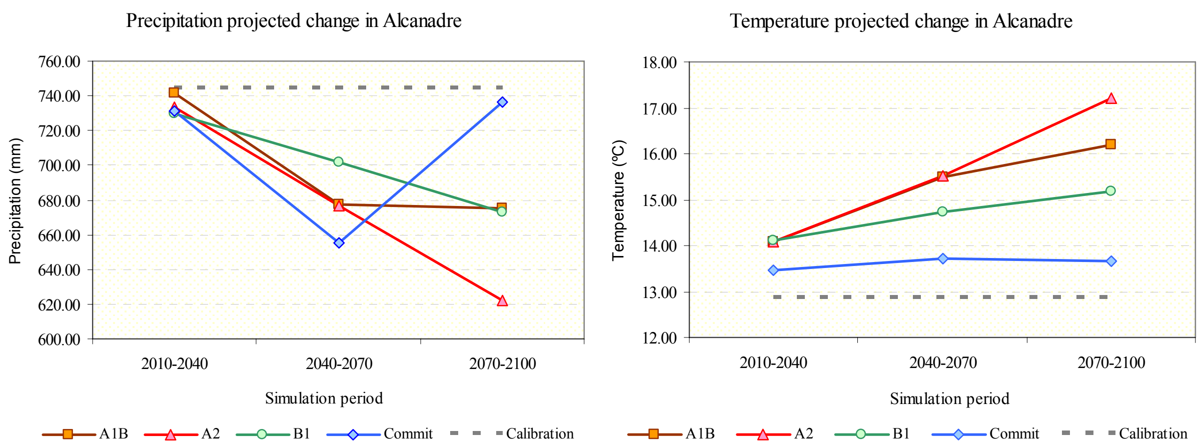

Fig. 1. Changes in precipitation and temperature for different scenarios and simulation periods in Alcanadre basin.

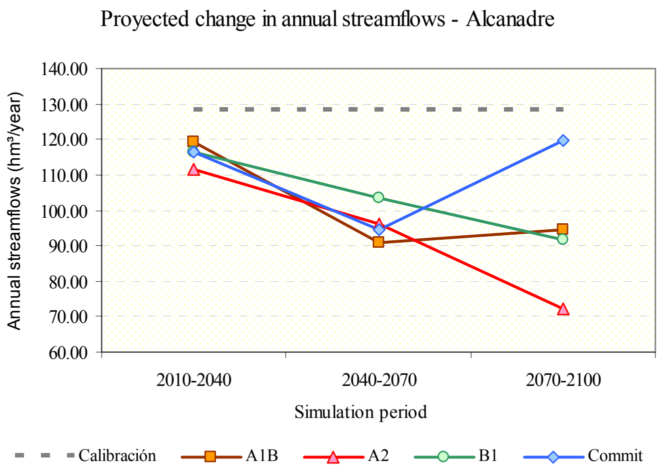

Fig. 2. Streamflows impacts due to climate change in Alcanadre basin.

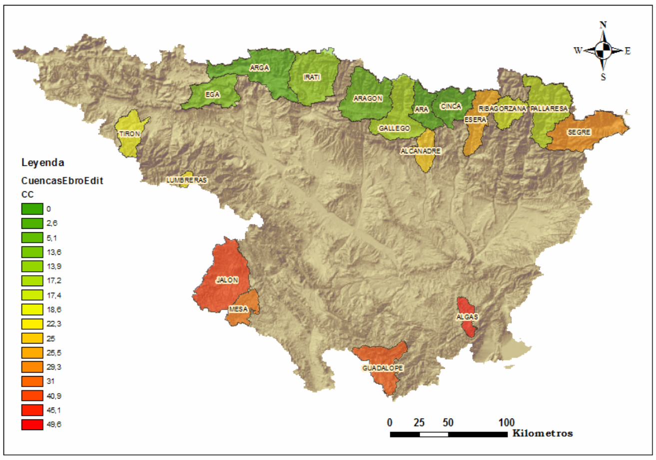

Fig. 3. Decrease in streamflows (%) in the simulation period (2070-2100) compared to the calibration period (1970-2000).

Keywords: GIS-BALAN, hydrologic model, climate change impacts

Impacts of the climatic changes on the water resources in the plain of Mejjate (Tensift-Haouz Basin, Morocco)

Karima ABDELOUARITH, Younes FAKIR.

Laboratory GEOHYD, Department of Geology, Faculty of Science Semlalia, PB 2390,
40000 Marrakech, Morocco.
Email: karima_abdelouarith@yahoo.fr , fakir@ucam.ac.ma.

ABSTRACT

The plain of Mejjate belongs to the western part of the plain of Haouz (basin of Tensift, Morocco). It has a continental and arid climate. The surface water network is represented by the rivers (wadis) of Tensift, Chichaoua, Seksaoua and Assif El Mal. Two principal aquifers are targeted: the unconfined alluvial Plioquaternary layer and the deep layer of cretaceous limestones.

The principle objective of this work is the description of the impact of the climatic changes on the evolution of the system of the water resources in the area. The analysis of the hydroclimatic data was established mainly by the method of moving average, applicable to assess the principal tendencies in the time series data.

The study of the tendencies in the pluviometric series show that several synchronous periods of drought appear at the various climatic stations. The longest one extends between 1973 –1993 and is characterized by a deficit of approximately 50 %. Few rainy years intersect these periods and contribute to reduce the existing hydraulic deficit.

The analysis of the average, maximum and minimal temperatures indicated a clear upward trend. They highlighted a reheating of 1.2°C since 1982.

The tendency in the monthly average hydrological data of the principal wadis showed a reduction in the volume of runoff during the summer and an increase in winter, thus marking a clear correlation with the precipitation. The time series of the annual runoff is marked by a long period of drought between 1973-1987 and 1991-2005 with a remarkable rise of the flows rate in 1996-1997 (exceptional rainy year).

In the monthly average series of the spring's flows, the dry period extends from May to October. The high waters are between December to April. The variability index (I) which oscillates between 2 and 10, showed that the flow rates of the springs are slightly variable. The resurgence of Abainou (526 l/s) is marked by the most stable flow rate $1<I<2$, which may be explained either by a weak effect of the rain flow recharge or by a significant regulating of the aquifer concerned.

The tendencies in the piezometric series showed that the groundwater levels have been dropping since 1985, by 4 m to 15m.

The reduction of the hydraulic potentialities in the area can be related, amongst other possible causes, to the climatic changes. The latter are marked by the increase of the temperatures and the rainfall reduction. To face the increasing need for water and insure a sustainable development of the local population, new resources are being investigated along with new water management strategies.

Keywords: climatic changes, moving average, water resources, plain of Mejjate, basin of Tensift, Morocco

Mitigation of Impacts on Groundwater Dependent Vegetation Through Adaptive Abstraction Regimes.

[1]Muriel BERTUCH, [1]Ray H FROEND, [1]William STOCK, [2]Derek EAMUS, [3]Keith SMETTEM, [4]Michael MARTIN, [4]Chengchao XU, [5]Sandie MCHUGH, [1]Caroline CANHAM

[1]Centre for Ecosystem Management, Edith Cowan University, Australia, e-mail: m.bertuch@ecu.edu.au, r.froend@ecu.edu.au, w.stock@ecu.edu.au, cacanham@student.ecu.edu.au
[2]Department of Environmental Sciences, University of Technology Sydney, Australia, e-mail: derek.eamus@uts.edu.au
[3]School of Environmental Systems Engineering, University of Western Australia, Australia, e-mail: keith.smettem@uwa.edu.au
[4]Water Corporation of Western Australia, Australia, e-mail: Michael.Martin@WaterCorporation.com.au, Chengchao.Xu@WaterCorporation.com.au
[5]Department of Water, Western Australia, Australia, e-mail: sandie.mchugh@water.wa.gov.au

ABSTRACT

A drying climate coupled with altered land use and increased abstraction for public and private water supply, has led to the need to mitigate the environmental impacts of groundwater development. The consequences of unsympathetic and excessive groundwater abstraction from the Gnangara Mound on the Swan Coastal Plain (SCP) of Western Australia, has lead to a general decline in groundwater levels over the last 30 years. Much of the Mound is overlain with phreatophytic *Banksia* woodland that is susceptible to prolonged separation from the unconfined aquifer over the hot, dry Mediterranean summer. As community and industry demand for groundwater are highest during this time of the year, current bore field operation is often in conflict with environmental needs.

The consequences of excessive summer drawdown on phreatophytic *Banksia* woodland have been recorded several times over the last 22 years. The first was during the summer of 1985 in Whiteman Park adjacent to the Wanneroo and Mirrabooka bore fields. Then during the summer of 1990/91, following two dry winters and a period of extreme hot weather conditions, extensive tree decline was observed near the Pinjar bore field. As the *Banksia* woodlands of the SCP are considered functionally important in providing food, shelter and nesting resources for fauna sustainable management of water resources is imperative. This has resulted in constraining the use of existing bore fields. Therefore, in response to statutory water level criteria set by the Department of Environment, currently over 40% of the Water Corporation of Western Australia's superficial bores (for public water supply) are turned off in 'high risk' areas of shallow groundwater.

Whilst the precautionary response is valid, the loss of production from existing bore fields due to environmental risk and regulation represents a significant economic loss to the water providers and industry. Therefore modification of bore field operation strategies to be sympathetic to, rather than in competition with environmental demand offers benefits for sustainable operation of existing bore fields and provides for opportunistic resource utilisation. The types of bore operation modifications proposed for this research include altering the timing of abstraction as well as the magnitude and rate of drawdown to avoid times of peak environmental demand. It is hoped that this will significantly reduce the risk to phreatophytic *Banksia* woodland by allowing adaptation of the phreatophytes to a lower water table. There is potential to recover >5GL/year from existing bore fields, if it can be demonstrated that resource use from 'high risk' areas is possible without degradation of dependent ecosystems.

A series of research sites, with initial depth to groundwater of <5m have been established both adjacent to and distant from, two existing abstraction bores within *Banksia* woodland on the SCP. Sites with <5m depth to groundwater are currently considered at 'high risk' from an environmental impact perspective. It should be noted that the existing abstraction bores in the research area are currently turned off due to environmental regulation. However, in collaboration with the environmental regulator, selected bores will be allowed to operate at a reduced capacity for the research to take place. Exact pumping rates and water table response were determined by a pumping test during late 2006 and abstraction is due to begin in June 2007.

Prior to site establishment the stratigraphy of the sites were characterised to ensure a degree of similarity between sites. Neutron access tubes and groundwater monitoring wells are being used to obtain regular data on soil moisture conditions and water levels. Individuals of *Banksia ilicifolia* (obligate phreatophyte) and *Banksia attenuata* (facultative phreatophyte) have been monitored since late 2006. Both soil and *Banksia* stem segments are also collected for isotope analysis in an attempt to discriminate water source use for the trees. Further rationale behind this experiment and its current outcomes will be discussed.

Keywords: adaptive abstraction, phreatophytic vegetation, groundwater, changing climate, *Banksia* woodland.

Palaeoenvironmental development of the Quiaios – Tocha dunes based on geological and palynological investigations

[1]Ana Maria CASTILHO, [2]Randi DANIELSEN, [3]Pedro DINIS

[1] Centro de Geociências, Earth Sciences Department, University of Coimbra, P-3000-272 Coimbra, Portugal; e-mail: amcastil@dct.uc.pt

[2] Universidade de Minho/ Instituto Português da Arqueologia (IPA) (Laboratório de Paleoecologia e Arqueociências), rdanielsen@yahoo.com

[3] Centro de Geociências, Earth Sciences Department, University of Coimbra, P-3000-272 Coimbra, Portugal; e-mail: pdinis@dct.uc.pt

ABSTRACT

The coastal region between Cape Mondego and Mira is characterized by its recent sand dunes and former late Pleistocene to Holocene aeolian deposits.

A string of shallow lakes is found at the transition between the younger E-W oriented dunes, to the west, and the Gândara plain with Pleistocene aeolian sands, to the east. The Quiaios Lakes (Braças, Vela, Salgueira, Teixoeiros) are shallow, freshwater lakes currently under hydrogeological and palynological investigation.

During a borehole network installation all relevant geological, hydrogeological and palynological information has been listed and samples collected for laboratory analyses. The interdisciplinary investigation of these palaeosoils has revealed information on the hydrological and vegetational environmental dynamics. Few of the samples are dated so far and temporal relations between layers are not well known. However, facies similarities between deposits suggest temporal relations.

From the analyses of the borehole data it is possible to consider two distinct geological successions at the western and eastern locations.

At the eastern fringe over the Upper Cretaceous basement the sediment fill comprises, from the top to the bottom, non-podzolized aeolian sand, podzolised aeolian sand with lenses of palustrine organic rich mud and coarse sands or muddy coarse sands.

The palynological results show an early phase of forest dominance followed by deforestation and the development of an open heathland that prevailed until the reforestation in the last 2 to 3 centuries.

The pollen content of the podzolised upper mud layers reflect a habitat of extensive wetland systems dominated by heathland scrubs like Ericaceae species and Cistaceae. This vegetation was dominant in the area during the formation of the Quiaios lakes. Paludification of the Vela and Braças wetland system started around 1630 BP (Cal 420 AD), the lakes initially being shallow, oligotrophic seasonal basins, inundated in the wet seasons. An increase in lake level and proper lake genesis is only found in the last centuries.

The palustrine organic rich mud, further down in the sediment column, stems from an older period of forest vegetation. The forest seems to have been dominated by pines. There are many indicators of grazing and agriculture in some of the forest soil samples pointing towards anthropogenic influence as an important factor in the deforestation process that resulted in the above mentioned open heathland.

In general, in the western locations, the Quaternary record is exclusively of aeolian sands over beach and fluvial sediments. However, along most of the coastline, in a zone near the coast, until around 1 km inland, a brackish lagoonal mud deposit is found. It is usually under aeolian sands and above beach sands and may be intercalated with wash-over fans deposits.

Palynological records from this lagoonal deposit indicates that the surrounding vegetation was a mixed pine/oak forest. Pollen from local hygrophilous vegetation is also indicative of a brackish environment, in accordance with malacological investigations of similar deposits from southern locations (Leirosa beach).The origin of the brackish mud deposits is probably from an extensive lagoon or many smaller lagoon systems, protected behind a sand barrier that was created during the Flandrian transgression.

The result of the geological, hydrogeological and palynological investigation was used to make a 3D conceptual model of the palaeoenvironments present at the Quiaios coastal area.

Keywords: Lagoons, Palaeoenvironment, Hydrogeology, Palynology

Potential Climate Change Impacts on the Groundwater Resources in the Upper Danube Watershed - a Scenario Case Study using the DANUBIA Decision Support System

[1]Roland BARTHEL, [2]Wolfram MAUSER, [2]Ulrich STRASSER, [3]Ralf LUDWIG,
[4]Winfried WILLEMS, [5]Barbara FRUEH

[1]Institute of Hydraulic Engineering, Universitaet Stuttgart, Germany (roland.barthel@iws.uni-stuttgart.de),
[2]Faculty for Geosciences, Ludwig-Maximilians University (LMU), Luisenstr. 37, D-80333,
[3]Institute for Geography, University of Kiel, Germany,
[4]Institute for Applied Water Resources Management and Geoinformatics IAWG, Ottobrunn, Germany,
[5]Institute for Meteorology and Climate Research, University of Karlsruhe, Germany

ABSTRACT

To understand and predict the potential effects of climate change on water resources in general and, in particular, on stream flow, groundwater discharge, groundwater levels and wetland ecology, it is necessary to be aware of the complexity of the interactions between climate and the land surface, and to consider the influence of the scale on which these interactions are investigated. In mountainous watersheds and their forelands, the hydrological situation is particularly complex because of lateral flows which are of considerable importance. To be able to realistically simulate the impact of different scenarios of future climate change on the water cycle of such sites, physically based hydrologic models with high predictive ability are necessary. Within the GLOWA-Danube project the physically based Global Change decision support system DANUBIA was developed, with the aim to minimize external calibration and thereby maximize predictive capabilities.

The DANUBIA system is applied on the Upper Danube catchment (with an area of 77,000 km^2 until the gauge at Passau) in which groundwater is the main source of drinking water (with a share of roughly 90 percent) and contributes more than 50% to industrial water use. Groundwater discharge is also the main source of river discharge in dry summer periods – which, according to recent IPCC predictions, will become even longer and dryer in the near future.

Climate scenarios in DANUBIA are based on a stochastic procedure to derive long time series of synthetic future climate data from measured historical records. The stochastic procedure is used to create realizations of future climate scenarios since regional climate models still fail to provide high resolution precipitation fields for mountainous regions at reasonable CPU costs. To compile a future meteorological data set spanning the next 100 years, the procedure considers measured relations between temperature and rainfall, applies a random variation of temperature, overlays the trend, and selects the appropriate time slice from the given basic population of measurements (34 years of DWD - German Weather Service - recordings). The stochastic climate generator was applied to the 77,000 km^2 Upper Danube catchment (gauge Passau). DANUBIA calculates the energy and water balances, as well as discharge, with a temporal resolution of 1 h and a spatial resolution of 1 km. In our case study, we compare DANUBIA model runs for a 35 year period based on an IPCC B2 type scenario (which predicts a temperature increase of 2.7 K until 2100) to: a) a reference period (1970-2003) and b) a 'worst case scenario' composed of a sequence of very dry years.

Our investigation mainly focuses on the simulated changes of the groundwater system with respect to drinking water supply and ecological aspects (low flow – droughts, wetland depletion). Even if the stochastic climate generator has some obvious deficiencies as a tool for creating regional climatic scenario input and the DANUBIA system still needs improvement, results indicate that climate change will probably not be an immediate threat to the groundwater based water supply system of the Upper Danube catchment – since it is a water rich region – within the next 25 years, even under relatively extreme conditions. More alarming seems to be the increasing number and severity of low flow situations that was determined in the scenario simulations. According to the hydrological simulation, the changing climatic conditions of the IPCC B2 type scenario may lead to slightly less groundwater recharge and, as a consequence, to declining groundwater levels. However, the changes show a strong spatial pattern and temporal variability, partly because of the regional and seasonal climate change patterns and partly because of the different hydrological and hydrogeological conditions. Such assessment and understanding of the variability and dynamics of groundwater resources is crucial for their sustainable management under future changing conditions.

Keywords: climate change, groundwater recharge, groundwater model, hydrological model, Danube river basin, DANUBIA

TOPIC 12

EU Water Framework Directive and groundwater daughter directive ecological requirements: management and economic tools to protect groundwater

A geohydrological basis for assessing risk, monitoring requirements and ecological sensitivity for groundwater dependent wetlands for management purposes under the Water Framework Directive

[1]Garrett KILROY, [1]Catherine COXON, [1]Paul JOHNSTON, [2]Donal DALY, [2]Matthew CRAIG, [3]Jim RYAN, [3]Áine O'CONNOR, [4]Fiona DUNNE, [5]Henning MOE

[1]Trinity College Dublin, Ireland, e-mail: kilroygg@tcd.ie, cecoxon@tcd.ie, pjhnston@tcd.ie
[2]Environmental Protection Agency, Dublin, Ireland, e-mail: d.daly@epa.ie, m.craig@epa.ie
[3]National Parks & Wildlife Service, Dublin, Ireland, e-mail: jim_ryan@environ.ie, aine_o'connor@environ.ie
[4]Consultant Ecologist, Dublin, Ireland, e-mail: fiona.dunne@imagine.ie
[5]CDM Consulting Engineers, Dublin, Ireland, e-mail: MoeH@cdm.com

Introduction

Objectives under the European Union Water Framework Directive (WFD) include the requirement that anthropogenic pressures shall not result in any "significant damage" to wetlands or specifically groundwater dependent terrestrial ecosystems. The ecology of groundwater dependent wetlands is fundamentally reliant on the supporting hydrogeology. Therefore, ecological damage in these wetlands is frequently reflected in corresponding changes in that hydrogeology. Understanding this ecohydrological connectivity is basic to the management of these wetlands under the WFD.

In this study three case examples of contrasting wetland types common in Ireland (raised bog, fen and turlough) were examined to identify their ecohydrological connectivity and so develop their monitoring and management requirements under the WFD. This paper arises from a project to develop a national framework for monitoring and managing groundwater dependent ecosystems. The evaluation of damage will require a clear understanding of the water supply mechanisms of different wetland types to know where and what to monitor and the identification of key ecological indicators to evaluate the condition of the wetland. Monitoring is required not only to assess the condition of the habitats but also to identify likely causes of damage and to monitor the efficacy of mitigation measures.

Conceptual Framework for the Management of Groundwater Dependent Wetlands

The development of sound conceptual models for different wetland types is an essential starting point for understanding and managing wetlands. Subsequent monitoring will help validate or modify these conceptual models so that they become refined during the WFD the river basin management cycles. The groundwater requirements of different wetlands will include quantifiable metrics such as groundwater flow, groundwater level and chemical flux. However, there are few detailed studies in Ireland that relate these metrics to quantifiable responses in the wetland ecosystems. The few studies that do exist will be essential for guiding the development of conceptual models for the first WFD river basin cycle. Three contrasting wetlands typical of the Irish environment are examined here as a basis for developing a conceptual framework for managing groundwater dependent wetlands. All three wetlands have been studied intensively, the water supply mechanisms are reasonably well understood and all contain priority habitats in Annex I of the Habitats Directive. Table 1 below sets out the relevant habitats and groundwater attributes of each wetland.

Table 1 Groundwater attributes of three different wetlands.

Wetland	Relevant Habitats	Groundwater flow contribution to wetland (Low-high)	Variability of groundwater level (Stable-Dynamic)	Sensitivity to chemical changes (low-high)
Peterswell Turlough	Turlough	High	Dynamic	Moderate
Clara Bog	Active raised bog	Low	Stable	Low
Pollardstown Fen	Alkaline fen, Cladium fen, Petrifying springs	High	Moderate Stability	Moderate-high

Peterswell Turlough (a groundwater-fed temporary lake) is a Special Area of Conservation (SAC) located in Co. Galway and situated in a Carboniferous Limestone karst aquifer. Clara Bog is an SAC located in Co. Offaly and situated in a glacial till basin underlain by a poorly productive Carboniferous Limestone aquifer. Pollardtsown Fen is an SAC located in Co. Kildare and situated in a sand and gravel aquifer.

A conceptual framework for the management of groundwater dependent wetlands under the Water Framework and Groundwater Directives is provided in Fig. 1. The three axes aim to incorporate the main hydrogeological and hydrochemical attributes of groundwater dependent wetlands required for their management under these directives. The relative groundwater contribution to the wetland (x-axis) can be calculated by carrying out a water balance and will, for example, be more important for fens than bogs. The variability of groundwater level (y-axis) can be measured through changes in water table and expressed as a coefficient of variation. The sensitivity to chemical changes (z-axis) in the groundwater discharging to a wetland will be determined by the chemical conditions needed to maintain a habitat in a favourable condition. The Ellenberg index, for example, could be used as a metric for the nutrient requirements of different habitats. The sensitivity and groundwater dependency of a wetland increases along the three-dimensional red line, which integrates all three axes. The location of a habitat within this cube can inform the key monitoring and management issues for different groundwater dependent wetland types.

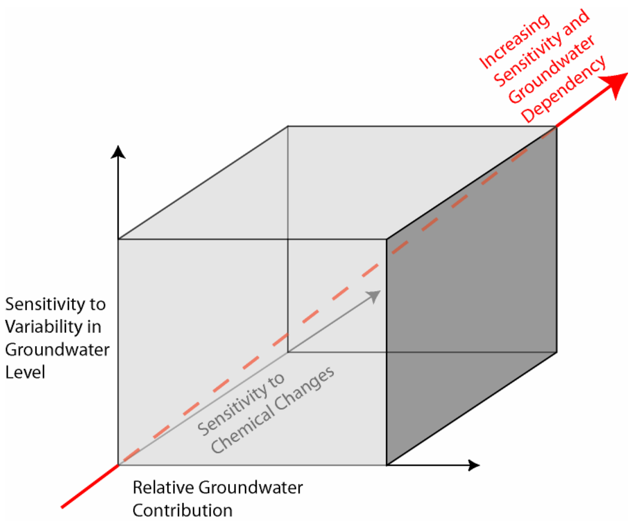

Fig. 1 Conceptual framework for managing different groundwater dependent wetlands for the Water Framework Directive. The location of a particular wetland within this cube will be determined by its groundwater needs in terms of relative contribution, variation in groundwater levels and sensitivity to chemical changes in groundwater.

The relative position of the three study wetlands in this conceptual framework will be determined by their groundwater attributes listed in Table 1. This study examines the field data from these groundwater dependent wetlands to test this conceptual framework and provide a basis for their monitoring and management.

Conclusions

The proposed conceptual framework is being developed and tested using data from the three study wetlands. The degree of dependency and sensitivity to groundwater will dictate different monitoring and management strategies. The hydrogeological monitoring of raised bogs may focus particularly on the lagg zones that fringe the bogs whereas fens are more directly dependent on groundwater and require monitoring along the flow lines to the supply points. The hydrogeological monitoring needs of turloughs will vary depending on the degree and nature of the karstification, the presence of epikarst and connectivity to surface water sources. Ecological monitoring will need to take into account the complexity of each wetland so as to provide key indicators of the habitats sensitivity to groundwater inputs. The evaluation of the risk to these ecosystems depends on identifying relevant sensitive species and their relationship to corresponding hydrological indicator characteristics.

Keywords: Groundwater Dependent Terrestrial Ecosystems, Wetlands, Monitoring, Management Framework

Case studies supporting the derivation of natural background levels and threshold values in European groundwater

[1] Klaus HINSBY and [2] M. Teresa CONDESSO DE MELO

[1] Geological Survey of Denmark and Greenland (GEUS), O. Voldgade 10, 1350 Copenhagen, Denmark.
E-mail: khi@geus.dk

[2] Geosciences Department. University of Aveiro. Campus Universitário Santiago. P-3810-193 Aveiro. Portugal.
E-mail: tmelo@ua.pt

ABSTRACT

A methodology for deriving natural background levels and threshold values for assessment of groundwater chemical status as requested by the EU Water Framework and Groundwater Directives was developed as part of the EU research project "BRIDGE" and applied in more than 20 groundwater bodies in 14 case studies. The investigated groundwater bodies were selected to represent as many aquifer typologies, climate settings and European ecoregions as possible among research sites of the project group that included partners from 17 EU countries. The selected case studies include transboundary groundwater bodies, EU Pilot River Basins and other important groundwater systems. Some are known to interact with dependent ecosystems, while others do not have any significant interaction. The proposed method derives groundwater threshold values from natural background levels for groundwater and environmental quality standards for groundwater dependent aquatic ecosystems (or groundwater itself using drinking water standards as EQS values). Results demonstrate that the proposed methodology is operational and may be used to protect human health and the environment. Further, they show that groundwater threshold values derived based on environmental objectives for dependent ecosystems may be much lower than drinking water standards, e.g.for nitrate.

Keywords: groundwater, threshold values, ecosystems, nutrients, pollutants

Comparison between different implementation WFD strategies and their implications in groundwater Daughter Directive

[1]Ester VILANOVA, [1]Salvador JORDANA, [1]Jordi GUIMERÀ, [2,3]Teresa CONDESSO DE MELO

[1]ENVIROS-SPAIN, Passeig de Rubí, 31, Valldoreix (08197), Spain, e-mail: evilanova@enviros.biz
[2]ELMAS, Departamento de Geociências da Universidade de Aveiro, Aveiro, Portugal
[3]Instituto Superior Técnico, Lisboa, Portugal, e-mail: tmelo@ua.pt

ABSTRACT

Water Framework Directive Article 5 (WFD, 2000/60/CE) and Annex 2 requires that every Member State should carry out (before December 2004) a review of the impact of human activity on the groundwater status. WFD also sets out the criteria for developing this analysis in every river basin district lying within their national territory. Using the information about the magnitude and the type of pressures, each Member State had to identify the groundwater bodies at risk of failing to achieve the environmental objectives. As a result, a management plan and a programme of measures must be produced nine years after the date of entry into force of the Directive.

The first phase of WFD implementation has been carried out simultaneously with the development of the necessary legislation and in part this explains the wide diversity and the difference in quality of the implementation that has been checked in a preliminary analysis. In this context, on the 12th December the Directive 2006/118/CE on prevention and control of groundwater pollution and, in particular, setting measures for assessing the chemical status of groundwater and measures to reduce the presence of pollutants, came into force. This directive is called the Daughter Directive or the Groundwater Directive and it has not been transposed yet in most of the Member States regardless of the fact that it should be implemented before 16th January, 2009. The Groundwater Directive responds to the requirements of Article 17 of the WFD and introduces, for the first time, quality objectives obliging Member States to monitor and assess groundwater quality, on the basis of common criteria, and to identify and reverse trends in groundwater pollution. This Directive aims to ensure the good status of all waters in EU by means of the pressure and impact analysis results (Article 5 and Annex 2) and setting quality threshold values.

In this paper, approaches, assumptions and procedures adopted in 5 different Member States and 7 River Basin Districts (among them 3 pilot river basins) to carry out the WFD implementation are reviewed and compared. Each one has adopted the best methodologies to study the intrinsic characteristics for their respective territory based on EC guidance documents. It has been shown that despite the use of these common documents, the results have not been homogeneous. Local characteristics such as land use, available data or groundwater management structure have been determinant factors in the achievement of results as well as the procedures adopted for carrying out the impact and pressure analysis. As a result, following WFD implementation could be successful to different degrees in spite of the Groundwater Directive trying to synchronise the results by taking into account local characteristics to establish quality criteria. In this paper, the degree to which the Daughter Directive could achieve these results, by depending on the previous procedures, is also evaluated.

The study areas are the Severn and Thames River Basins Districts in England and Wales; the Scotland River Basin district in Scotland; the middle Loire River Basin District in France; the Internal River Basins of Catalonia and Ebro River Basin District in Spain; and the Vouga-Montego-Lis River Basin District in Portugal. These areas include basins with a high population density (Thames river basin), basins mainly of agricultural land use (Ebro river basin), transboundary basins (Severn River basin), basins with coastal groundwater bodies (Internal Catalan basins), basins with diverse water use (Vouga river basin) or where surface water is more extensively used rather than groundwater (Scottish river basins).

The Member States where only one authority has been in charge of implementing the process (UK and Portugal) have shown more homogeneous and coherent results. Here, the design of the next implementation strategies will be more direct and easier. Nevertheless, this does not ensure the achievement of detailed results.

The processes of delineation and characterization of groundwater bodies have been very similar in all the River Basin Districts studied. The management criterion has not been practically considered in any of the study cases. It has been taken into account as a secondary factor but it is recommended that it be used in the Groundwater Directive application, to redefine sectors of different quality objectives. This study also shows that there is not a relationship between the layers used to map the groundwater bodies (2 in Loira and Ebro; 3 in Catalonia; 1 in the rest) and the results achieved with the pressure and impact analysis.

The analysis of the different procedures carried out in each river basin district have shown that the most common and important uncertainties are related to available data and to the methodology followed to calculate the risk of failing to meet environmental objectives. As there were no harmonised criteria and threshold values to evaluate the risk, in most of the river basins it has been calculated by using a probabilistic approach.

It has been observed that the dimensions of the groundwater bodies are important in final risk evaluation. The larger River Basin Districts have identified less groundwater bodies at risk with respect to the total river basin surface extension. Portugal is an exception to this observation, where none of the River Basin Districts have described more than two groundwater bodies at risk and a great number of groundwater bodies have been identified that are doubtful with respect to risk. This is due in part to a lack of data and mainly to the pressure and impact methodology followed. As in Portugal, where the percentage of groundwater at risk with respect to the total surface is larger, these bodies are added to the total groundwater bodies at risk to arrive at the conclusions described in this paper (Table 1). It is shown that in the Districts where there are twice as many groundwater bodies, the total of groundwater bodies at risk is reduced to a half. In groundwater bodies with larger dimensions the local impacts are masked in the calculation of mean values.

The amount of pressures that have been considered in the risk analysis has very little influence on the final results. In some of the Districts where lower number of pressures have been used, a lower number of groundwater bodies at risk have been identified (for instance in Loire-Bretagne basin), but this also depends on the amount of data used in the impact analysis. Nevertheless, the most important pressures are common in all countries (agricultural practices) and these have been taken into account in all cases but to a different degree (in some basins they are considered as a pressure while in others, like the Vouga river basin, they are classed as an impact). Thus, a wide range of pressures is a secondary factor in this initial implementation phase, while the system used in the risk evaluation has more influence on the result. In the countries where the starting point has been the impacts (France and Portugal), or where the vulnerability of groundwater bodies has not been considered (Portugal), the pressures have been simplified and less groundwater bodies at risk have been identified. In the Districts where the procedure of pressure and impact analysis have been systematized it has not been necessary to define groundwater bodies suspected of being at risk (Catalonia and England). In these areas the Daughter Directive could be applied in a direct way, as the criteria of good and bad chemical status coincides well with values and procedures applied. For instance, in the Internal Basins of Catalonia where probable and proved impacts have been included in the risk analysis, it is expected that results of a monitoring network will not highlight new groundwater bodies with bad chemical status. A detailed conceptual model will be required only in some places. The number of pressures used will determine the further studies required by the Groundwater Directive, as an analysis will have to be done for each contaminant that contributes to the final risk (Annex III).

The difference between the chemical threshold values used in risk estimation has no influence on the final results. In spite of this, the application of the Groundwater Directive criteria could result in groundwater bodies that have not been declared at risk in the first approximation being changed to bad chemical status. A program of measures will have to be implemented in them. It is recommended that management criterion be used to redefine zones within these bodies.

Table 1. Summary of comparison results (No: number, pp: punctual pressure, dp: diffuse pressure, GWB: groundwater body)

	No of GWB	**GWB at risk**	**% of surface at risk**	**No Pressures**
Thames (16133 km^2)	45	7 pp + 41 dp	92%	2 pp + 6 dp
Severn (21590 km^2)	52	0 pp + 38 dp	57%	0 pp + 7 dp
Scotland (113929 km^2)	106	17 pp +21 dp	41%	3 pp + 2 dp
Loire middle (27000 km^2)	32	11 dp (+6 at doubt)	37% of GW bodies	0 pp + 2 dp
Ebro (85975 km^2)	105	11 pp + 35 dp (+11 at doubt)	35%	4 pp +3 dp
IB Catalonia (16628 km^2)	39	23 total	47%	8 pp + 5 dp
Vouga (12633 km^2)	20	0 pp + 1 dp (+ 7 at doubt)	40% (including doubt)	2 pp + 1 dp

Keywords: Groundwater body, Water Framework Directive, Daughter Directive, Implementation strategies, Good chemical status

Delineation of priority areas for the planning and implementation of nitrogen reduction measures in Lower-Saxony

[1] F. WENDLAND, [2] M. EISELE, [2] W. SCHÄFER and [1] R. KUNKEL

[1] Research Centre Jülich, D-52425 Jülich
[2] Geological Survey of Lower Saxony; Stilleweg 2, D-30655 Hannover

ABSTRACT

The implementation schedule for the EU water framework directive requires the creation of monitoring programmes for water bodies according to the intensity of the pollution risk by the end of 2006. Until 2009 river basin district management programmes have to be established followed by the implementation of measures from the management plans (until 2012). Within the EU – LIFE – Environment project WAGRICO (Water resources management in co-operation with agriculture) methods of geographical prioritisation and determination of environmental targets have been developed and derived in three pilot water bodies in the Federal State of Lower Saxony, Germany.

For a geographical prioritisation / ranking of low, medium and high priority units ("hot spot" areas) in catchment areas a decision tree has been developed. The geographical prioritisation comprises information directly obtained from observed data as well as model results. As a measure for the current anthropogenic pressure to groundwater nitrogen concentrations in groundwater are considered. Additionally, modelled nitrogen emission data and modelled hydrologic/hydrogeologic parameters are used. By doing so, the nutrient surpluses by agriculture are coupled to the relevant runoff components (groundwater recharge, direct runoff) and a residence time/nitrate degradation model. As a result of this step, the actual nitrogen emissions into groundwater and surface waters as well as the relevant hydrologic/hydrogeologic key factors controlling the inputs are quantified area-differentiated.

For the hot spot areas subsequently regionally adapted nutrient reduction measures will be developed, whose efficiency with regard to their environmental impact and socio-economic feasibility will be predicted based on the linked agro-economic / hydrologic-hydrogeologic model system.

Keywords: Diffuse nitrate pollution, river basin management, EU - Water Framework Directive, multicriteria assessment, GIS; nitrogen reduction measures

Eco-hydrological requirements of groundwater-dependent ecosystems in England and Wales

[1]Mark WHITEMAN, [2]Bryan WHEELER, [3]Sue SHAW, [4]Tim LEWIS,
[5]Mark GROUT and [6]Kathyrn CHARLES

[1] Technical Adviser Hydrogeology, Environment Agency, Rivers House, 21, Park Square South, Leeds, United Kingdom LS1 2QG, e-mail: mark.whiteman@environment-agency.gov.uk
[2] Reader in Wetland Ecology, Dept of Animal & Plant Sciences, University of Sheffield, Sheffield S10 2TN, e-mail: b.d.wheeler@sheffield.ac.uk
[3] Dept of Animal & Plant Sciences, University of Sheffield, Sheffield S10 2TN, e-mail: s.shaw@sheffield.ac.uk
[4] Entec UK Ltd., Canon Court, Abbey Lawn, Abbey Foregate, Shrewsbury, SY2 5DE, e-mail: lewit@entecuk.co.uk
[5]Environment Agency, Kingfisher House, Peterborough, PE2 5ZR, e-mail: mark.grout@environment-agency.gov.uk
[6] Environment Agency, Lutra House, Dodd Way, Bamber Bridge, Preston, Lancs, PR5 8BX, e-mail: Kathryn.charles@enviroment-agency.gov.uk

ABSTRACT

The Environment Agency of England and Wales has been working with internationally-recognised academic researchers to develop an understanding of the interactions between vegetation types, environmental conditions and sources of water to groundwater-dependent wetlands.

A new approach to conceptual understanding of water supply mechanisms (WETMECs) has been developed for fens and mires. WETMECs represent a series of hydrological conceptual models with an ecological overlay. This approach has the advantages of being “bottom-up” and based upon observed site data. Named categories of water supply mechanisms are identified, which allow the development of conservation management strategies which work with the “ecohydrological grain” of sites rather than against it.

The new method has enabled the Environment Agency to make assessments of hydrological impacts upon groundwater-dependent wetlands for the EU Habitats Directive. It has also contributed to the assessment of groundwater-dependency of vegetation for the EU Water Framework Directive. The WETMECs approach has been extended to other groundwater-dependent habitats including wet heath, wet woodland, wet grassland, ditches and swamps, and wet dune slacks.

Examples are given of the practical application of the new approach, from sites with differing water supply mechanisms (WETMECs), to show how different considerations may be dominant depending on the site (e.g. soil moisture, upflow, stream discharge etc.). We would like to bring these differences, which are often caused by things which hydrogeologists traditionally ignore (e.g. local variations in the composition of the topmost soil/drift layer) to the attention of the wider groundwater community for use in their work. In applying regional groundwater models to evaluate impacts upon groundwater-dependent wetlands, it has been important to consider not only the groundwater levels required to maintain vegetation, but also the maintenance of upward hydraulic gradients and springflows.

Keywords: Groundwater, wetlands, impacts, water supply mechanisms, conceptual models

Groundwater threshold values in the Netherlands: choices & consequences

[1]Hilde F PASSIER, [2]Peter SCHIPPER, [1]Hans Peter BROERS, [1]Jasper GRIFFIOEN

[1] TNO- Subsurface and Groundwater. PO Box 80015, 3508 TA Utrecht, The Netherlands, hilde.passier@tno.nl
[2] Grontmij, PO Box 119, 3990 DC Houten, The Netherlands, peter.schipper@grontmij.nl

ABSTRACT

The European Groundwater Directive threshold values for groundwater quality will be important instruments to assess the status of groundwater bodies. Threshold values indirectly point out where measures have to be implemented in order to improve the status of the groundwater. All member states will have to derive the threshold values for compounds that could pose a problem in achieving the goals of the Water Framework Directive. A series of choices has to be made for the actual derivation of the threshold values.

This paper is about the consequences of the choices that have to be made along the path to derivation of threshold values for groundwater quality in the Netherlands. We discuss different approaches to derive the threshold values (for example regional versus national threshold values) and different approaches for compliance testing. The consequences of the determined threshold values are considered. Hereby we assess whether the 'right' choices are made to identify the 'right' problems, so that appropriate river basin management plans will be made. We want to insure sufficient protection of receptors, including terrestrial and surface-water ecosystems and other legitimate functions and future uses. The consequences of different pathways to derive threshold values, were tested in a number of groundwater bodies within several river basins in the Netherlands. We studied both synthetic and non-synthetic substances. In addition to new data-processing, we used recent results of several studies that were carried out in the Netherlands, like the case study in river basin Rijn-West, that was carried out within the European FP6 project BRIDGE. This case study clearly showed the regional differences in natural background levels (Fig. 1).

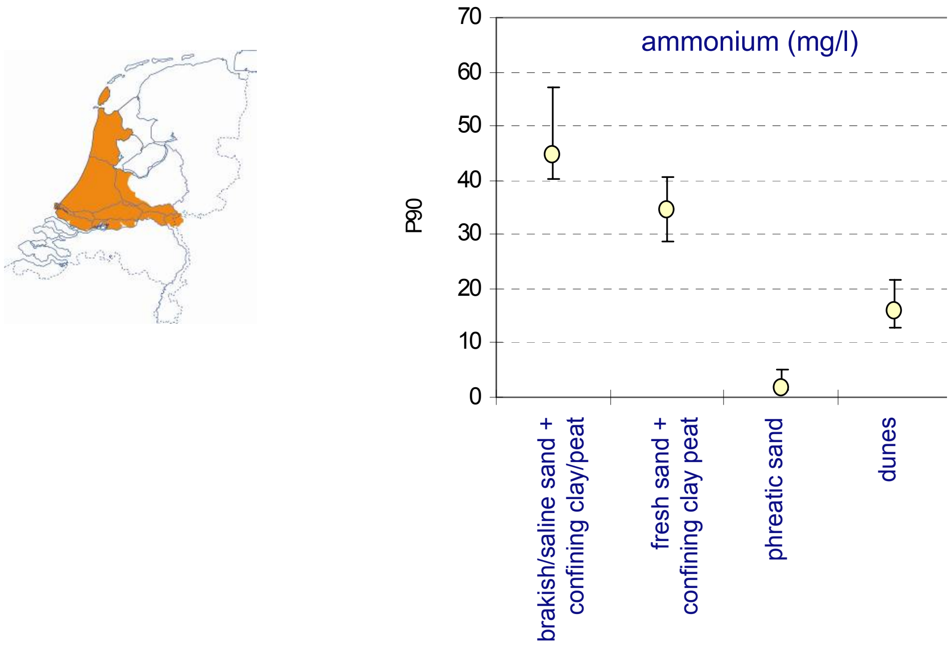

Fig. 1. River Basin Rijn-West in the Netherlands and the natural background levels of ammonium in the different groundwater bodies in the river basin. Here, the 90-percentile is shown, including 95% confidence intervals, of the groundwater ammonium concentration till about 30 meters below surface, after the exclusion of anthropogenically influenced samples via preselection.

Keywords: Groundwater quality, threshold values, Groundwater Directive

Application of the Water Framework Directive to a pilot Mediterranean basin: delineation of bodies of groundwater

Damián SÁNCHEZ, Francisco CARRASCO, Bartolomé ANDREO

Department of Ecology and Geology, University of Malaga, Campus de Teatinos s.n. 29071-Malaga, Spain

ABSTRACT

Since December 2000, the Water Framework Directive (WFD) established quality objectives for all European waters, including groundwater, that Member States were asked to accomplish by December 2015. Some of these objectives have to be applied to 'water bodies', a new administrative tool that the WFD defines in Article 2, both for surface and groundwater bodies. The term 'water body' is essential to the implementation of the WFD since several aspects of the Directive such as the typology, the reference conditions, the monitoring or the status, are directly related to it.

The WFD asks Member States to identify 'water bodies' as part of the analysis of the characteristics of the river basin districts. This information was sent to the European Comission in March 2005. However, the characteristics of the river basin districts, including the identification of bodies of water, must be reviewed and updated in 2013 and, after that, every six years.

The definition of 'body of groundwater' in Article 2 of the WFD (*a distinct volume of groundwater within an aquifer or aquifers*) is not free from ambiguity and is not sufficiently specific to permit a clear application of the term in practice. In order to carry out a coherent and harmonious implementation of the Directive, the EU Member States and the European Comission prepared horizontal guidance documents on the application of the term 'water body' from a methodological point of view.

This paper presents the results of the identification of bodies of groundwater in the Guadalhorce River basin, a Mediterranean river basin located in southern Spain. This practical approach permitted the establishment of a methodology to carry out delimitations of bodies of groundwater in areas with similar characteristics. The criteria used to do this, was taken from the WFD and the horizontal guidance documents elaborated by both the European Comission and the Spanish Administration.

This application of the term 'body of groundwater' has tackled some of the major difficulties in its practical use such as the identification of bodies of groundwater in multilayer aquifers; boundaries between superposed groundwater bodies; the identification of bodies of groundwater in low-permeability materials; or its delineation in dismembered aquifers.

The delimitation of bodies of groundwater has been done following a 3-step approach. First of all, the "Hydrogeologic Units" previously defined by the Spanish Geological Survey were identified as bodies of groundwater. Secondly, low-permeability rocks and very small aquifers not defined as "Hydrogeologic Units" but with drinking water catchments consistent with the WFD specifications (serving more than 50 persons or abstracted flow higher than 10 m^3/day) were also identified as bodies of groundwater. Finally, new groundwater bodies have been created where groundwater flow was directly related to surface water bodies or terrestrial ecosystems.

The results of this paper are two different delimitations of bodies of groundwater for a Mediterranean pilot river basin. The first one has been done following the criteria set out in the WFD and in the horizontal guidance documents, and the second one is a proposal of the authors based on hydrogeological criteria. In doing that, it has been possible to highlight the main difficulties in identifying the bodies of groundwater, as well as to evaluate what the term 'body of groundwater' should designate and should not.

Keywords: Water Framework Directive, body of groundwater, Guadalhorce River basin

Initial studies of nutrient occurrence in the saturated and unsaturated zones of a sand & gravel aquifer under tillage farming in the Barrow catchment, South-Eastern River Basin District, Ireland

[1, 2] Alina PREMROV, [1] Catherine COXON, [3] Richard HACKETT, [2] Karl RICHARDS

[1]School of Natural Sciences, Geology, Trinity College Dublin, Dublin 2, Ireland,
e-mail: premrova@tcd.ie, cecoxon@tcd.ie
[2]Centre for Soils & Environmental Research, TEAGASC-Johnstown Castle Research Centre, Wexford, Ireland,
e-mail: Alina.Premrov@teagasc.ie, Karl.Richards@teagasc.ie,
[3] TEAGASC-Oak Park Research Centre, Carlow, Ireland, e-mail: Richie.Hackett@teagasc.ie

ABSTRACT

The requirements of the EU Water Framework Directive (2000/60/EC) are to obtain the 'good' water status by December 2015 (EEC 2000). According to the Irish Article 5 Characterisation and Analysis Report to the EU, the River Barrow catchment, which lies within the South Eastern River Basin District (SERBD), is dominated by agricultural land cover (WFD Ireland 2005). The surface water ecosystems are often groundwater dependent. The report also states 56 % of total Irish groundwater water bodies are probably at risk mainly due to diffuse and point source pollution, where the diffuse pressures are one of the most significant. Further, all groundwater bodies in Ireland are considered as potential drinking water sources (WFD Ireland 2005). Therefore it is important that the groundwater in general meets the drinking water limit of 50 mg/l N (or 11.3mg/l NO_3-N) set by Drinking Water Directive (98/93/EC) (EC 1998). The Characterisation and Analysis Report maps most parts of the River Barrow as nutrient sensitive, while the parts of the River Barrow estuary are designated as a Special Area of Conservation (Register of protected areas) (WFD Ireland 2005) and this estuary is at risk of eutrophication (Toner *et al*., 2005). Eutrophication of surface waters is attributed to enrichment by nutrients such as phosphorus and nitrate, with nitrate being of particular importance in estuarine waters. The present study was conducted at an experimental site located at Oak Park Research Centre, Carlow, within the River Barrow Catchment, as part of an ongoing project on nitrate leaching losses from tillage land under spring barley production. The overall experiment aims to examine the effect of measures such as green cover over winter on nitrate concentrations in the saturated and unsaturated zones (Premrov *et al*. 2007).

The site is underlain by a sand and gravel aquifer with localised clay lenses (Premrov *et al*. 2007). The water table is shallow (approximately 2-5 metres below ground level); the hydraulic gradient is low, and groundwater flows beneath the site from the north and east, towards the River Barrow, which lies to the west of the area (Fig. 1). Following preliminary hydrogeological investigations, a network of shallow boreholes and ceramic cups was established in the experimental field during August and September 2006, to investigate nutrient occurrence in the saturated and unsaturated zones. Shallow boreholes (n=20) were drilled (~ 4 - 5 m deep) by continuous auger drilling using a Giddings Hydraulic Soil Sampling, Coring and Drilling Machine and 25 mm diameter HDPE piezometer pipes were installed. A total of 60 ceramic suction cups were installed at depths of 0.9 and 1.5 m (SPS 200, SDEC France).Levelling and GPS positioning of all installations was done by differential GPS system Trimble 4700. Groundwater levels were determined using an electric water-level indicator (Van Walt Ltd, U.K.). Groundwater samples, for nutrient determination, were taken after purging 3 well volumes using a Solinst peristaltic pump. Samples were filtered and stored at 4ºC for transport to the laboratory. Unsaturated zone suction cups were sampled by applying a 50 kPa suction for one week. Water samples were analysed in duplicate colorimetrically for NO_3-N, NO_2-N, NH_4-N and dissolved reactive phosphorus (DRP) on a Thermo Konelab 20 auto-analyser. The saturated and unsaturated zone nutrient data were spatially modelled using GW-Contour 1.0 visualisation and interpolation software (Waterloo Hydrogeologic, Canada).

Initial nutrient results (November 2006) from the shallow (0.9m) unsaturated zone and the saturated zone are presented in Table 1, and the geographical distribution of NO_3-N in the saturated zone is shown in Fig. 1. In the unsaturated zone, at 0.9 meters below ground level, the mean NO_3-N concentration was 59.7 mg/l (range 13. 4 to 104.7 mg/l), while the mean unsaturated zone NH_4-N and NO_2-N concentrations were both 0.01 mg/l. High nitrate concentrations, with a mean of 35.0 mg/l NO_3-N or over three times the drinking water and Nitrate Directive limit, were observed in the saturated zone. Observed groundwater NO_2-N, NH_4-N and DRP concentrations were all below environmental quality targets for groundwater and surface waters in Ireland (Keegan 2003). Water nutrient concentrations from both the unsaturated and saturated zones showed quite high spatial variability. The unsaturated and saturated zone nutrient results indicate that the area is affected by high rates of nitrate leaching. The study site and surrounding farmland is likely to be contributing significant

quantities of nitrate to the nearby surface water. Groundwater does not appear to be an important pathway of other nutrients, such as phosphorus, in this area. Research will continue to identify the role of green cover in reducing nitrate leaching to groundwater in this area to assist in compliance with the Nitrates and Water Framework Directives.

Table 1. Main nutrient concentrations in unsaturated and saturated zones

	Unsaturated zone [14/11/2006]				Saturated zone [01/11/2006]			
Ion	**Mean**	**Max.**	**Min.**	**St. dev.**	**Mean**	**Max.**	**Min.**	**St. Dev.**
NO_3-N	59.7	104.7	13.4	24.0	35.0	57.4	10.4	12.1
NO_2-N	0.01	0.02	< 0.006†	0.01	< 0.006†	0.07	< 0.006†	0.02
NH_4-N	< 0.09†	0.2	< 0.09†	< 0.09†	< 0.09†	0.1	< 0.09†	< 0.09†
DRP	-‡	-	-	-	< 0.008†	< 0.008†	< 0.008†	< 0.008†
Cl	48	137	14	27	51	79	7	18

†below detection limit; ‡ not determined

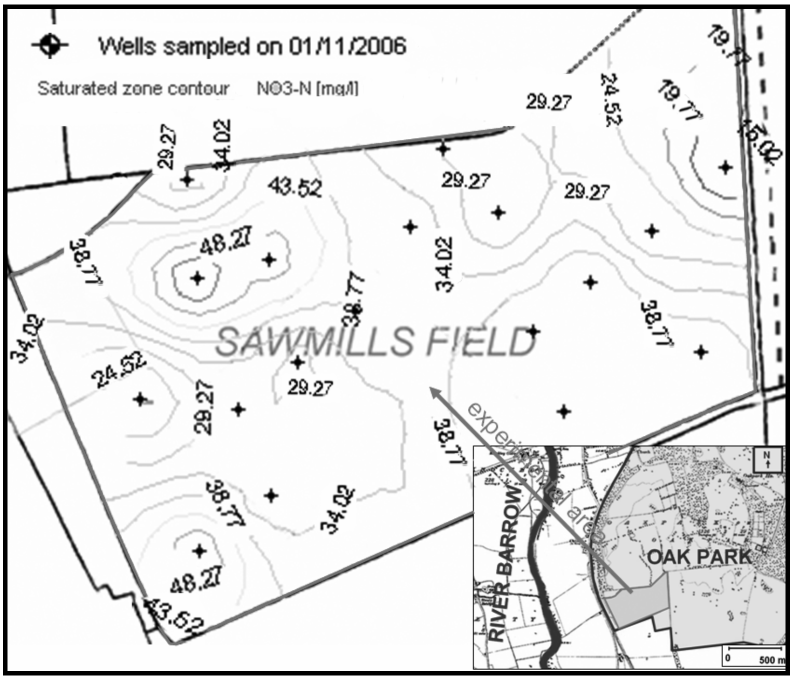

Fig. 1. Geographical distribution of NO_3-N in saturated zone

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Keywords: Water Framework Directive, groundwater contamination

Monitoring of the groundwater chemical status in the Azores archipelago (Portugal) in the context of the EU Water-framework Directive

[1]J Virgílio CRUZ, Dina PACHECO, Raquel CYMBRON, Sandra MENDES

[1]Direcção Regional do Ordenamento do Território e dos Recursos Hídricos, Av Antero de Quental, 9C, 2º Piso, 9500-160 Ponta Delgada, Portugal, Jose.VMF.Cruz@azores.gov.pt

ABSTRACT

Monitoring of the chemical status of groundwater bodies, in the overall context of EU legislation, has been implemented at the Azores archipelago. The present paper describes the methodology and results gathered at Santa Maria, São Miguel, Flores and Pico islands, where the project was first implemented.

The archipelago is located in the North Atlantic Ocean, between 37° to 40°N latitude and 25° to 31°W longitude, and is made up of nine islands of volcanic origin. It has a surface area of 2333 km^2 and about 240000 inhabitants. Groundwater is a strategic resource in the Azores archipelago, playing an important role as the main water supply source and as an ecosystem support matrix. However, and despite the environmental, social and economical value of groundwater, aquifers at Azores are under increased pressure, as already recognized in several studies.

Hydrogeology characteristics in the archipelago are heterogeneous, depending on primary and secondary factors. Specific capacity is on the range of 1.40×10^{-2}-266.67 L/sm (n=65), with a median of 32.29 L/sm. Transmissivity also shows a large range of values, between 1.65×10^{-5} m^2/s to 4.03×10^{-1} m^2/s (median=3.66×10^{-2} m^2/s). Groundwater resources calculation points to a volume of about 1600×10^{6} m^3/yr, asymmetrically distributed all over the archipelago as shown by the range observed (8.3×10^{6} m^3/yr-582×10^{6} m^3/yr).

The Water-framework Directive (2000/60/CE), adopted on the 23rd of October 2000, is the main EU water policy instrument, associated with a rather demanding implementation strategy. According to the Water-framework Directive, groundwater should achieve the so-called “good status” by 2015, regarding quantitative and chemical aspects, and to reach this overall objective a proactive approach toward sustainable resource exploitation is defined. Therefore, several environmental objectives were directed at groundwater: to prevent or limit the input of pollutants to groundwater, to protect, enhance and restore all groundwater bodies, to implement measures to reverse any sustained and significant enrichment trend on the concentration of any pollutant introduced in groundwater due to human activities and to allow compliance for protected areas according to the respective standards and objectives.

In order to achieve the “good chemical status” the observation of several criteria is required, namely the non-existence of saline intrusion effects, the compliance regarding to EU quality standards and that the groundwater discharge to surface water bodies will not cause that these bodies are not able to attain their environmental objectives.

Water monitoring is one of the key aspects of the Water-framework Directive and the newly Daughter Groundwater Directive (2006/118/CE), which came into force on 12 December 2006, is also partially focused on this practice viz. as a tool to evaluate groundwater quality and to provide data needed to identify and define measures to reverse upward trends in pollutants.

The Azores Water Plan, that came into force on 23rd of April 2003, also recommends monitoring as a strategic priority, with the year 2006 as the deadline to implement a full monitoring scheme for all water bodies, including groundwater, according to the Water-framework Directive.

To reach this objective a monitoring network was defined according to the 54 groundwater bodies in the Azores, and considering a phased approach: collection of samples started in 2003 at Santa Maria and São Miguel islands, in 2004 at Pico and Flores, in 2006 at Corvo, Faial, Graciosa and São Jorge, and will be started at Terceira in 2007. The main criteria adopted, due to financial constraints, was to couple surface and groundwater monitoring, in a holistic perspective, and therefore field work was initiated in 2003 and 2004 in islands, like São Miguel, Pico and Flores, where several surface water bodies in risk were identified, namely eutrophicated lakes, some of then classified as vulnerable zones according to EU Nitrates Directive (91/676/CEE).

The monitoring network is composed of 72 springs and 32 drilled wells, representative of more than 1000 groundwater origins (950 springs and 83 drilled wells) identified in the Azores (Fig. 1). The methodology consists of two sampling campaigns by each year, one with a large spectrum of analysed parameters (temperature, pH, electrical conductivity, dissolved oxygen, Ca, Mg, Na, K, HCO_3, Cl, SiO_2, NO_3, NO_2, NH_4, PO_4, Al, Fe, Cu, Cd, Hg, Mn, Pb, As, other List I and List II from 80/68/CE (pesticides, cyanides, Cd, Hg, total hydrocarbons), coliform bacteria (total and faecal, faecal streptococcus), and the remaining one with a minor number of determinations (temperature, pH, electrical conductivity, dissolved oxygen, NO_3, NO_2, NH_4, coliform

bacteria (total and faecal) and faecal streptococcus). For drilled wells Cl content was determined in the two sampling campaigns.

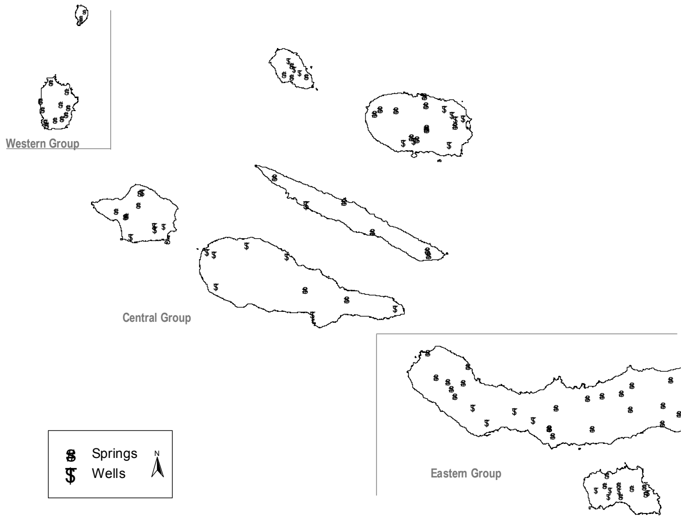


Fig. 1. Monitoring network for groundwater chemical status assessment on the Azores archipelago.

In the present paper results obtained on the islands of Santa Maria, São Miguel, Flores and Pico are discussed further as these data sets are the most extensive so far.

Spring discharges at São Miguel corresponds mainly to HCO_3-Na type waters, with a pH range between 6.0 and 7.8, which present a low mineralization, as shown by the conductivity values (49-336 µS/cm). Discharges from Santa Maria are mainly from the Cl-Na and Cl-HCO_3-Na water types, with a similar pH range (6.3-7.6) and also showing low mineralization, but with conductivity values (138-618 µS/cm) higher comparing to São Miguel.

Wells in both islands are from the Cl-Na and HCO_3-Cl-Na types, respectively for São Miguel and Santa Maria islands, and conductivity range is broader compared to spring waters (291-514 µS/cm; 255-4000 µS/cm). This maximum level of the conductivity expresses the overall mineralization enrichment due to mixing with seawater.

Water samples at Flores are mainly from the HCO_3-Na, HCO_3-Na-Mg and Cl-Na-Mg types, with low mineralizations as shown by electrical conductivity, and which range between 101 and 243 µS/cm (November 2004) and 103 to 246 µS/cm (March 2005). The pH in the same sampling campaigns varies respectively between 6.2 and 7.6 and 6.2 and 7.7, with temperatures between 14.4 and 16.1ºC and 13.4 and 15.6ºC.

Compared to Flores springs, discharges at Pico present slightly lower conductivities, in the range of 75 to 88 µS/cm and 73 to 84 µS/cm, respectively in samples collected in November 2004 and May 2005, with HCO_3-Na and HCO_3-Na-Ca. The pH is in the basic range (7.7–8.1 and 7.6–7.7) and temperatures between 12.4 and 12.5ºC and 12.0 and 13.3ºC. Samples collected in the year 2006 are on the same range of values.

In drilled wells from Pico water mineralization is substantially higher (conductivities between 400 to 2000 µS/cm and 222 to 2340 µS/cm, respectively in November 2004 and May 2005, and 127 to 2000 µS/cm in May 2006). The pH is always in the basic range (7.0-8.4, 7.1-7.8 e 7.0-8.3), which considering the facies, mainly from the Cl-Na type, and the Cl content, that in some wells reach values about 600 mg/L, shows the effect of seawater mixture.

Considering the nitrate as an indicator of the agriculture impact on groundwater quality, it is possible to show that values observed in Pico and Flores islands are generally lower than 5.4 mg/L and therefore in compliance with standard values. Values at São Miguel and Santa Maria are generally higher, with a maximum content of 31 mg/L and 24 mg/L, but also in compliance with standard limits.

Hydrocarbons and pesticides were generally under the detection limits by these analytical methods. Heavy metals and metalloids are in compliance with standard values and frequently are also under the detection limits.

The most common cause of non-conformities related to standard values are the total and faecal coliform, which suggest the influence of animal wastes from pasture lands and waste water rejection.

Acknowledgement: financial support from the EU INTERREG IIIB program to the AQUAMAC project has to be acknowledged.

Keywords: Chemical status, Water–framework Directive, Azores.

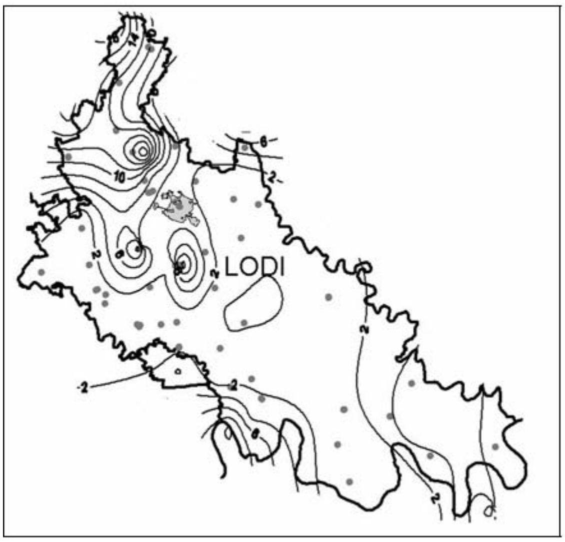
Regional-scale assessment of factors affecting non-point sources pollution: nitrate in groundwater

[1] M MASETTI, [2]S POLI, [3]S STERLACCHINI, [1]G P. BERETTA, [4]M BRAMBILLA

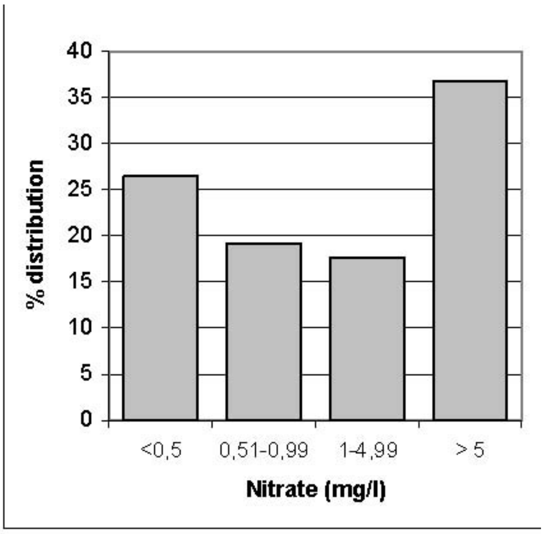
[1]Department of Earth Sciences, "Ardito Desio", University of Milan, Via Mangiagalli 34, 20133 Milan, Italy, marco.masetti@unimi.it, giovanni.beretta@unimi.it
[2]Department of Environmental and Territorial Sciences, University of Milan-Bicocca, Piazza della Scienza 1, 20126 Milan, Italy, simone.poli@unimib.it
[3]Institute for the Dynamic of Environmental Processes, National Research Council (CNR-IDPA), Piazza della Scienza 1, 20126 Milan, Italy, simone.sterlacchiniòunimib.it
[4] Department of Biology, University of Milan, Via Celoria 26, 20133 Milan, Italy, mattia.brambilla@unimi.it

ABSTRACT

Worldwide Non-Point Sources (NPS) pollutants are recognized as the major contributors to surface and groundwater contamination. Characteristically NPS pollutants present some common features: are difficult to trace to a specific source; enter the environment over an extensive area; have the potential for maintaining a relatively long active presence in groundwater. So assessment of NPS pollution in groundwater at the local or regional scale is a key component to a sustainable environmental policy. Nitrates are among the most common global NPS pollutants and groundwater nitrate contamination and the associated health concerns are among the most common problems adversely affecting groundwater quality worldwide. Considering its behaviour in groundwater, given the wide range of nitrate sources and the frequency with which it has been measured in groundwater, nitrate is a good indicator to study groundwater contamination, to NPS and factors affecting it. Logistic regression and Weights of Evidence Modeling Technique have been used to analyze both natural and anthropogenic factors influencing the occurrence of high nitrate concentrations in groundwater resources located in the central part of the Po Plain (Northern Italy). The proposed methodology was applied in the Lodi District (central part of the Po Plain, Northern Italy), a wide area identified as a Nitrate Vulnerable Zone by the European Community, as a result of the implementation of EU Nitrate Directive (91/976/EC). It combines measurements of nitrate concentrations (response variable) with spatial data representing both categorical and numerical variables (explanatory variables or predictors). The measurements were carried out by means of a monitoring net consisting of 69 wells, irregularly distributed in the study area (Fig. 1), while the geo-environmental factors describes the potential sources of nitrate and the relative ease with which it may migrate towards groundwater. They include population density, nitrogen fertilizer loading, groundwater recharge, soil protective capacity, vadose zone permeability, groundwater depth, and saturated zone permeability.



(a)



(b)

Fig. 1: a) nitrate concentration map (values in mg/l) with monitoring points in gray, and b) frequency of concentration in wells

The statistical model was developed by first testing each single explanatory variable in a logistic-regression model to determine the most significant factors. Moreover, in order to avoid colinearity problems among predictors, a hierarchical partitioning analysis (HP) was performed to check whether the statistical model reflects the supposed real importance of the tested variables. Then, factors were tested in a probabilistic-based model (Weights of Evidence Modeling Technique) to determine negative and positive correlations between each variable class and nitrate concentration in groundwater. The abovementioned procedure is automatically performed exploiting the potentialities of SPSS for logistic regression and ArcSDM for the Weights of Evidence. The resultant specific susceptibility map (Fig. 2) is expressed in terms of classes, representing a relative ranking of the degree of susceptibility to aquifer nitrate contamination. Simple statistical techniques are also performed to investigate the correlation between the spatial distribution of susceptibility classes and nitrate concentrations occurring in contaminated wells, as an indicator of the quality of the final result.

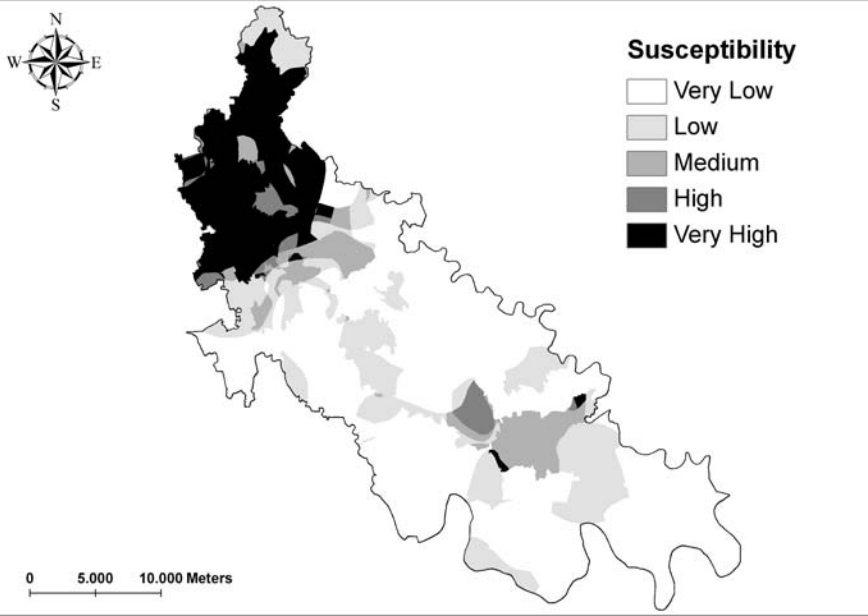


Fig. 2: Susceptibility map to nitrate contamination.

At the end, the statistical model has made it possible to outline: the overall influence each variable and each variable class has on the presence/absence of nitrate; the range of their values mostly influencing this presence/absence; the most and least critical combination of factor classes existing in each specific zone. Results have shown how groundwater nitrate contamination is due to both agricultural and urban sources; while the former has a clear direct correlation with the response variable, the latter has only some particular values which strongly affect nitrate distribution in groundwater. Among natural factors the saturated hydraulic conductivity has given the clearest (inverse) correlation with nitrate, which seems to indicate the effective action of the dilution process occurring in groundwater in the area. The analysis of influencing factors and the estimate of their importance can also be used to obtain a specific map indicating groundwater susceptibility to nitrate contamination. The obtained results provide a useful tool to evaluate the potential effect of development on groundwater quality for future planning of land use, especially regarding the decision of agricultural practice in a specific area. This last aspect could represent an important support for managers and decision-makers responsible for the development of physical planning or land use management to preserve groundwater quality.

Keywords: Groundwater, Non-Point Sources, nitrate, Weights of Evidence, Logistic Regression

The changing role of science in groundwater and river basin management

[1]Adriaan F.L. SLOB and [1]Mike DUIJN

[1]TNO Built Environment and Geosciences, the Netherlands, e-mail: Adriaan.slob@tno.nl

ABSTRACT

A shift is taking place in the way science, scientific knowledge and technical expertise is being used in groundwater and river management. The EU Water Framework Directive and its groundwater Daughter Directive are asking for integrated approaches, as the river basin *system* is the policy object in these directives. This leads to an increasing complexity as the scale is becoming wider (the whole river basin) and brings the issue of (ground) water management to the spatial planning arena. The field of (ground) water management is thus being brought in contact with a variety of related issues, like nature conservation, industrial development or degradation, other spatial, economic and social issues, with competing claims and interests. Ground water management is therefore confronted with a huge variety of stakeholders, with interests ranging from nature conservation to entrepreneurial interests, who want to be involved in (ground)water management. The traditional, monodisciplinary, approach to water management, which has been common practice until now, does not fit well with these developments, because it neglects the complexity of the river basin system. New management approaches as well as new ways of involving science in water management are needed. In this paper we will put these developments in perspective and we will explore the new role of science in (ground)water management.

With reference to Gibbons et al. (1994), it is argued that the societal context is becoming increasingly important for the production of scientific knowledge. This can be shown by the historic development of environmental policies. The changing interaction between (scientific) research and policy making can be explained by the changes that environmental policy itself have been undergoing during the last decades. Four generations of environmental policies are distinguished. The fourth generation (starting roughly from 2000) is directed towards societal reform and uses a 'systemic approach', especially under influence of the adoption of the concept of sustainable development in environmental policy. In the fourth generation environmental policy, co-production of knowledge with stakeholders and joint fact finding processes will become important methodologies. The mono-disciplinary approach will become less important and multi- and transdisciplinary ways of knowledge production should be developed. A closer interaction between policy and research, for instance in workshops or even co-production of policies, is needed. Learning, evaluating and monitoring to enhance the societal meaning of both research and policies will become new instruments to develop the fourth generation further.

These trends are illustrated with two research projects that are aimed to generate knowledge for groundwater and river basin management.

The EU Project AquaTerra (http://www.attempto-projects.de/aquaterra) is a multi-disciplinary project in the EU sixth framework research programme, which aims to develop and integrate soil and water research to provide a better understanding of the river basin system. Scientists of a variety of disciplines, but mainly from natural sciences, are working together to generate knowledge to better understand the river basin system (groundwater, sediments, water, soil). We have observed that the research community in itself encompasses many smaller factions, grouped around separate disciplines. Although the AquaTerra researchers share a scientific background, the involved disciplines have their own specific practices and languages, which make integration of knowledge a difficult task. This is enforced by the fact that the AquaTerra scientists are working in different contexts and countries. The integration of the outputs of the AT research is therefore a formidable task, especially with respect to the generation of meaningful results that can be used in integrated water management by both policymakers and stakeholders. The EUPOL workpackage of the AquaTerra research project, studies the relation between the AquaTerra results and policy. This study revealed the policy questions that could be addressed by AquaTerra, and are most commonly related to land use, river basin management, water and climate change, while questions related to agriculture and soil were the least common. In the follow-up, workshops are organised to facilitate the discussion between water managers and AquaTerra scientists to enhance the uptake of AquaTerra results by river basin managers. The results from these discussions and the lessons learned will be highlighted.

The other example of a new approach of knowledge generation is the so-called MIPWA-project in the Netherlands. MIPWA stands for Method for Interactive Planning in Water Management. In 2003 the National Governance Agreement Water was signed by the water managing parties in the Netherlands. It was agreed that one of the policies to reach a better balance between water management and spatial development, was the implementation of a so-called ‘desired surface and groundwater regime’. This regime helps to identify the appropriate combinations of groundwater levels and spatial functions, such as agriculture, housing, nature and recreation. It also helps to decide on the feasible policy measures to influence surface and ground water levels in the desired direction. To determine the regime for each water management area a new and detailed groundwater model was needed. This model will support cooperation in catchment areas, induced by the WFD.

The modelling project, called MIPWA, will result in a ground water model that will support water managing authorities, mainly provinces and water boards, to ex ante evaluate (or pre-test) the impact of future groundwater measures, before being implemented. This type of detailed model that is also widely accepted among water managing authorities is not available yet. Currently the model is under construction in a participatory modelling process in which scientists, engineers and policy professionals work together, combining their knowledge into a model that is scientifically viable and has practical meaning for policy making. Together they identify the ‘blank spots’ in the available knowledge and negotiate on measures to fill in these blanks spots, in order to live up to the expectations they and their constituents had, before starting the modelling process. The construction of the groundwater model is largely supported by knowledge and insights from the natural sciences, but the participatory modelling process - based on insights from social sciences - is the crucial factor that keeps the different actors connected and drives the co-production of a ready-to-use policy instrument for groundwater management.

The paper ends with “lessons learned”, and implications for the interface between science and (ground) water management.

Keywords: EU policy, complexity, integrated water management

The macro-ecological model: making sense of the conflicts in integrated catchment management

[1]David N LERNER, Ben SURRIDGE, Achim PAETZOLD

[1]Catchment Science Centre, Kroto Research Institute, University of Sheffield, Broad Lane, Sheffield S3 7HQ, UK, email: d.n.lerner@shef.ac.uk

ABSTRACT

Many people in Europe are considering how to create River Basin Management plans as a result of the Water Framework Directive. This legislation has laudable objectives, seeking to integrate all aspects of catchment management to protect ecological quality. Inevitability, problems are looming with its implementation. For example, the concept of a baseline ecological status for water bodies, to which conditions should be returned, will be hard to realise, given the long history of land use change and water engineering throughout Europe. The apparent lack of flexibility in the definitions of ecological and chemical status, the strong monetary emphasis on cost-benefit considerations, and the neglect of uncertainty issues will all cause tensions in reaching decisions and persuading stakeholders to implement them.

Engaging stakeholders in the decision-making process, and then resolving the conflicts between them, will be extremely difficult. For example, if nutrients are the major pressure in a catchment, how will it be possible to decide if agriculture should cut back on diffuse pollution releases with consequences for crop yields and farm incomes, if sewage treatment works should remove more nutrients through more capital expenditure and greater use of energy, or if river restoration projects should increase the attenuation capacity of the riparian zone with costs to flood defence? Only the negative aspects of the alternatives have been listed; there are likely to be positive effects of each as well. The decisions to be made for river basin management are complex and will have major consequences. It is likely that all major decisions will end up under judicial review or appeal in a court of law. Arriving at the optimum decision will require both methods of engaging stakeholders and tools to predict the complex outcomes of the potential choices for management. There is a growing body of research on decision making processes, but little on predicting the outcomes of alternative choices to support these processes.

The ecological and chemical status of water bodies are one expression of a complex web of interactions. A simplistic view is that the status of a water body is determined by the interplay between physical, chemical, biological and socio-economic processes within river catchments. A change in one process (eg driven by river restoration, or a tax on nutrients) may cause changes in many other processes, and therefore affect chemical and ecological status through multiple cause-effect pathways. Unless we can predict the changes resulting from potential actions, we will not have any objective evidence to help the decision making process to weigh up the alternatives and resolve the interests of stakeholders. But the web of interactions is frighteningly complex and poorly understood; particular problem areas for example are how ecological systems respond to changes within their associated catchments, and the interaction of social, cultural and historical factors with the physical catchment. Process-based models of catchment behaviour are not feasible, particularly for these challenges, but we do need some other kind of modelling framework.

This paper explores the Catchment Science Centre's ambition to build a macro-ecological model to represent the complex web of interactions. It discusses the policy choices which need to be examined in the context of the WFD and other planning and regulatory instruments, the objectives and indicators at the core of such a model, how the results can be presented for users, and the systems modelling approaches being considered by us and others.

Keywords: Water Framework Directive, catchment management, systems analysis, stakeholder conflicts

TOPIC 12

EU Water Framework Directive and groundwater daughter directive ecological requirements: management and economic tools to protect groundwater

Águas do Oeste, S.A. groundwater sources for drinking water: establishing its wellhead protection areas

[1]Sandra CARVALHO, [1]Cátia ALVES, [2]José MARTINS CARVALHO

[1] Águas do Oeste, S.A. Convento de São Miguel das Gaeiras 2510-718 Gaeiras, Portugal, e-mail: s.carvalho@aguasdooeste.com, c.alves@aguasdooeste.com
[2] TARH-Terra, Ambiente e Recursos Hídricos Lda. Rua Forte Monte Cintra, 1-2ºC 2685-141 Sacavém, Portugal, e-mail: jmc@tarh.pt

ABSTRACT

In the past years Portugal has witnessed the construction of mega infrastructures developed in order to supply adequate public drinking water supply distribution systems, with the main water source relying on superficial contributions.

However, in many cases, for example in Águas do Oeste, S.A. (AdO), which is the company responsible for the Multimunicipal System of Water Supply and Wastewater Treatment of the western region of the Portuguese Continent, it is convenient to maintain operational former groundwater systems, on one hand as a strategic reserve, and on the other hand as a primary source in certain locations where the qualitative and quantitative characteristics allow its use for drinking water.

In those cases, it becomes necessary to design and implement wellhead protection areas to protect water quality and quantity available but also to fulfil Portuguese law requirements.

Adding to the fundamental lack of adequate hydrogeological information, the exploitation and traditional monitoring routines were assessed to be of a rudimentary quality.

Due to this fact, before designing and implementing the wellhead protection areas according to the legal terms, AdO has decided to perform systematic auditorships of the wells and of the extraction and monitoring equipment in order to define the long term well capacity, improve the sanitary conditions and introduce simple, but efficient, control routines.

Selecting groundwater wells with the purpose of establishing its wellhead protection areas corresponds, thus, to a complex task in the domain of water resources engineering, including the evaluation of the hydraulic performance of the groundwater exploitation system, the sanitary conditions, the physical, chemical and microbiological quality of the water and the sustainability of the aquifer.

Keywords: groundwater, drinking water, wellhead protection areas

Groundwater utilisation and protection: the experience and the comparison of Argentine and Italian regulations

[1] M. POLEMIO, [2] H. MASSONE, [1] V. DRAGONE, [2] E. BOCANEGRA

[1] CNR-IRPI, via Amendola, 122/I, Bari, Italy
[2] CGCyC- Universidad Nacional de Mar del Plata, Funes 3350, Mar del Plata, Argentina

ABSTRACT

As water is a vital resource for life, health and human development, it is a worldwide shared value that water management must aim at providing not only economic efficiency but mainly social equality. These goals are pursued utilising mainly groundwater resources, as in the cases of Italy and Buenos Aires Province (Argentine), where more than 80% of drinking water is discharged by springs and wells.

At same time, the population and the per capita consumption of fresh water is increasing worldwide while the population is being concentrated in coastal areas; climate change and groundwater contamination will increase the stress on available drinking groundwater resources and valuable ecosystems.

This contribution describes the approach of two wide coastal areas, located in two very different countries Argentina and Italy, to the regulation of groundwater utilisation and protection, considering the general purpose to satisfy the current demand of water of high quality and to guarantee sustainable utilisation of the groundwater resources.

The contribution considers also some local government initiatives concerning the protection of water resources, in terms of availability and quality, and of ecosystems. Attention is given also to the effect of the whole water cycle management in terms of environmental protection, realising a comparison of Italian national legislation, defined in the framework of European Union criteria, considering the local specificities of Apulian region, with Argentine national legislation, considering the specificity of Buenos Aires province. Natural resources management is considered from two perspectives: legislation and the government structure managing it.

The availability of drinking groundwater is particularly important in a city such as Mar del Plata (630,000 inhab., Province of Buenos Aires, Argentina), whose sole water supply consists of groundwater.

As regards the Argentine legislation, this is a federal country, where each province generates its own law. Article 28 of the provincial Constitution (highest provincial law) states that natural resources belong to the provincial state and this entity must look after their preservation, recovery and conservation. Law 12257 called "Código de Aguas" (Water Code) from 1999 establishes the system of protection, conservation and management of water in Buenos Aires Province. It regulates the planning and inventory of this resource as well as the rights and obligations of users. In Mar del Plata, Obras Sanitarias (a public yet autonomous entity) is responsible for the supplying of water. Although it must adjust to the provincial law, this entity also generates local regulations concerning drillings and well closures. As regards water quality regulations, there are two, a national one, "Código Alimentario Argentino" from 1975 (the one traditionally used) and a second one, present in the provincial law of 1996. The application of one or the other of the said regulations does not have clear-cut limits.

As regards government structure, in Buenos Aires Province there exists a pyramidal design of responsibilities. The Executive Power (presided by a governor) has a Ministry of Infrastructure, Housing and State Services. Within the sub-secretary of State Services (which depends on the Ministry mentioned before) there exist four head offices. These deal with groundwater management. The most relevant of these is the "Water Authority", which controls the fulfilment and execution of the "Código de Aguas."

Town hall also has local prerogatives as regards the regulation and control of the services of exploitation and supply of running water. All of this leads to a certain overlapping of actions that may render operational functioning difficult.

The oldest Italian law on water utilisation, the royal decree 1775 of 1933, called "Testo Unico sulle acque", main water law, which defined water resources as resources of public interest, regulates the water utilisation. From this starting point, many laws concerning partial aspects have been defined, enriching the legislation and pursuing a better groundwater utilisation, but creating some overlapping of competence of more public institutions. A clarification and new impetus to water protection was obtained by so called Merli law of 1976, concerning the regulation of any kind of discharge inside water bodies, the organisation of public service of water distribution, sewer system and purification, and the surveying of quality of any kind of water body. From the eighties the legislation was oriented to pursue the competence transfer from the national level to the regional level on one hand, and the effect of European directives on the other. The so-called Galli law of 1994

defined an integral approach to the management of water cycle, considering the whole drainage basin, and adopting criteria of sustainable utilisation of water resources.

Concerning the situation of Italian legislation on water management and protection, it is now focused on the water framework directive 2000/60 of the European Union which will provide the major driver for achieving sustainable management of water in each member state for many years to come. It requires that all waters, inland, surface, transitional and coastal waters as groundwater, must reach at least good state by 2015 and defines how this should be achieved through the establishment of environmental objectives and ecological targets. The result will be a healthy water environment, achieved by taking due account of environmental, economic and social considerations.

The main protection and management tools available to regional scale is the recent Water protection plan defined to recover and to preserve the environmental quality and to protect the availably and the quality of water resources, mainly groundwater in the case of Apulian region.

The comparison of these two national experiences shows some similar environmental and hydrogeological characteristics but also a very different approach to the management and the protection of groundwater resources, showing very interesting and different advantages and disadvantages.

Keywords: legislation, protection, management, groundwater resources

Using surface water monitoring stations to assess groundwater chemical status in the scope of the Water Framework Directive surveillance programmes. Application to crystalline basement groundwater bodies of the Loire-Bretagne river district (France)

[1]Ariane BLUM, [2]Bruno MOUGIN, [3]David RATHEAU

[1] BRGM, 3 avenue Claude Guillemin, 45060, Orléans Cedex 2, France, a.blum@brgm.fr
[2] BRGM SGR Bretagne, 2 rue Jouanet, 35700 Rennes, France, b.mougin@brgm.fr
[3] Agence de l'Eau Loire-Bretagne, Avenue de Buffon, BP 6339, 45063 Orléans Cedex 2, France, david.ratheau@eau-loire-bretagne.fr

ABSTRACT

The Water Framework Directive 2000/60/EC has asked Member States to implement groundwater bodies quality monitoring networks by the end of 2006. As a river district in charge of this network, the Loire-Bretagne Water Agency, with the technical support of BRGM, has in 2005 and 2006 carried out a project that aimed at making the groundwater quality monitoring network evolve in order meet the WFD requirements. Groundwater bodies of the Loire-Bretagne river basin are of different types: confined or unconfined sedimentary bodies (limestones, sandstones, chalk), impermeable layers locally aquifers (marls and clays with local aquifers layers), volcanic aquifers and crystalline basement aquifers. This last type covers 50% of the total surface of the basin and is therefore of major importance. However, all the data obtained over the last 6 years in recent scientific studies on hydrogeological and geochemical properties (Wyns *et al*., 2004; Ayraud *et al*., 2006) of such aquifers showed how heterogeneous these systems are (Fig. 1). This point raises the question of the monitoring networks

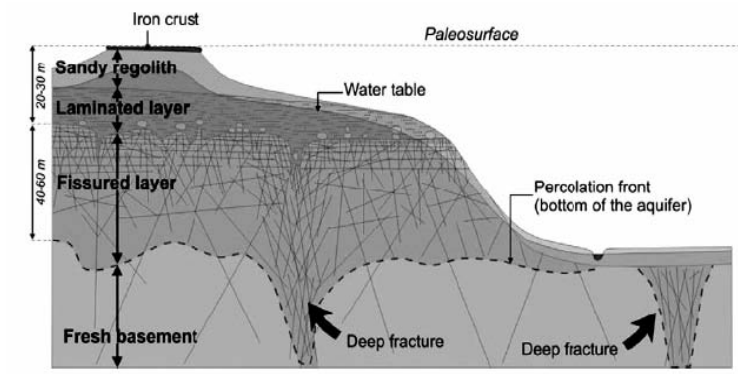


Fig. 1. Stratiform conceptual model of the structure and hydrogeological properties of hard rock aquifers (Wyns al, 2004 in Dewandel *et al*., 2006).

For the purpose of the study, groundwater bodies of the Loire-Bretagne river basin have been divided into subunits following pressures (crop and livestock farming) and flow criteria (surface basins and hydrogeological basins). The high number of sub-units per crystalline basement groundwater body (average of 26 sub-units per body) thus obtained, also confirms that such systems are particularly heterogenous.

In this context, how to meet the WFD objectives which require that each groundwater body has to be monitored and at the same time, make sure that expenditures are controlled and optimized. Because the available money is insufficient for enough monitoring sites, how does one find monitoring sites that represent a significant part of the whole groundwater body? Although this problem can be solved in some types of groundwater bodies such as karstic systems where springs can be selected, the situation is different in crystalline basement aquifers. In these systems, springs as boreholes are for the reasons mentioned above generally representative of only a few km² and sometimes only one layer of the aquifer (regolith or fissured layer).

In an attempt to solve this problem and following national and European guidelines (Grath and Ward, 2006), the Loire-Bretagne Water Agency has studied the pertinence of sampling surface water instead of groundwater. It is indeed well-known that, especially during low levels periods, surface waters are fed by groundwaters. In France, Brittany, the SILURES project (Mougin *et al*., 2006) illustrated this hypothesis and quantified the contribution of groundwater to river basins baseflow, according to the season. For the purpose of this project, modelling was done on 62 rivers catchments using the BRGM Gardénia© global model with local climatic data and river flow. One result of this study is that the average annual contribution of groundwater to the surface baseflow varies from 38 to 83%. In addition, an assessment of the monthly contribution of groundwater to surface water baseflow has permitted the evaluation of seasonal variations of the system.

The results obtained on the 62 catchments (see fig.2 as an example) show a predominant influence (80-90% of the total baseflow) of the deeper and fissured layers during the low-water level period (June to September). From July to September, the contribution reaches its maximum (100% of the total baseflow). Over the rest of the year, the situation is different. During the high-water level period, the rate of groundwater feeding the rivers ranges between 20 to 50%.

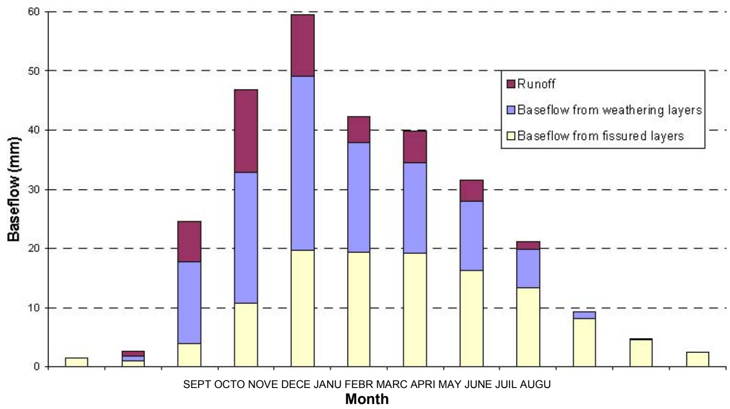


Fig. 2. Noë sèche catchment. Interannual average baseflows (1995-2000). SILURES programme (Mougin *et al*., 2006).

Based on these results, surface water monitoring stations have been selected from the existing ones on the Loire-Bretagne river basin (stations from the WFD network or from local networks). Only representative stations have been selected i.e. stations that are not influenced by human activities (dams, waste water treatment plants) neither by natural processes (denitrification, presence of a lake upstream). Furthermore, only samplings preceded by a dry period have been kept. Summer rainfalls are of course responsible of a significant contribution of runoff to the river baseflow. Taking these constraints into account, only a limited number (190) of the 2000 available stations has been selected.

In a conclusion, using surface water monitoring stations for the purpose of the WFD appears to be relevant in crystalline basement groundwater bodies where boreholes and springs are most of the time not representative. However, because surface water is not always totally fed by groundwater, more detailed studies should be carried out to use the data and to determine concentrations in groundwater, using concentrations in surface waters.

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Keywords: crystalline basement aquifers, Water Framework Directive, groundwater quality monitoring, networks representativity, conceptual model, groundwater – surface water relationships modelling.

Water management in aquifers subject to complex anthropogenic pressures: the Colli Albani volcanic system (Central Italy).

[1]Alfredo DI DOMENICANTONIO, [1]Manuela RUISI, [1]Paolo TRAVERSA

[1]Autorità di Bacino del Fiume Tevere, 12 via V. Bachelet, 00185 Roma, Italy, e-mail: didom@abtevere.it, manuela.ruisi@abtevere.it, paolo.traversa@abtevere.it

ABSTRACT

The proposed work gathers all of the experiences carried out by the Tevere River Basin Authority in regard to the management of water resources in the Colli Albani area within the institutional activities, within the Common Implementation Strategy for the Water Framework Directive 2000/60/EC and within the BRIDGE project (Background Criteria for the Identification of Groundwater Thresholds) under the Sixth European Community Framework Programme for research and technological development. The study area is characterized by:

- the presence of a volcanic aquifer system, where complex interactions between phreatomagmatic fluids and groundwater determine very diverse geochemical facies
- strong interactions between groundwater and surface water circulation
- strong quantitative and qualitative anthropogenic pressures.

The Colli Albani volcanic structure is situated south of the city of Rome and it is delimited by the left side of the Tevere and Aniene rivers and by the Tyrrhenian sea. It is constituted by an isolated relief with a characteristic truncated cone shape that surmounts the Roman countryside with an altitude of 970 m asl. During the final phases of the volcanic activity, the top of the structure was subject to violent explosions, which created a vast caldera with a diameter of about 10 km. Today, two secondary craters, formed in a subsequent phase within the calderic ring, are filled by the Albano lake and Nemi lake.

This territory has an important value from a landscape, historical and cultural point of view and has been widely exploited since the Roman epoch. It comprises important natural protected areas of local, national and European interest.

In the last 50 years this area has been subject to growing pressures due to the expansion of urban settlements, scattered houses, industrial activity and agriculture (water-demanding crops). The water demand was mainly satisfied by groundwater abstraction from wells, facilitated by the development of drilling techniques and by the relative shallowness of the water.

The Colli Albani structure's water circulation develops in radial direction (Fig. 1) from the centre to the periphery following complex patterns and it is characterized by a substantial interaction between groundwater and surface water circulation. In the south-western side the groundwater circulation flows into the Tyrrhenian Sea. In this area saline intrusion is developing in the fresh water in the coastal strip.

The geological setting originated an aquifer in the central area, sustained by low permeability volcanic rocks and a basal aquifer, sustained by marine pre-volcanic clay deposits and contained in the more ancient volcanic rocks. Water also circulates through the lakes from the superior to the basal aquifer complexes. The characteristic springs in this system are linear springs that feed the perennial surface water circulation at the bottom of the riverbed. The water circulation was subdivided into four sectors delimited by potential levels, where it was possible to carry out water balance calculations. These areas are defined as Water Bodies in accordance with the Water Framework Directive 2000/60.

Furthermore, some areas where the water enters into contact with the surfacing magma fluids from the later phases of the volcanic activity, are characterized by the presence of thermal springs and water with particular chemical compositions.

In the four GWBs hydrogeological balance calculations were carried out analyzing the spatial and temporal variability of precipitations and climatic conditions on a monthly basis, analyzing the effects of morphological, lithological, pedological conditions, vegetation and land use on runoff and evapotranspiration with elevated spatial detail, estimating the withdrawals. Fig. 1 illustrates the total hydrogeological balance of the Colli Albani hydrostructure.

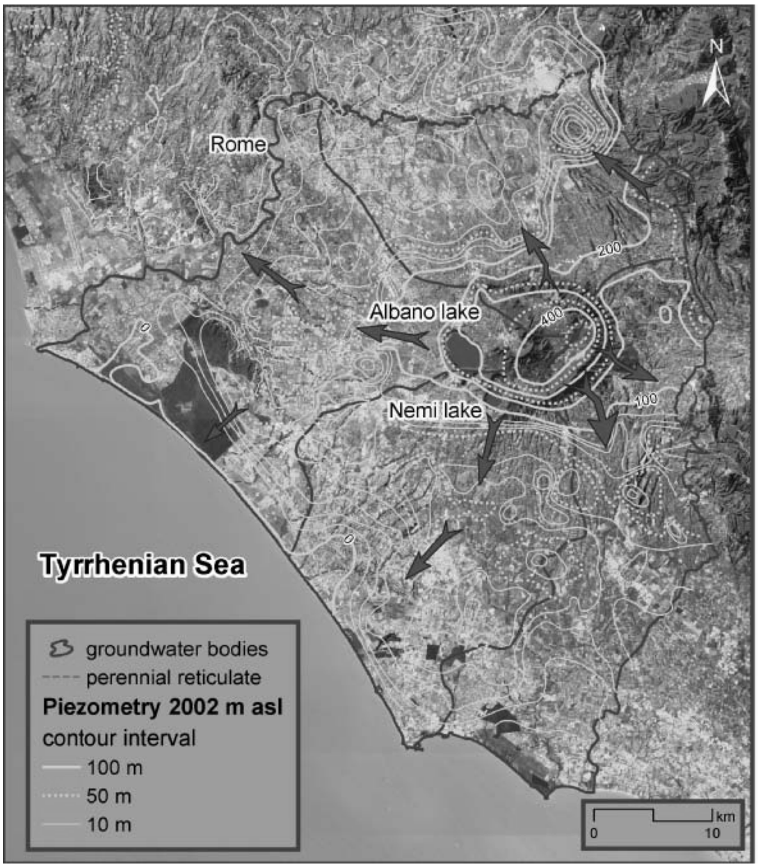
The most important results of the hydrogeological study carried out on the Colli Albani aquifer showed how in the last years, also due to a decrease of rainfall, especially during the winter season, the base flow in surface watercourses dropped by 50%. In particular, the water level of Albano lake, which is in direct contact with the aquifer, dropped by about 2 m.

Considering that surface base flow is fundamental in sustaining aquatic ecosystems and that the flow of water bodies receiving wastewater discharge determines the quality status of water bodies, it is very important to maintain the base flow at a level compatible with the life of aquatic ecosystems and the achievement of good quality status.

Overexploitation is the main problem in this area and it varies from 44% to 111% (ratio of water abstraction rate to effective infiltration), with an average of 71%. The qualitative analyses were carried out in the context of the BRIDGE project, aimed at the definition of Natural Background Levels and the respective thresholds for groundwater in accordance with the Groundwater Daughter Directive, through the application of the methodologies developed under the BRIDGE project.

Numerous impacts regarding the following receptors have been identified: groundwater itself, terrestrial ecosystems dependent on water, aquatic ecosystems and drinking water. The background hydrogeochemical characteristics of the Colli Albani hydrostructure are very variable due to the interaction of surface groundwater circulation with deep-seated gasses and fluids. More or less aggressive waters react with aquifer rocks and mixing phenomena take place in different parts of the aquifer. In the case study the high geochemical variability of groundwater was demonstrated by a statistical analysis of data from 15 springs and 50 wells distributed in the entire structure. The high variability of the chemical characteristics and consequently of the natural background levels of volcanic aquifers suggests that WP3 methodologies can be applied successfully only if the water families that interact with receptors are identified first.

The methodologies were studied in depth and applied to two specific cases: saline intrusion and water abstraction for drinking water use. In the remaining cases further investigations to define NBL values and trend reversal thresholds are being carried out.



Annual average in mm of water balance components in the Colli Albani hydrostructure (average value of years 1997-2001).

	l/s	% of P
Precipitation*	45 925	100.0
Evapotranspiration	21 659	47.2
Runoff	8 610	18.7
Effective Infiltration	15 364	33.5
Base flow in the riverbed (from in situ measurements)	3 893	8.5
Abs. for agricultural use	2 900	6.3
Abs. for industrial use	4 696	10.2
Abs. for drinking water	3 347	7.3
Total abstraction	10 943	23.8

* Comprises 5.7 Mm^3/year of precipitation in the lakes

Fig. 1. Piezometric map of the Colli Albani volcanic hydrostructure indicating the main groundwater flow directions, water bodies and rivers generated by groundwater interactions. The table shows the hydrogeological balance components .

Keywords: Water management, Threshold values, volcanic aquifer, dependent ecosystems, groundwater/surface water interactions

TOPIC 13

Groundwater modelling: deterministic and stochastic approaches

A mathematical model for prediction of water table variation induced by time varying recharge and/or withdrawal

[1]S.N. RAI, [1]A. MANGLIK

[1]National Geophysical Research Institute, Hyderabad 500007, India, e-mail: snrai_ngri@yahoo.co.in

ABSTRACT

The dynamic behaviour of the water table is influenced mainly by recharge and/or withdrawal of ground water. Excess recharging of groundwater may lead to the increase of the water table near to the ground surface, which may cause several kinds of environmental problems such as water logging, soil salinity etc. On the other hand, withdrawal of ground water in excess to replenishment may lead to the undesired lowering of the water table. This too may cause several kinds of problems such as failure of the wells, subsidence, groundwater pollution due to encroachment of pollutants from nearby regions etc. Such groundwater related problems give rise to socio-economic problems to the water users. Therefore an accurate estimation of the water table variations in response to operational or proposed schemes of recharge and/or withdrawal is essential for the proper management of groundwater resources to avoid or at least minimize the effects of above mentioned problems. Artificial recharge and withdrawal are intermittently practiced depending on the the availability of rechargeable water and the demand for water supply, respectively and their rates are known to vary with time. The present work deals with the development of an analytical mathematical model to predict water table fluctuation induced by intermittently applied time-varying recharge and/or withdrawal from any number of recharge basins, pumping wells and leakage sites of different sizes. The time-varying recharge rate (or withdrawal) is approximated by a number of linear elements of different lengths and slopes depending on the nature of variation in recharge/ withdrawal rate. The advantage of this scheme of recharge rate approximation is that any type of variation in the recharge rate for any number of recharge cycles from any number of basins of different sizes in rectangular shape located anywhere within the region of model area can be approximated more accurately with the help of required numbers of line elements of different lengths and slopes depending on the nature of variation in recharge rate. The same logic is applicable to the pumping rates. Application of the model for prediction of water table fluctuations in the presence of recharging, pumping and leakage is demonstrated with the help of an example problem. Numerical results reveal that variation in the rates of recharge, pumping and leakage significantly influence the growth and decline of the water table. This model can be used to make a judicious selection of an appropriate groundwater resources development scheme out of many proposed schemes for proper management of groundwater resources. Accurate estimation of the varying rate of recharge is a major problem in the sustainable management of ground water resources. If the time history of water table variation at the site of observation well is known, then the present model can be used for the estimation of varying recharge rate by making a judicious selection of recharge rate using a trial and error method so that the computed water table matches well with the observed water table variation. This model can be also used to test the validity of results of a numerical model in the developing stages before its application to the real field problem.

Keywords: Mathematical model, Water table, Prediction, Recharge

Characterization of groundwater level fluctuation with respect to riverbank filtrate production and stream discharge

[1]Jae-Yeol CHEONG, Se-Yeong HAMM [2] Keon-Tae SOHN, [3]Hyoung-Su KIM,
[1]Jeong-Hwan LEE, [3]Hee-Jun SUCK

[1]Division of Earth and Environmental System, Pusan National University, Pusan 609-735, Korea,
e-mail: hsy@pusan.ac.kr
[2] Dept. of Statistics, Pusan National University, Pusan 609-735, Korea
[3] Korea Institute of Water & Environment, Korea Water Resources Corporation, Daejeon 305-730, Korea

ABSTRACT

In general, groundwater levels fluctuate as seasonal recharge and discharge change. Recharge and discharge rates are closely related to hydraulic parameters, hydraulic boundaries and the geometry of geological media. When an aquifer is located adjacent to a stream acting as a recharge boundary, the groundwater level of the aquifer is directly affected by the stream discharge variation. Thus, when developing riverbank filtrate, groundwater level fluctuations should be evaluated in conjunction with the variation in pumping rate and seasonal stream discharge.

In Korea, most of the country suffers from poor drinking water quality due to degradation of the surface water quality. In particular, the downstream area has critical water quality problems compared to the upstream area. Riverbank filtration is becoming attractive as a substitute water source for central and local governments. The drinking water for Changwon city is supplied mostly from the Nakdong River. Recently, Changwon City developed a riverbank filtration site in Daesan-myeon, near the Nakdong River, to supply drinking water. Total pumpage from the site is 6,000-8,000m^3/day and this will be increased gradually in the future.

The aim of this study is to characterize the seasonal fluctuation of the groundwater level through pumpage and stream discharge at the riverbank filtrate site, based on the relationship between the drawdown-pumpage ratio and stream discharge, and also time series analyses.

The geology is composed of fluvial deposits containing upper fine to medium sands and lower fine sands as well as a sand/gravel layer, with a high hydraulic conductivity, from the ground surface to a depth of 60 m. The geology data was obtained from the drilling logs of pumping wells and monitoring wells.

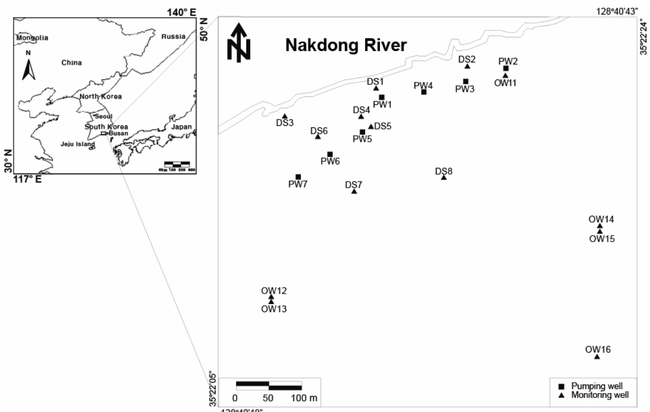


Fig. 1. Locality map of the study area, indicating well locations.

The ratio of drawdown at the 11 monitoring wells to the pumping quantity (pumpage) at pumping wells range from 105 to 2.639 m^3/day. The drawdown ratio slightly decreases in the dry season (January and February) and increases in the wet season (August) (Fig. 2). The relation of drawdown at the monitoring wells and stream discharge is not clear. However, a strong logarithmic relationship exists between the drawdown ratio and the stream discharge, with a correlation coefficient of 0.96. Hence, in the wet season, as the stream discharge increases the drawdown rate decreases. We can use the relationship between stream discharge and drawdown ratio to predict optimal pumping quantity when producing riverbank filtrate.

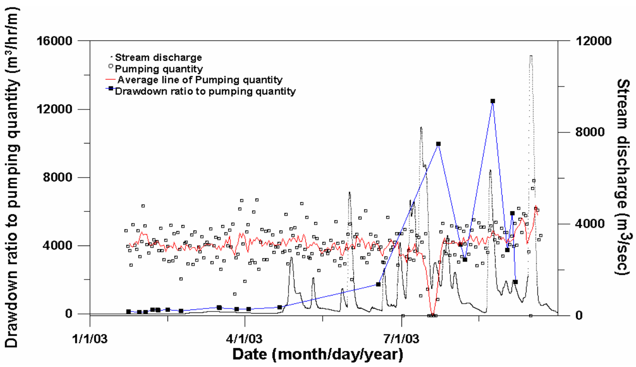


Fig. 2. Figure showing the drawdown ratio in relation to the daily pumping amount.

Time series analysis (autocorrelation, cross-correlation and spectral analysis) was carried out at six monitoring wells for characterizing temporal variation in groundwater level and groundwater quality. Autocorrelation analysis gives group 1 (DS1 and DS3) linked to the river-water level, group 2 (DS1 and DS6) linked to both pumping discharge and the river-water level, and group 3 (DS4 and DS7) strongly linked to pumping discharge (Fig. 3).

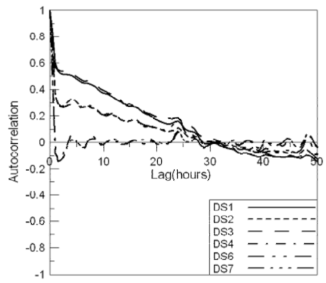


Fig. 3. Autocorrelation functions of half-hourly groundwater level fluctuations at the monitoring wells.

Acknowledgement

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Keywords: pumping quantity, groundwater level, drawdown ratio, stream discharge, time series analysis

Conceptual and numerical model of groundwater flow for a coastal plain (Piani di Sibari, southern Italy)

M. POLEMIO [1], G. LUISE [2]

[1] CNR-IRPI, via Amendola, 122/I, Bari, Italy
[2] HYDROCONTROL, Cagliari, Italy

ABSTRACT

The Sibari Plain, the main coastal plain of Calabria region (southern Italy), at most 300 m a.s.l, is 450 km^2 wide and comprises 24 hydrographic basins with mouths on the Ionian Sea. It is bordered by the carbonate group of Pollino Mount (to NW), the Coastal Chain (to W) and the Sila Massif (to S) and it is constituted by sedimentation of Crati river and its tributaries. In this plain, in different periods, the river network was subjected to a series of hydraulics works aimed at coping with both the flood damage and the diffuse water pounding which was the triggering factor for the malarial diffusion.

On the basis of a huge analysis of tens of geophysical studies and many hydrogeological surveying campaigns, the conceptual model of the whole plain is defined.

The numerical model of flow is calibrated taking into consideration climatic, river yield and piezometric data and it is utilised to evaluate the effect of current groundwater discharge by wells. The exchange with the river network, the deep outflow of mountainous aquifers, located on the boundaries of the plain aquifer, the exchange with deeper aquifers, the relationship with the sea, the effect of discharge for irrigation and the artificial recharge due to irrigation surplus, where other water resources are used for irrigation, are considered or simplified in the numerical modelling.

The numerical simulation of the current stage of groundwater discharge shows it is not sustainable. It shows that not only the quantity, but also the distribution of discharging areas is not rational. The discharge should be reduced and, mainly, redistributed to areas of high transmissivity and low discharge rate.

The numerical results are compared and validated using a time series approach based on the utilisation rainfall, temperature and piezometric data collected from the 1930s to 2006 *in-situ* measurements.

Keywords: porous coastal aquifer, modelling, groundwater/surface-water interaction

Choices between conceptual models and structure generating algorithms for heterogeneous hydraulic conductivity fields: impact on groundwater surface water interaction in a palaeochannel system

[1]R.W. VERVOORT, [1]C.P. VANAGS

[1] Hydrology Research Laboratory, Faculty of Agriculture, Food and Natural Resources, The University of Sydney, NSW 2006 and Cotton Catchment Community CRC.e-mail:w.vervoort@usyd.edu.au

ABSTRACT

The floodplains of the Murray Darling Basin of Australia, which are used extensively for furrow irrigated agriculture, are intersected widely by palaeochannels or prior stream deposits from distant ages. Recent pressure on water use efficiency due to prolonged drought has focused attention on water losses through these coarser grained sediments. One of the problems in deciding and focussing investment is the lack of quantification of water losses from irrigation channels and fields, partly due to expensive instrumentation. Using electromagnetic induction to characterise the sediments for parameterisation of groundwater models appeared an attractive option. However this leads to questions about the choice of conceptual forward model and the accuracy of the inversion algorithm. In this study three different major approaches were used to generate the hydraulic conductivity fields from electromagnetic and soil property data.

These three different approaches all incorporate a range of choices about inversion and structure generating algorithms, such as scaling, indicator kriging and the use of predefined geomorphic units. The first approach used the linear forward model suggested by McNeill (1980); the second approach used the Tikhonov inversion suggested by Borchers (1997). The final model used a random allocation of hydraulic conductivity using predefined geomorphic units. The use of predefined units is useful as the hydraulic conductivity distributions are distinctly tri modal, and a reasonable density of data is available to identify the units. The inversion algorithms were able to clearly delineate the palaeochannel stratigraphy (Fig. 1).However, the models predicted similar, but different hydraulic conductivity fields (Table 1).

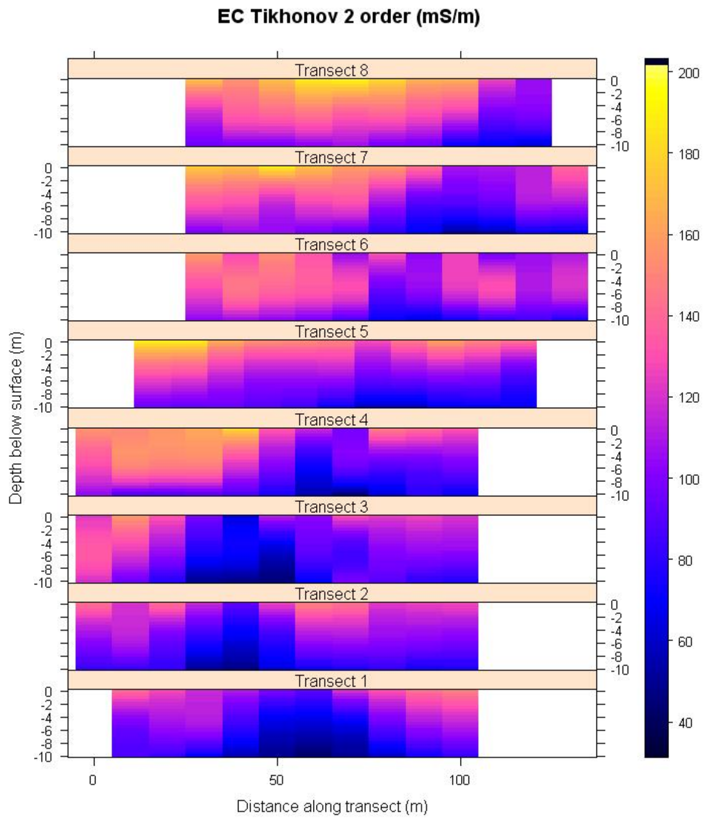


Fig. 1 Example of the inverted electromagentic data, clearly idenitfying the palaeochannel sediments as an area of lower conductivity. Transects are 60 meter apart along an irrigated field.

Table 1. Correlation matrix between spatial patterns of different inversion methods, McNeill (McN), Tikhonov (T) 0 order, 1st order and 2nd order and different scaling methods; clustered (C), not clustered (NC) and logistic (L). The matrix indicates that most methods and inversions are fairly corrletaed in the spatial patterns, except for the McNeill inversion method, which fails to positivelycorrelate with any of the other results.

	McN C	**McN NC**	**McN L**	**T0 C**	**T0 NC**	**T0 L**	**T1 C**	**T1 NC**	**T1 L**	**T2 C**	**T2 NC**	**T2 L**
McN C	1.00											
McN NC	-0.05	1.00										
McN logis	-0.10	0.91	1.00									
T0 C	0.07	-0.75	-0.65	1.00								
T0 NC	0.07	-0.81	-0.71	0.99	1.00							
T0 logis	0.08	-0.91	-0.82	0.89	0.94	1.00						
T1 C	0.21	-0.36	-0.27	0.76	0.70	0.49	1.00					
T1 NC	0.15	-0.43	-0.29	0.75	0.70	0.51	0.92	1.00				
T1 logis	0.14	-0.51	-0.39	0.72	0.68	0.54	0.79	0.90	1.00			
T2 C	0.17	-0.45	-0.39	0.79	0.74	0.54	0.95	0.89	0.78	1.00		
T2 NC	0.15	-0.54	-0.45	0.82	0.78	0.62	0.93	0.95	0.84	0.96	1.00	
T2 logis	0.15	-0.69	-0.60	0.81	0.80	0.72	0.75	0.85	0.92	0.80	0.88	1.00

Comparison of the predicted groundwater surface water interactions using MODFLOW with the observed field data indicate a distinct difference, with some structure generating algorithms (linear inversion of the EM data and all subsequent scaling algorithms) clearly not being able to represent the groundwater surface water interactions in the system. Others do give reasonable results, but its added value is questionable due to the large data needs and low correlations (regression kriging of the soil and EM data). This has clear implications for the use of such algorithms to derive heterogeneous hydraulic conductivity fields for modelling in this area.

Keywords: Hydrogeology, electromagnetic inversion, groundwater modelling, palaeochannels

Density dependent flow and multi species reactive transport modeling: Application to calcareous coastal aquifers

Ezzeddine LAABIDI & Rachida BOUHLILA

Lab. De Modélisation en Hydraulique et Environnement (LMHE)-ENIT- TUNISIA
bouhlila.rachida@enit.rnu.tn

ABSTRACT

Several experimental works and real situations show calcite dissolution - precipitation mechanism in coastal aquifers (Andersen *et al.*, 2005, Rezaei, *et al.*, 2005). These processes are governed by calcite equilibrium displacement in freshwater and seawater mixing zone. They can induce notable modifications of the hydrodynamic properties, porosities and permeabilities, in aquifers (Romanov *et al.*, 2006). We present, in this work, a density dependent flow and multi-species geochemical model in porous media (Bouhlila, 1999 and 2006) extended to carbonate species (Laabidi, 2007). Salts and brine geochemistry is described according to the Pitzer model (Morel, 1994) and a consistent numerical scheme for Darcy's velocities in density dependent flow (Bouhlila, 1999 and 2006) is used. The Hydrogeochemical model thus written, checked and validated, is used to simulate flow, solutes transport and calcite dissolution – precipitation reactions in a calcareous coastal aquifer with a geometry and hydrodynamic parameters that correspond to the Henry's problem.

Keywords: multi species reactive transport; density dependent flow; calcite dissolution; costal aquifer; Henry problem

Several experimental works and real situations (Andersen *et al.*, 2005, Rezaei, *et al.*, 2005) show calcite dissolution - precipitation mechanism in coastal aquifers. These processes are governed by calcite equilibrium displacement in fresh and sea water mixing although both the two waters do not dissolve this mineral. They can induce notable modifications of the hydrodynamic properties, porosities and permeabilities, in aquifers (Romanov *et al.*, 2006) and thus enhance the salt water intrusion. We present in this work a density dependent flow and multi-species geochemical model in porous media (Bouhlila, 1999 and 2006) extended to carbonate species (Laabidi, 2007). To take into account these species, the geochemical module, initially based on Pitzer model for salt and brine, is extended to consider equilibrium reactions between H^+, OH^-, $CO_3^{=}$, HCO_3^- and H_2CO_3 in the solution. Experimental results of calcite dissolution precipitation in fresh water – sea water mixture are used to validate the geochemical module.

In the same way, the density dependent flow and transport module was extended to all these species and checked with respect to known solutions and compared to other models' results.

The coupling procedure between the two modules consists of testing at each point of the medium, and each time the solution equilibrium with respect to all the salts of the data base. A saturation index higher than 1 will induce the precipitation of the corresponding salt and of less than one, will induce the dissolution of the corresponding salt if it is present in the solid matrix. According to the computing time step length, these reactions are considered as equilibrium ones or with a kinetic evolution. Obviously, the porosity and the permeability of the medium will be modified consequently.

The hydrogeochemical model thus written, checked and validated is used to simulate flow, solutes transport and calcite dissolution – precipitation reactions in a calcareous coastal aquifer. The geometry and parameters considered are those of the well known Henry's problem.

As an application, we simulate sea-water intrusion with and without calcite dissolution in a vertical section of Zeuss-Koutine aquifer (South-East of Tunisia).The results are expressed as a sea-water penetration length function of exploitation rates, with and without calcite dissolution.

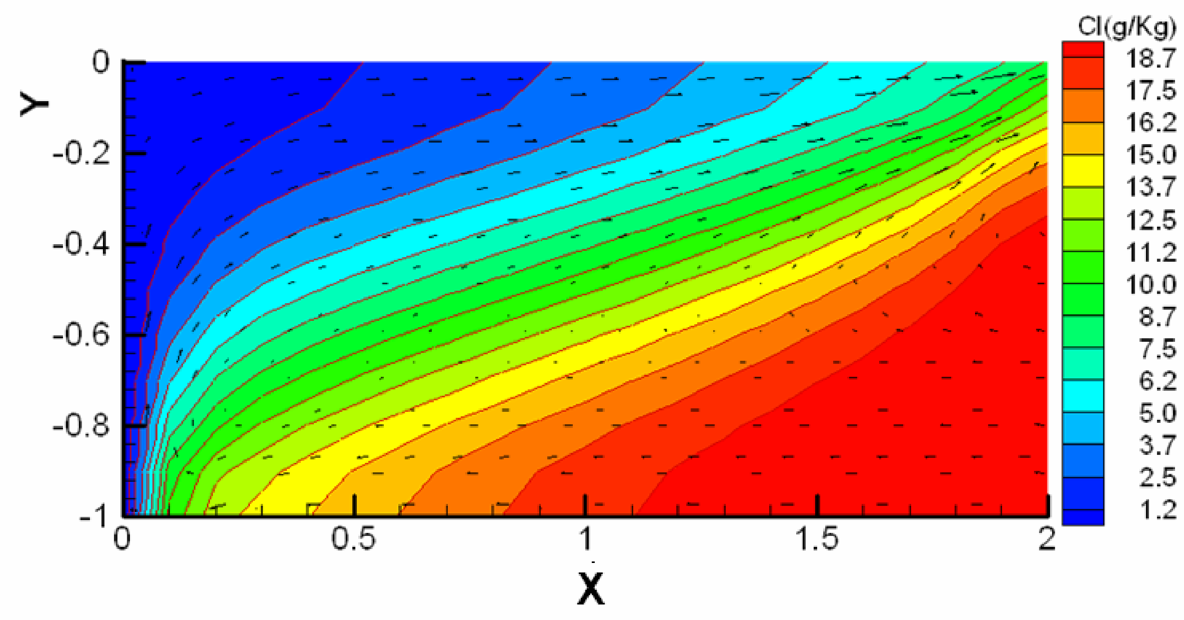


Fig. 1. Cl⁻ concentrations and velocities in the Henry problem with calcite dissolution.

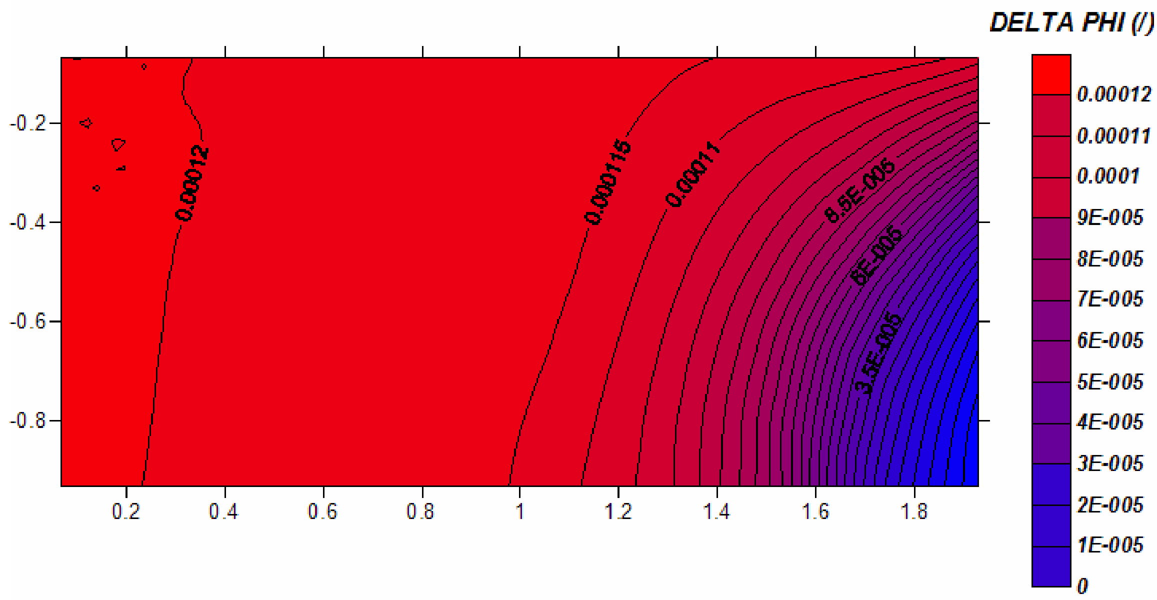


Fig. 2. Porosities change in the Henry problem with calcite dissolution.

Deterministic and stochastic Modeling of Groundwater Flow and Solute Transport in the heavily-stressed Bangkok coastal Aquifer, Thailand, and Investigation of optimal Management Strategies for possible Aquifer Restoration

Manfred KOCH and Phatcharasak ARLAI

Department of Geohydraulics and Engineering Hydrology, University of Kassel, Germany.
e-mail: kochm@uni-kassel.de, arlaip@uni-kassel.de

ABSTRACT

As part of a comprehensive study of the Bangkok coastal multi-aquifer system (Arlai, 2007) which, in the wake of a tremendous population- and industrialization increase in recent decades in that major part of Thailand, has come under heavy stress, leading to a decline of both groundwater tables and -quality, numerical simulations of the relevant groundwater flow and transport processes under the present-day- and possible future stress conditions have been performed. The major objectives of these investigations, the approaches taken, and the results obtained to that regard are as follows: (1) 3D steady-state and transient calibration of the multi-layered aquifer flow system using the MODFLOW model, including automatic parameter estimation code UCODE; (2) stochastic MC-simulations to take into account the uncertainties of aquifer parameters, observed heads and reported pumping rates and comparison with results of analytical stochastic theory; (3) MTD3MS solute transport modeling and the determination of the cradles of saline groundwater pollution encountered in most sections of the aquifer system and which are supposed due to either the horizontal seawater intrusion from the Gulf of Thailand and/or the widespread upper marine clay layer containing saline formation waters; (4) analysis of the present-day and future sustainability of the groundwater resources in the aquifer, both quantitatively and qualitatively, by calculation of the “sustainable yield” of the aquifer. It turns out that this has already been exceeded and will be even more in the future target year 2032. This means that there will be an “unmet water demand” that is computed for the various provinces; (5) numerical investigation of feasible aquifer restoration (remediation) schemes through groundwater management strategies that include “policy”- or “non-constructive” measures, as well as a combination of “policy”- and “constructive” (use of recharge- and clean-up wells) measures by trial and error approaches; (6) use of an optimization groundwater management tool (GWM) to fine-tune the search for optimal recharge-discharge schemes for aquifer restoration; (7) investigation of the possible effects of the, hitherto, neglected density-dependency of the flow on the saline plume concentrations on the results obtained above, using the variable-density SEAWAT-2000 model and where, surprisingly, the conclusions are that such a, computationally much more burdensome, approach may not be needed in the present groundwater flow and transport application. Putting all things together, the present exhaustive modeling exercise should offer Thai water management authorities some important guidelines for the future management of the Bangkok aquifer, one of the most precious, but also most vulnerable groundwater resources of Thailand.

Reference

Arlai, P. (2007), *Numerical Modeling of possible Saltwater Intrusion Mechanisms in the Multiple-Layer Coastal Aquifer System of the Gulf of Thailand,* Ph.D. Thesis, University of Kassel, Germany.

Keywords: Groundwater flow, solute transport, modeling, deterministic, stochastic, MODFLOW, UCODE, MT3DMS, SEAWAT-2000, Bangkok coastal aquifers, salt-, seawater intrusion, restoration schemes, optimization.

Differentiating between local and regional recharge of an alluvial aquifer in a semi arid area using multidimensional analysis and geochemical modeling

[1]F. ACHOUR, [2]J.P. MONTEIRO, [3]M. ASSABA

[1]ENVIRON International Corporation, 2010 Main Street, Suite 900, Irvine CA-92614
[2]UCTRA-CVRM – Algarve University, Geosystems Center, Portugal
[3]Cabinet Risser, 89 bd du Point du Jour 06700- Saint laurent du Var – France

ABSTRACT

Chelif basin is located in western Algeria in North Africa, between the Dahra and Ouarsenis mountain ranges. It has a rainfall of 370 mm/year and an evapotranspiration rate of 350 mm/year. Despite its proximity to the Mediterranean Sea, the Chelif basin is characterized by a semi arid climate. The river is considered to be the most important river in Algeria and is more than 700 km long. Its source is the Atlas Mountains and ends in the Mediterranean Sea. The Chelif plain is constituted by thick silty sand formations in the central and northern part of the plain, and by calcareous formation in the southern part. Triassic geological formation is known to be located several miles away in the high Ouarsenis mountain range.

Water resources availability and a vulnerability study was carried out in the Chelif plain, between the two major cities of El Asnam and Boukadir. However, several questions remained unanswered. These are: *What are the main recharge areas of the Chelif aquifer? How do the local and the regional groundwater recharge impact the quantity and quality of water both spatially and temporally of the plain?*

For this purpose, a new methodology, based on multidimensional analysis applied to geochemical and water level data was developed in order to reveal the hydrodynamic behavior of the Chelif aquifer, thus, optimizing the way the water resource might be utilized.

Water samples were collected from the plain in 60 wells sampled over a four year period during high and low water stand. Field data included water temperature, pH, alkalinity, and total hardness; other analyses determined Ca^{2+} ,MG^{2+}, NA^{+}, K^{+}, CL^{-}, NO3 + and SO_4^{2-} concentrations.

Principal Component Analysis (P.C.A) was used to determine the different water types present within the dataset and their source. Several successive factor analyses were necessary to select the appropriate samples and variables for extracting the hydrogeological information. Discriminant Factor Analysis (DFA) was used to validate the results obtained by PCA by adding a qualitative variable to the analysis which consisted in the belonging group based on spatial distribution as well as temporal distribution.

Geochemical modeling was used to compute the fictitious partial pressure of CO_2 within the sampled waters. The characteristics of PCO2 is that it is low for groundwater of shallow origin, influenced by surface waters, and high for groundwater of deep origin. The values obtained within the study showed that waters found in the plain, have both a regional and a local origin. The relative importance of each is based upon the climatic conditions prevailing in the basin and this confirms the results obtained by multivariable analysis.

Keywords: Semi arid area, recharge, principal component analysis, geostatistics, factorial discriminant analysis. Algeria

Estimation of actual evapotranspiration by numerical modelling of water flow in the unsaturated zone

Luis GUARRACINO, Andrés CESANELLI

CONICET, Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, Paseo del Bosque S/N, B1900FWA La Plata, Argentina, e-mail: luisg@fcaglp.unlp.edu.ar, chacho@carina.fcaglp.unlp.edu.ar

ABSTRACT

Knowledge of actual evapotranspiration (ET_a) is fundamental to obtaining reliable estimates of groundwater recharge and to understanding the occurrence of flood disasters in flatland areas of Buenos Aires Province (Argentina). The fraction of water extracted from soil by plant root system and evaporation process is approximately 80 % of long-term annual precipitation in the study region. Due to complex interactions amongst the components of the land-plant-atmosphere system the estimation of ET_a is one of the most difficult tasks in hydrogeology and soil sciences. The objective of this study is to present a new model to estimate ET_a from reference evapotranspiration (ET_0) by numerical modelling of evaporation, transpiration and water flow processes in the unsaturated zone of the soil. Water flow in the unsaturated zone plays an important role in root uptake and atmospheric interactions. Unsaturated flow is modelled by solving the highly non-linear Richards equation in conjunction with the van Genuchten constitutive model and appropriate boundary conditions. Evaporation from soil surface is modelled as a Neumann boundary condition and root uptake is simulated by adding a sink term in Richards equation. The top boundary condition and the sink term are assumed to be functions of both ET_0 and Leaf Area Index (LAI). Richards equation is solved in one dimensional domains using a mixed finite element method for space discretization combined with a backward Euler scheme in time and a modified Picard method to treat the non-linear terms. Finally, the values of ET_a are obtained by applying correction factors to ET_0 to account for soil moisture changes during simulation period. The proposed numerical model is used to estimate ET_a in an experimental plot located in La Plata (Buenos Aires). In this study ET_0 is computed using the Penman-Monteith equation with daily resolution. The available meteorological data include air temperature, wind speed, sun shine hour, relative humidity and precipitation. LAI values and soil properties are obtained form the literature. Numerical results show that the proposed model is a useful tool for evaluating evapotranspiration under different scenarios and for studying problems like the influence of crop rotation on flood events.

Keywords: actual evapotranspiration, unsaturated zone, numerical modelling

Hydrogeology and thermal modelling of the site for a borehole heat exchanger system

Byoung Ohan SHIM, Yoonho SONG

30, Gajeong-dong, Yuseng-gu, Daejeon-city, South Korea, e-mail: boshim@kigam.re.kr

ABSTRACT

The long-term monitoring of ground temperature and borehole heat exchange rate have been conducted with the use of a geothermal heat pump system installed in the earthquake research center building of Korea Institute of Geoscience and Mineral Resources (KIGAM). A total of 79 heat pumps were installed in the building. Monitoring equipment at three borehole heat exchangers and observation borehole were used to measure circulating fluid temperatures, flow rates and groundwater temperatures (Fig. 1). Data on three borehole heat exchangers were automatically transmitted to a monitoring system, and heat exchange rate variation and the ground temperature of the geothermal heat pump system in winter and summer period were analyzed. Different heat exchange patterns were registered in summer and winter because of the heat source and heat sink of the system. The long term operation of the system can affect the performance of the system and cause underground thermal storage to occur. Therefore, the monitored data could be used to predict the performance and prevent the decrease of heating or cooling capacity. Also, in order to define hydraulic characteristics and groundwater temperature variation, the relationships among air temperatures, groundwater temperatures, water table, and precipitation were analyzed. The estimated heat flux of the site is 59.7mW/m-K which is obtained from the geothermal gradient (20^{o}C/km) and thermal conductivity (2.98 W/m-K). In order to estimate future performance of the system, numerical modeling is carried out to simulate long-term thermal diffusion around the borehole heat exchanger system.

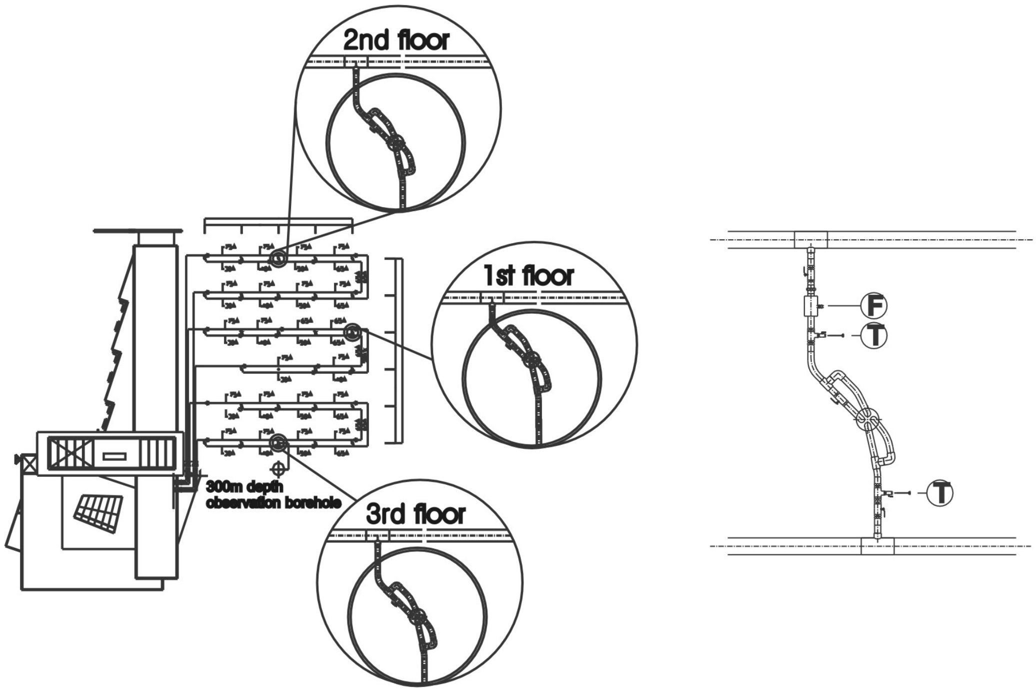


Fig. 1. Layout of borehole heat exchanger and monitoring system (F: flow meter, T: temperature sensor) of earthquake research center building in KIGAM.

Keywords: Hydrogeology, thermal diffusion, monitoring, modelling, borehole heat exchanger

Impact of burial of M30 highway in the subsurface hydrology of Madrid near the Manzanares river: 1. Evaluation with 3D numerical models

[1]Javier SAMPER, [2] Pedro E. MARTÍNEZ ALFARO, [3] Jorge MOLINERO, [2] Pedro MARTÍNEZ, [1]Liange ZHENG, [1] Mercedes BONILLA, [1]Changbing YANG, [4]Manuel MELIS

[1] Escuela Ingenieros de Caminos,Univ. de A Coruña. Campus de Elviña, s/n. 15071 Coruña: jsamper@udc.es
[2] Facultad de Geologia. Universidad Complutense de Madrid.
[3] Escuela Politécnica Superior. Univ. de Santiago. Campus de Lugo
[4] Escuela Ingenieros de Caminos,Universidad Politécnica de Madrid.

ABSTRACT

Burial of highway belt M30 in Madrid from Puente del Rey to Nudo Sur foreseen for the period 2005-2007 will create a large green area in the heart of the city. Highway M30 runs close to the Manzanares river over the alluvial aquifer which is surrounded by the Detritic Tertiary Tagus basin. Civil works could affect subsurface hydrology and cause changes in water table depths that might in turn damage foundations of nearby buildings (see Fig. 1).

Sophisticated three-dimensional (3D) groundwater flow models have been constructed in order to quantify the effects of tunnel works on groundwater heads and discharges to the Manzanares river. First, a regional-scale flow model (100 km x 30 km) was constructed which provided insight into the interactions of the regional detritic and alluvial aquifers and gave appropriate boundary conditions for the local-scale model.

The second 3D model is a local-scale finite element model which was divided into two parts of 2.5 km x 1 km and 50 m thickness each one (see Fig. 2). This model was calibrated under unaffected conditions (previous to start of works) using groundwater heads at 30 boreholes. The local-scale model was used to evaluate changes in groundwater heads caused by tunnel walls. Model results confirm that the foreseen underground drainage system is effective in maintaining hydraulic heads within the range of "original" values plus/minus an error bound of 0.5 m (see Fig. 3). Model results were used to propose a network of boreholes to monitor hydraulic heads during and after construction of the tunnel. Here we report the main features of both 3D models.

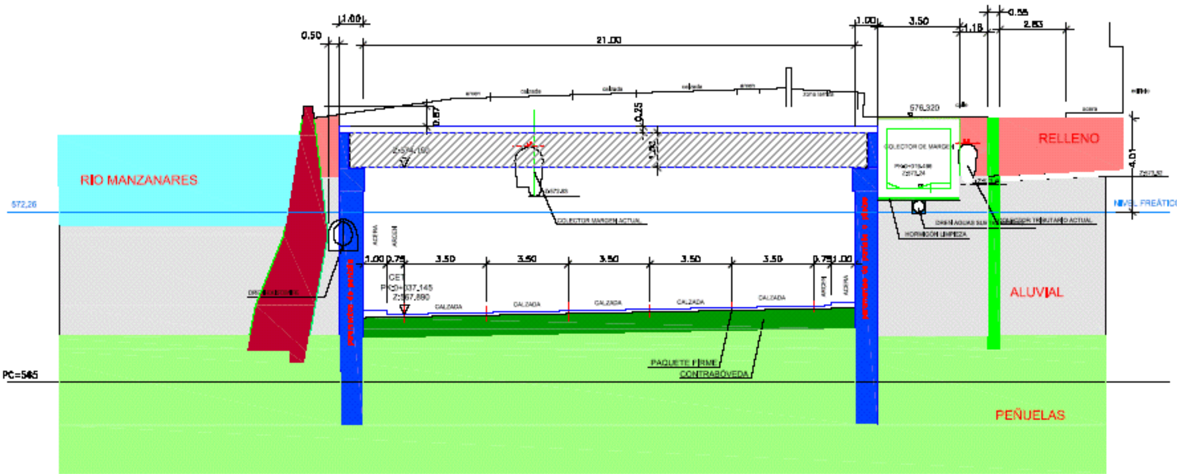


Fig. 1. Vertical cross-section perpendicular to Manzanares river. It shows the tunnel for the buried highway.

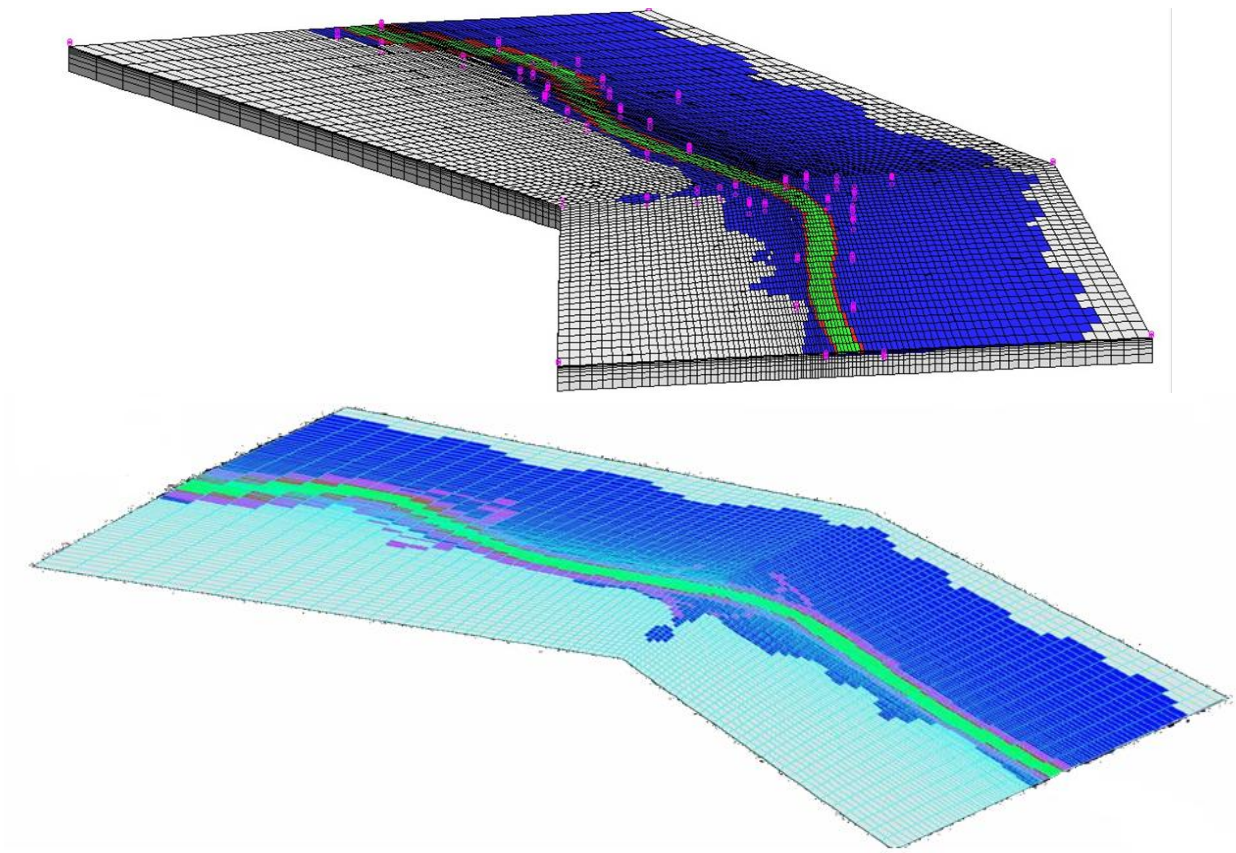


Fig. 2. Finite element grid used for the downstream half of the project from Puente de San Isidro to Nudo Sur to simulate: natural conditions (top) and affected conditions (bottom).

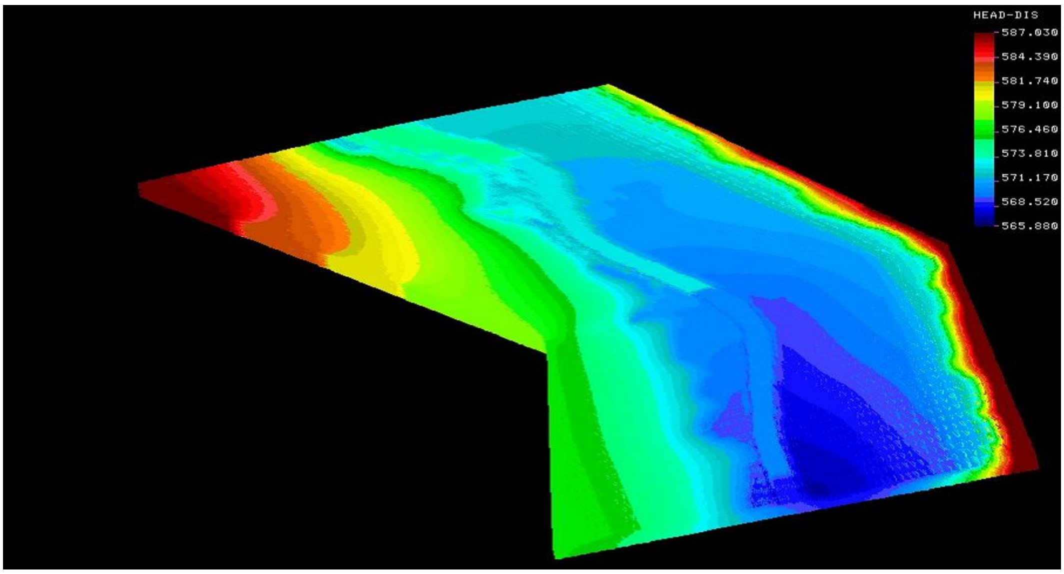


Fig. 3. 3D view of computed heads after construction is finished.

Keywords: Numerical model, groundwater/surface water interactions, civil works

Impact of burial of M30 highway in the subsurface hydrology of Madrid near the Manzanares river: 2. Transient head data from monitoring network and model testing

[1] Javier SAMPER, [1]Mercedes BONILLA, [2]José Antonio DÍAZ-LÁZARO, [2] José Luis BARROSO, [3] Fernando LÓPEZ-VERA, [1]Liange ZHENG, [4]Manuel MELIS, [5]Pedro ROMO, [5] Carmen GONZÁLEZ, [6] Pilar JAÉN, [1]Changbing YANG,

[1] Escuela Ingenieros de Caminos,Univ. de A Coruña. Campus de Elviña, s/n. 15071 Coruña: jsamper@udc.es
[2] Confederación Hidrográfica del Tajo. Madrid. Spain.
[3] Facultad de Ciencias. Universidad Autónoma de Madrid.
[4] Escuela Ingenieros de Caminos, Universidad Politécnica de Madrid.
[5] SECOIM. Ayuntamiento de Madrid. Spain
[6] GINPROSA. Madrid. Spain

ABSTRACT

Burial of highway belt M30 in Madrid from Puente del Rey to Nudo Sur foreseen for the period 2005-2007 will create a large green area in the heart of the city. Highway M30 runs close to the Manzanares rive over the alluvial aquifer which is surrounded by the detritic Tertiary Tajo basin. Civil works could affect subsurface hydrology, change water table depth and damage foundations of nearby buildings (see Fig. 1). Sophisticated three-dimensional (3D) groundwater flow models were constructed in order to quantify the effects of tunnel works on groundwater heads and discharges to Manzanares river (see the first of our 2-parts contribution). Model results confirmed that the foreseen underground drainage system will be effective in maintaining hydraulic heads within the range of "original" values plus/minus an error bound of 0.5 m. Models were used to delineate a network of more than 100 boreholes.

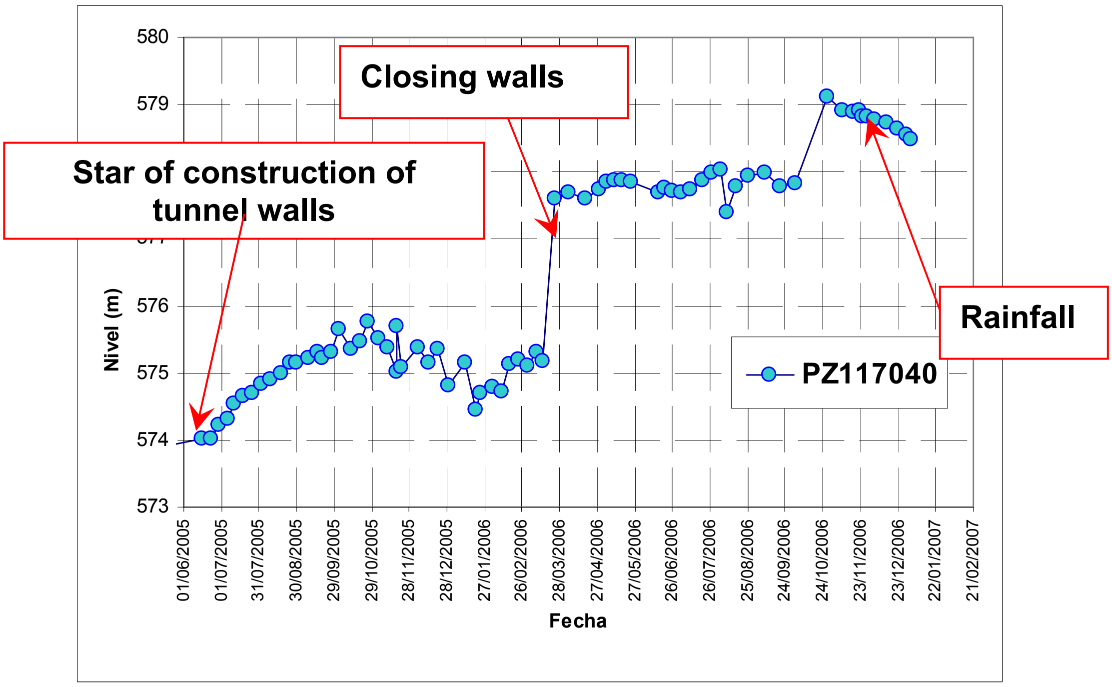


Fig. 1. Hydrograph of borehole PZ117040 which shows several trends associated to civil works and natural conditions (see level rising in Nov. 2006 caused by a heavy rainfall).

Groundwater levels have been monitored weekly since construction started in spring 2005 (see Fig. 1). Hydraulic head data have been useful to: 1) test and confirm model predictions; 2) Identify critical points, and 3) Identify situations in which pumping was required in order to prevent water table rising. Interpretation of water table drawdown data in some areas has been done by using 2-D finite element groundwater flow models (see Fig. 2). Here we report the main trends of transient head evolution during construction and the lessons learnt during this part of the project.

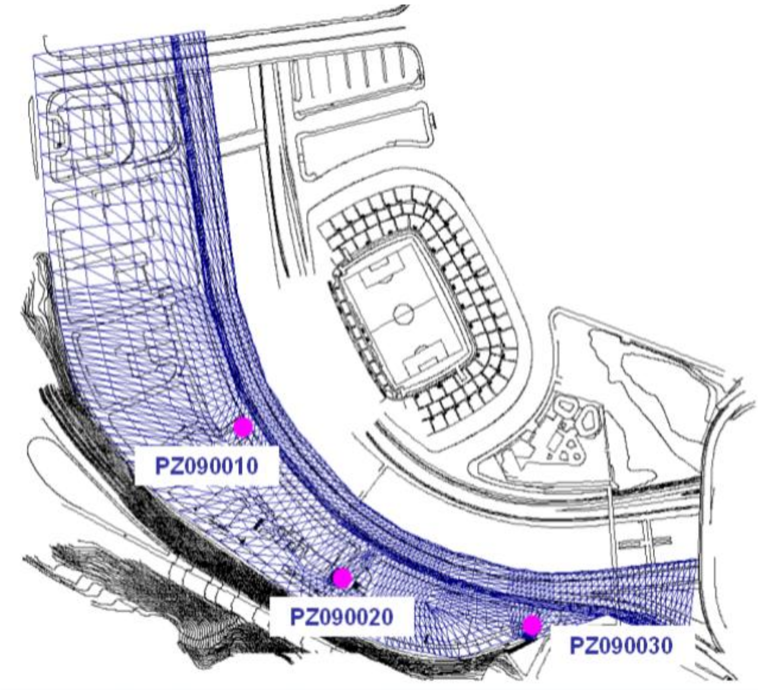


Fig. 2. Finite element mesh for a 2-D flow model of the Calderón area. Observation boreholes used to calibrate the model are also indicated.

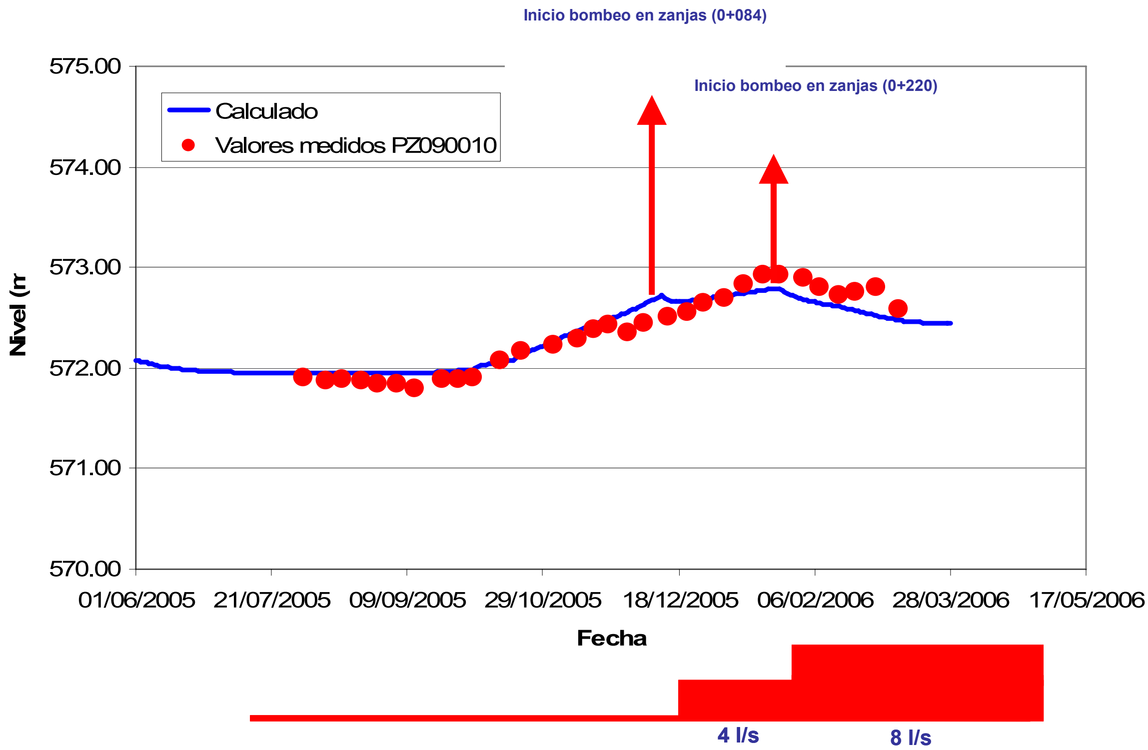


Fig. 3. Results of 2D numerical model for observation borehole PZ090010 (line is model results and symbols correspond to measured heads). Bottom histogram illustrates rates of pumping to lower groundwater table.

Keywords: Numerical model, groundwater/surface water interactions, Civil works

Impact of the Replacement of Groundwater by Dam Waters in the Albufeira-Ribeira de Quarteira and Quarteira Coastal Aquifers

[1]José Paulo MONTEIRO, [2]Manuel M OLIVEIRA, [3]João Pinheiro COSTA

[1] Universidade do Algarve, FCMA, Geosystems Centre CVRM, Campus de Gambelas, 8005-139 Faro, Portugal, e-mail: jpmontei@ualg.pt
[2] Laboratório Nacional de Engenharia Civil, Av. do Brasil, 1700-066 Lisboa, Portugal, e-mail: moliveira@lnec.pt
[3] Università degli Studi di Genova, Dipartimento di Ingegneria delle Costruzioni, dell'Ambiente e del Territorio (DICAT), Via Montallegro, 1 - 16145 Genova, Italy, e-mail: joao.costa@unige.it

ABSTRACT

Before the use of dam waters for urban water supply on a regional scale in the Algarve (Portugal) region at the end of XX century, coastal karst aquifers constituted the most important source of water for all kind of users. Therefore, almost all the hydrogeological research work, conducted in the Algarve Region in the 80's and 90's was based on data whose spatial distribution and temporal evolution were certainly biased by the superimposition of the pumping effects due to the water supply systems for domestic, industrial and agricultural use.

The substitution of the groundwater supply system by a system that explores dams at the start of the twenty first century, for public supply purposes, approximates the hydrodynamics of different coastal aquifers in Algarve in their natural conditions. The impacts of this substitution in the Albufeira-Ribeira de Quarteira and Quarteira aquifer systems are analysed.

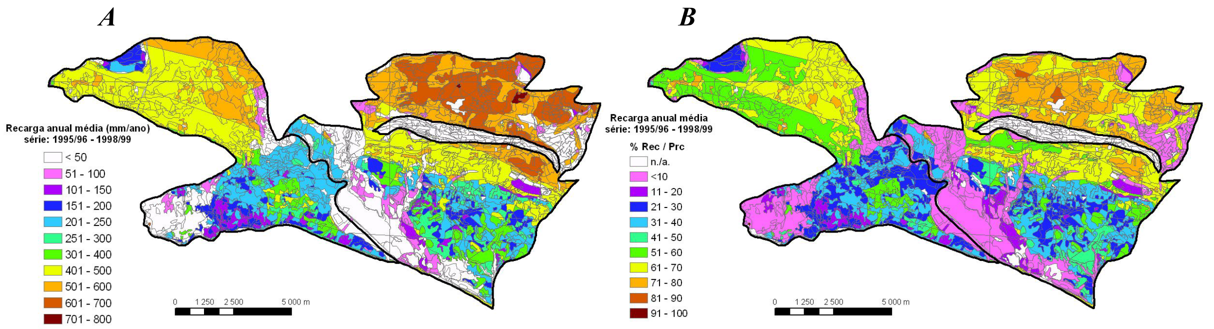
The Albufeira-Ribeira de Quarteira and Quarteira aquifer systems are divided in porous and in karst sub-systems. The main recharge area corresponds to the north system area (Jurassic limestones). In the places where the Miocene formations cover the Jurassic rocks, the recharge process is less important (due to the clay fraction of the cover deposits). The discharge area is located on the littoral strip and at the sea (Submarine Groundwater Discharge). The hydraulic behaviour of the systems is affected by the influence of the Quarteira river which is effluent on its final course, and influent toward north.

The research results presented in this paper are based in methodologies related to the characterization of the aquifer recharge and the inverse calibration of a finite element regional groundwater flow model. A number of conclusions can be drawn from the analysis of the impact of the changes in the hydraulic behaviour of the studied aquifer system, based on the analysis of different scenarios for the origins of the water supply.

The recharge was estimated with a daily sequential water balance model, which uses as input data the daily rainfall and the daily reference evapotranspiration and which quantifies the processes of the surface infiltration, the real evapotranspiration and the deep infiltration of the soil. The analysis comprised a period from 1995-10-01 to 1999-09-30.

The results obtained made it possible to estimate the recharge of the aquifer system of Albufeira-Ribeira de Quarteira, at about 308 mm/year and the recharge of the aquifer system of Quarteira in 349 mm/year. These values represent approximately 44% of the rainfall that occurs on the systems, corresponding to about 23% of the rainfall on the areas of occurrence of formations with an intergranular porosity, and between 63% and 69% on the areas of occurrence of karst formations. Fig. 1 shows the recharge distribution on the aquifer systems and the relation to the precipitation.

On the other hand, the simulations of different model variants, allowing the comparison between the natural balance of the aquifer system and different scenarios of water use, is a valuable contribution for the analysis of quantitative and qualitative risks associated to groundwater extractions. For instance, Fig. 2 shows the residuals calculated between two variants of the model implemented for the studied aquifers taking into account the natural water balance and the extractions in the main water wells used for water supply at the end of the XX century.



Source: Oliveira (2005)

Fig. 1. "Quarteira" and "Albufeira-Ribeira de Quarteira" aquifer systems: (A) Yearly average recharge (mm/yr) and (B) recharge rate in relation to precipitation (%). Hydrologic years 1995/96-1998/99.

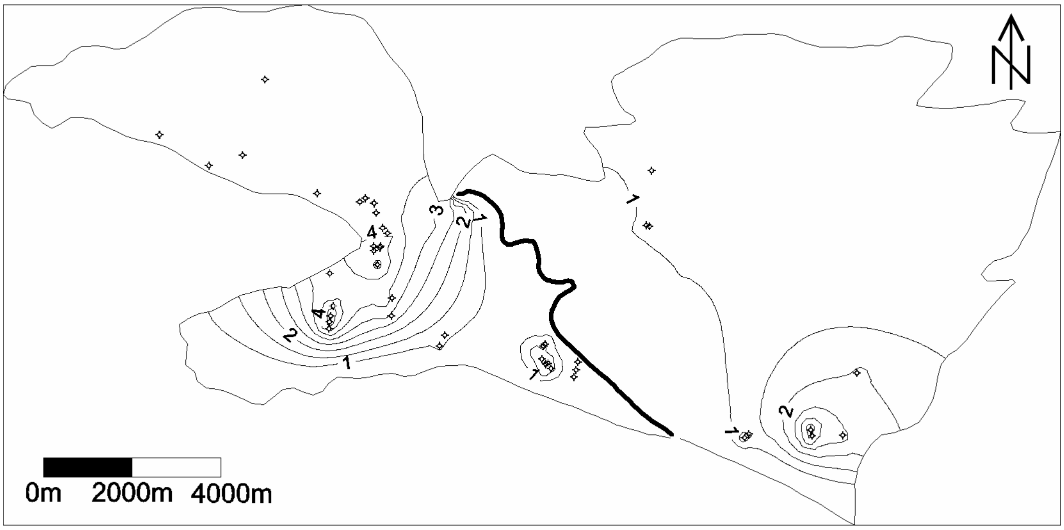


Fig. 2. Simulation of the impact of water wells in the spatial distribution of hydraulic head at the regional scale. Residuals calculated between two variants of the model implemented for the studied aquifers taking into account: (1) the natural water balance and (2) extractions in the main water wells used for water supply at the end of the twentieth century.

In addition to analysing the impact of the changes in the origins of the water supply that occurred in the Algarve in the last few years, the results of the research presented in this paper could contribute to establishing significant improvements in the formation of strategies for water management.

This study is being developed in the framework of the Project POCTI/AMB/57432/2004 "Groundwater flow modelling and optimisation of groundwater monitoring networks at the regional scale in coastal aquifers – The Algarve case study". This dissemination action is included in LNEC's Programmed Research Plan for 2005-2008 "Methodologies for the exploitation characterisation, management and sustainable development, quantitative and qualitative, of the groundwater resources" (Proc. 0607/11/16253).

Keywords: Inverse modelling, recharge, Portugal, water management

Karst springs discharge modelling by using the composite transfer functions: example of the Žrnovnica and Jadro Springs

[1] Vesna DENIĆ-JUKIĆ, [2] Damir JUKIĆ, [3] Goran VEGO

[1] Faculty of Civil Engineering and Architecture, University of Split, Matice hrvatske 15, 21000 Split, Croatia
e-mail: vdenic@gradst.hr
[2] Croatian Waters, Water Management Department Split, Vukovarska 35, 21000 Split, Croatia,
e-mail: djukic@voda.hr
[3] Civil Engineering Institute of Croatia, Hydrotechnics Department, Matice hrvatske 15, 21000 Split, Croatia,
goran.vego@igh.hr

ABSTRACT

This paper presents the results of the application of Composite Transfer Functions (CTF) on the Jadro and Žrnovnica Springs located in the Dinaric karst area of Croatia. By using the CTF, irregular shapes of the tails of identified transfer functions can be avoided, and the simulations of long recession periods as well as the simulations of complete hydrographs become more successful. Investigations were performed in order to test practical applicability of CTF for karst springs discharge modelling and to give a contribution to the existing knowledge about hydrological functioning of the Jadro and Žrnovnica Springs. The results of the application of CTF are compared with the results obtained by applying nonparametric transfer functions and discussed. In spite of the results of the tracer tests which show that the Jadro and Žrnovnica Springs share mostly the same catchment, the results reveal that these two adjacent springs have different hydrological characteristics.

Keywords: Karst spring, Rainfall-runoff model, Transfer function, Jadro Spring, Žrnovnica Spring

Modeling the daily discharges of large karstic aquifers using artificial neural networks (ANN) methodology. Analysis of single-parameter vs. multiple-parameters inputs ANN models.

[1]Bedri KURTULUS and [1]Moumtaz RAZACK

[1]Hydrogeology Department (UMR 6532), University of Poitiers, 40 avenue du Recteur Pineau, 86022 Poitiers Cedex, France. udibedo@yahoo.com, moumtaz.razack@univ-poitiers.fr

ABSTRACT.

The artificial neural networks (ANN) methodology has been widely used in surface hydrology to predict rivers discharges. However its application in hydrogeology is still uncommon. This paper is focused on the analysis of the ANN ability to predict daily discharge responses of karstic aquifers. The study site is the La Rochefoucauld karst, which is a large system and plays a major role in the social and economical context of the Charente region (South-West France). Water resources of this aquifer are used for irrigation and drinking water supply to the city of Angoulême, the regional capital. The approach discussed here consists of selecting different parameters combinations as inputs in the ANN model and testing its predictive ability. The ANN model used in this study is elaborated with Levenberg Marquart backpropagation training algorithms. The model is developed for single and multiple-parameters inputs, which are the rainfall and/or the water-table levels. A multiple-inputs model is shown to provide a better prediction of the discharge responses in such a large size catchments compared with single-input models. The simulated hydrographs shape is quite similar to that of the actual hydrographs. Accordingly, this ANN methodology, based on multiple-parameters inputs, provides a systematic approach for discharge estimation and represents an undeniable improvement in prediction accuracy over other modeling approaches such as distributed models. These encouraging results make it possible to consider interesting and new prospects for the modeling of karstic aquifers, which are highly non-linear systems.

Keywords: ANN, karstic aquifers, daily discharges, modeling.

Modelling Groundwater and soil salinisation processes in the irrigated coastal plain of Korba, North of Tunisia

[1]Fairouz SLAMA., [1] Rachida BOUHLILA., [2]Pierre PERROCHET., [2]Philippe RENARD., [3]Emna TRABELSI., [3]Jamila TARHOUNI

[1]Laboratoire de Modélisation en Hydraulique et Environnement. Ecole Nationale d'Ingénieurs de Tunis. BP 37 Le Belvédère 1002, Tunis, Tunisia, Slama_fairouz@yahoo.com, fairouz.slama@unine.ch.
[2]Centre of Hydrogeology (CHYN). University of Neuchâtel. 11, rue Emile-Argand. CH – 2007, Switzerland, Pierre.perrochet@unine.ch
[3]Institut National Agronomique de Tunisie, 43, Avenue Charles Nicole 1082 -Tunis- Mahrajène, Tunisia, Tarhouni.jamila@iresa.agrinet.tn

ABSTRACT

Groundwater and soil salinisation are of great concern as they both threaten environmental, economic and social sustainability in several regions of the world. Tunisia is one of the countries that are facing this problem especially in coastal irrigated areas where groundwater is used for irrigation intensively. This can lead to seawater intrusion which can be superimposed to groundwater quality degradation due to salt recycling under evaporation processes. This study aims to understand and predict groundwater and soil salinisation processes in coastal irrigated areas using experimental and numerical tools.

Field experiment was carried out in Korba coastal aquifer along a 5 km transect perpendicular to the sea. The transect is located in a piezometric depression and it is affected by seawater intrusion. The experiment involved soil and groundwater sampling and Electrical Resistivity Tomography Imaging. Soil sampling was performed along the entire unsaturated zone (varying from 4 to 15 m deep) in three irrigated plots, after irrigation has ended (September 2006). Irrigation water comes from groundwater pumping. Groundwater was sampled at different periods of the year in 25 observation wells along the transect. Soil samples were used to determine vertical soil salinity and major ion analysis profiles on extractions from saturated soil paste. Electrical conductivity and major ions were also determined for groundwater samples.

HYDRUS2D was used to simulate vertical soil salinity and impacts on groundwater salinisation. Considered geometry is a two dimensional section. Simulations were first performed for a cycle corresponding to the irrigation season and second for a 10 year cycle.

Experimental data showed salt accumulation in the surface reaching 17.5 mS/cm (Fig. 1).

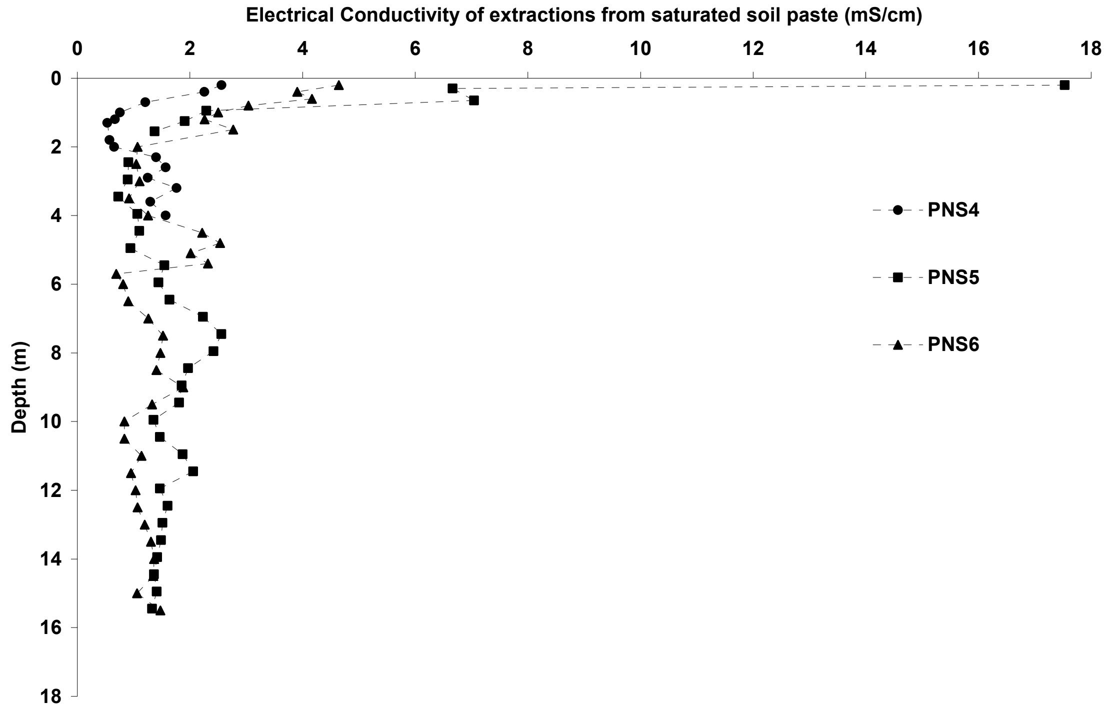


Fig. 1. Electrical conductivity of extractions from saturated soil paste profile for three irrigated plots (PNS4, PNS5, PNS6) in Korba coastal aquifer measured in September 2006

Groundwater presents, also, high electrical conductivity reaching 9.6 mS/cm Numerical model also simulated surface salinisation during the irrigation season. Impacts on groundwater quality are relative to both seawater intrusion and salt recycling. They are rather visible after some years of simulation. This shows that salinisation processes follow different dynamics for soil compared to groundwater.

Keywords: Modelling, soil, groundwater, seawater intrusion, irrigation, salt recycling

Modelling the impacts of historical extractions in the Jumilla-Villena aquifer (SE Spain)

[1]E. RUIZ, [1]J. GUIMERÀ, [2]F.J. ELORZA, [3]J. LAMBÁN, [4]J.A. Hernández

ENVIROS SPAIN, SL, eruiz@enviros.biz; jordi.guimera@enviros.biz ETS Ingenieros de Minas, UPM, jelorza@dmami.upm.es Instituto Geológico y Minero de España, javier.lamban@igme.es Diputación Provincial de Alicante, jahernan@dip-alicante.es

ABSTRACT

Aquifer overexploitation often leads to a decline of piezometric levels, changing the groundwater regime and compromising associated surface ecosystems. The Spanish Mediterranean coastal and inland aquifers have been heavily utilized for decades, which has lead to a situation where the decline in water resources has disconnected any potential associated ecosystem. Among these aquifers, the Jumilla-Villena is an example of former associated surface-groundwater ecosystems that decades ago were decoupled and wetlands transformed into arable lands. Nowadays, no more permanent surface water courses exist. A comprehensive study is presented, and a numerical model calibrated to develop scenarios to maintain a sustainable exploitation of groundwater resources.

The aquifer system is formed by a cretaceous carbonate aquifer, underlain by an aquitard. Below the aquitard, jurassic dolomites extend down to triassic clays and evaporites, which conforms the limit of the system. Lateral boundaries are of tectonic nature, associated to outcrops of impervious materials from the Triassic. The surface extension is some 350 km^2 and the thickness of the upper cretaceous aquifer is 550 m; the aquitard is in average 200 m and the jurassic dolomites around 200 m.

The aquifer presents a tectonical water divide in its central part, and discharged naturally to a lake in the Vinalopó river valley (E) and Jumilla (W). Natural discharges were drained decades ago and further substituted by deep water wells that maintain the piezometric head tens of meters below ground surface. Water levels in wells show a decline of 2-3 m/year in average, depending on the position in the aquifer. Recharge occurs across permeable outcrops and no lateral flows from other permeable formations exist. The soil water balance has been established taking the land use of the CORINE database into account. Hence, a total of 13-70 mm/year in average have been found, out of 325 mm/year of average rainfall for a period of 26 years. Parameters of the cretaceous limestones indicate a widespread range of values, with no clear evidence of zonation. Hence, transmissivity values from 100 to 1000 m^2/day are the most common found in former studies. Storativity values found ranged from 0.06 to 0.0015. Groundwater extraction rates records exist for the last 20 years, despite the fact that some gaps exist. This led to a total of 30 hm^3/year which compared to the renewable 15 hm^3/year from natural recharge, leads to an imbalance of –15 hm^3/year, which can be up to 20 depending on the assumptions. Groundwater chemistry shows an influence of the triassic evaporites when water levels decline dramatically close to the boundaries of the aquifer. On the contrary, declines at the center of the aquifer do not show particular evidences of salinization or adverse changes in groundwater composition. Conspicuous differences in composition sulfate vs. bicarbonate contents indicated a degree of compartmentalization of groundwater, which was tested against piezometric values during the numerical model calibration The objectives of the numerical model were to test the conceptual model and once calibrated, to simulate long term water management scenarios taking into account different origins of water resources.

The model consisted of a three layers grid of cells solved with a finite differences code (MODFLOW), with refinements around the pumping centers, trying to maintain one extraction water well per cell to prevent dry-cells during simulations. The lateral boundary conditions were of either prescribed head or no flow, depending on the geologic or hydraulic situation. Recharge on top of the model was assigned to the different polygons extracted from the soil water balance taking CORINE database into account. Initial conditions were taken from piezometric values taken in 1980. Simplifications were made on the nature of the aquifers, which were taken homogeneous and isotropic. In general terms, the initial runs with original parameter values, extraction rates and aquifer geometry were unable to match the piezometric trends observed in water wells along the years. Hence, the model was used to calibrate the water well withdraws, which lead to a total o some 40 hm^3. Thus, the imbalance with renewable resources grows up to 20 hm^3. Also, the model showed that the conspicuous differences found between water levels and chemical composition could be better reproduced by means of low permeability zones that match regional transversal faults.

Model simulations show that depending on the aquifer sector, water uses for agriculture should be reduced by a factor of 5 in order to stop the current water well decline. Also, the actual extraction rate could lead to dry outs in water wells in the next five to ten years. In any respect, the actual management of the aquifer conforms to the WFD and severe restrictions on agricultural uses should be applied.

Modelling nitrate transport for groundwater source protection in an agricultural area

[1]Alexandre BONTON, [2]Alain ROULEAU, [3]Christian BOUCHARD, [4]Manuel RODRIGUEZ, [5]René THERRIEN

[1]Département de génie Civil, Université Laval, Pavillon Adrien-Pouliot, G1K 7P4, Québec, Canada, e-mail: alexandre.bonton.1@ulaval.ca
[2]Département des sciences appliquées, Université du Québec à Chicoutimi, 555 boulevard de l'Université, G7H 2B1, Chicoutimi, Canada, e-mail: arouleau@uqac.ca
[3]Département de génie Civil, Université Laval, Pavillon Adrien-Pouliot, G1K 7P4, Québec, Canada, e-mail: Christian.Bouchard@gci.ulaval.ca
[4]École supérieure d'aménagement du territoire et du développement régional, Université Laval, Pavillon Félix-Antoine-Savard, G1K 7P4, Québec, Canada, e-mail: manuel.rodriguez@ame.ulaval.ca
[5]Département de géologie et de génie géologique, Université Laval, Pavillon Adrien-Pouliot, G1K 7P4, Québec, Canada, e-mail: Rene.Therrien@ggl.ulaval.ca

ABSTRACT

The development of efficient strategies for groundwater protection in agricultural areas requires a good understanding of the relations between agricultural activities and the quality of pumped water. This relationship is the focus of an investigation carried out at a municipal well site in an agricultural area in Quebec, Canada, using field data and numerical simulation. A 3D groundwater flow and nitrate transport model in an unconfined aquifer was developed in order to better understand the causes of the relatively high nitrate concentrations (near 10 mgN/L) observed in recent years in the pumping well, in relation with agricultural practices applied during the same period and before. Forty piezometers were installed within the capture zone of approximately 3 km^2. Water levels and nitrate concentrations were measured during several campaigns conducted in 2005 and 2006. Data on nitrate levels at the pumping well, as well as pumping rate since 1995, were also considered in the analysis.

Modelling using Agriflux2.0® was carried out in order to estimate nitrate fluxes leaching from the root zone in each one of the 70 agricultural parcels located within the capture zone. This software uses a mechanistic stochastic approach to simulate water flow, as well as nitrogen cycle processes in the unsaturated zone. Modelling considers the AgroEnvironmental Fertilization Plan of every agricultural parcel that is susceptible to contribute to well contamination. It also takes into account crop rotation and fertilization practices. The Hydrogeosphere® software, which is based on the control volume finite element approach, was used to simulate transient 3D groundwater flow and mass transport in the saturated zone of the aquifer, using the results from Agriflux2.0® as input values for nitrate fluxes.

The discussion and results of this study are based on 1) the adequacy between the observed and simulated hydraulic heads, 2) the adequacy between the observed and simulated nitrate concentrations in each piezometer, 3) the temporal variations of observed and simulated nitrate levels in the well since 1995, and 4) the use of a simulation model to predict groundwater quality according to different land management scenarios in the capture zone.

Keywords: municipal well, nitrate, capture zone, modelling, fertilization plan

Numerical heat transport modeling of the temperature profiles of the Danube river at Paks, Hungary

Judit MURÁTI

Centre of Hydrogeology, University of Neuchâtel, Rue Emile-Argand 11, 2009 Neuchâtel , Switzerland,
e-mail: judit.murati@unine.ch

ABSTRACT

The nuclear power plant at Paks, Hungary uses the water of the Danube river for cooling. After cooling it emits the water whose temperature is 8-12 °C higher back into to the river. Part of the warm cooling water is emitted into fishing ponds which are situated between the power plant and the river.

This work is about to answer the question: What is the effect of the heat emission on the surface water on the groundwater?

To analyze the problem along the river, shallow probes in the riverbank were installed in two sections. One was placed upstream from the power plant for monitoring the undisturbed situation, and the second downstream in the warm water channel. Level of the river and groundwater, temperature and electrical conductivity were registered and water samples were taken regularly for the most important chemical, isotopic and bacteriological analysis. Continuous monitoring of the hydraulic head and the temperature produced sufficient amount of data for a heat transport model.

A series of one dimensional heat transport models with Feflow software were made to simulate the impact of the different model parameters: hydraulic conductivity, porosity, solid heat conductivity; and with a variety of boundary conditions for hydraulic head and temperature.

Based on the simulations a one dimensional model was made using the measured data and then accurately calibrated for the above parameters. The temperature curve from the model fits the ones measured in the sondes well.

A two dimensional model was made in the 2[nd] section with the warm fishing pond in the background and the warm water channel using the previously created regional groundwater model's results as boundary conditions and flow parameters. The temperature curve below the riverbed, similar to the one dimensional model, fits the measured curve also. (Fig. 1.)

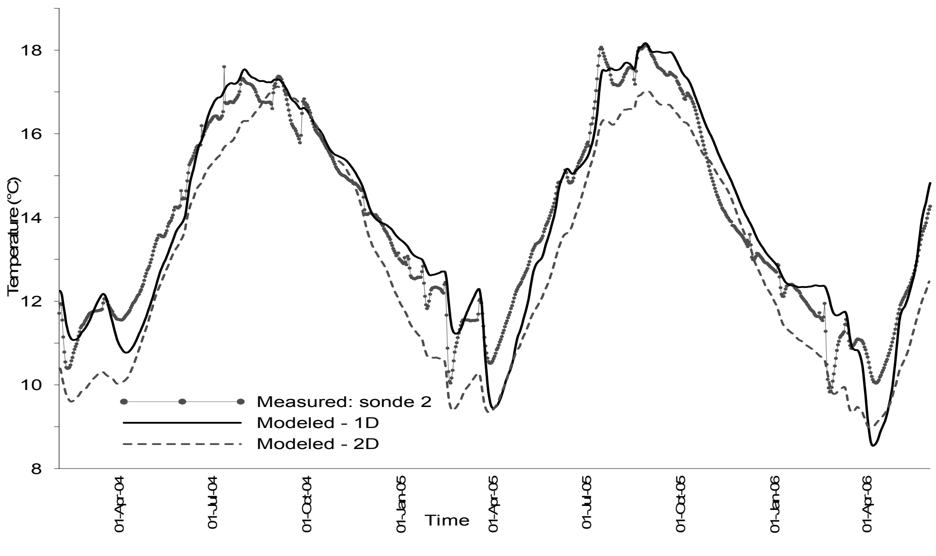


Fig. 1. Measured temperatures in the 2[nd] section's sonde and the modeled curves.

From the model a mass and heat balance can be calculated to survey the relationship between the river and the groundwater in the 2nd section. It shows that the groundwater discharge from the background into the river is significantly greater than the recharge occurring only during flood events.

The warm water infiltrating from the fishing ponds and recharging into the Danube adds a significant amount to the heat transmitted by the groundwater toward the Danube. The overall situation is that slightly more heat is transferred into the Danube river though warm water that is present in the river

The heat balance shows that the significance in recharge into the river originates from the warm-water filled fishing ponds by advection over the recharge into the groundwater below the warm Danube water is mostly by conduction.

The heat transport model shows the location of the heat affected zones. Based on the results, a detailed biological monitoring system plan can be created to reveal the ecosystem's behavior.

Keywords: Heat, modeling, Danube river

Optimal Management of Groundwater Withdrawals in Coastal Aquifers

[1]Júlio F. FERREIRA DA SILVA, [1]Naim HAIE, [2]Maria da Conceição CUNHA, [3]Luís T. RIBEIRO

[1] Department of Civil Engineering, University of Minho, Guimarães, Portugal, e-mail: juliofs@civil.uminho.pt, naim@civil.uminho.pt
[2] Department of Civil Engineering, University of Coimbra, Polo II, 3030-290 Coimbra, Portugal, e-mail: mccunha@dec.uc.pt
[3] Department of Mines IST, Av. Rovisco Pais, 1049-001 Lisboa, Portugal, e-mail: nlrib@alfa.ist.utl.pt

ABSTRACT

In this work, an optimisation model has been developed for planning and managing saltwater-intruded coastal aquifer systems. We apply this model, which uses the simulation / optimisation approach, for managing water resources in coastal areas. The management model finds the best policies to maximize the present value of economic results of meeting water demands and to keep the saltwater intrusion under control. The idea of security distance to a control point provides the establishment of a trade-off relationship between the increased management cost and the desired level of protection. The model was applied to a typical case with interesting results. It was also crucial to have an understanding of the tradeoffs between groundwater withdrawals, positions of the wells from the coast line, and the security distance. This model allows the sustainable use of coastal water resources.

Keywords: Seawater intrusion. Security distance for wells. Coastal groundwater withdrawals.

Seepage of pollutants through aquitard: a combined use of 3D deterministic modelling and tritium data

[1]Stanislaw WITCZAK, [1]Kazimierz ROZANSKI, [2]Janusz KNEZ

[1] AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Krakow, Poland, e-mail: witczak@uci.agh.edu.pl, rozanski@novell.ftj.agh.edu.pl
[2] Hydrogeotechnika Ltd., Sciegiennego str. 262A, 25-116 Kielce, Poland, e-mail: jknez@poczta.fm

ABSTRACT

Industrial centres frequently pose a serious threat to the near-by groundwater systems. Pollutants of various nature leaking from industrial installations migrate through unsaturated zone towards the water table and contaminate upper water-bearing strata often making them unusable. If the contamination persists over longer time intervals (decades) migration of pollutants continues through aquitard(s) threatening groundwater resources located below. The key issue from the perspective of groundwater protection is the quantitative assessment of the time scale of pollutant transport through the natural barriers constituted by aquitards.

The studied groundwater system consists of two aquifers: shallow and deep one, separated by an aquitard of approximately 20 to 30 m thick. The upper aquifer is heavily contaminated with LNAPL, mainly BTEX. This contamination has persisted since 1960s. The aquitard consist of glacial tills. Existing hydraulic conditions allow for downward seepage through the aquitard (hydraulic gradient around 1) to the lower water table aquifer. The lower aquifer is being used as a source of potable water.

The 3D hydrodynamic and transport model was constructed for the investigated groundwater system using MODFLOW and MT3D code. Verification of the model was based on migration of bomb tritium in the aquitard. A special borehole was drilled on the study area(P-A at Fig.1)) reaching the depth of 45 meters below the ground. Samples of glacial till were collected for subsequent analysis of tritium content in the pore waters(in total 19).Pore waters were extracted in the laboratory using vacuum distillation and the tritium content was measured using electrolytic enrichment and liquid scintillation spectrometry.

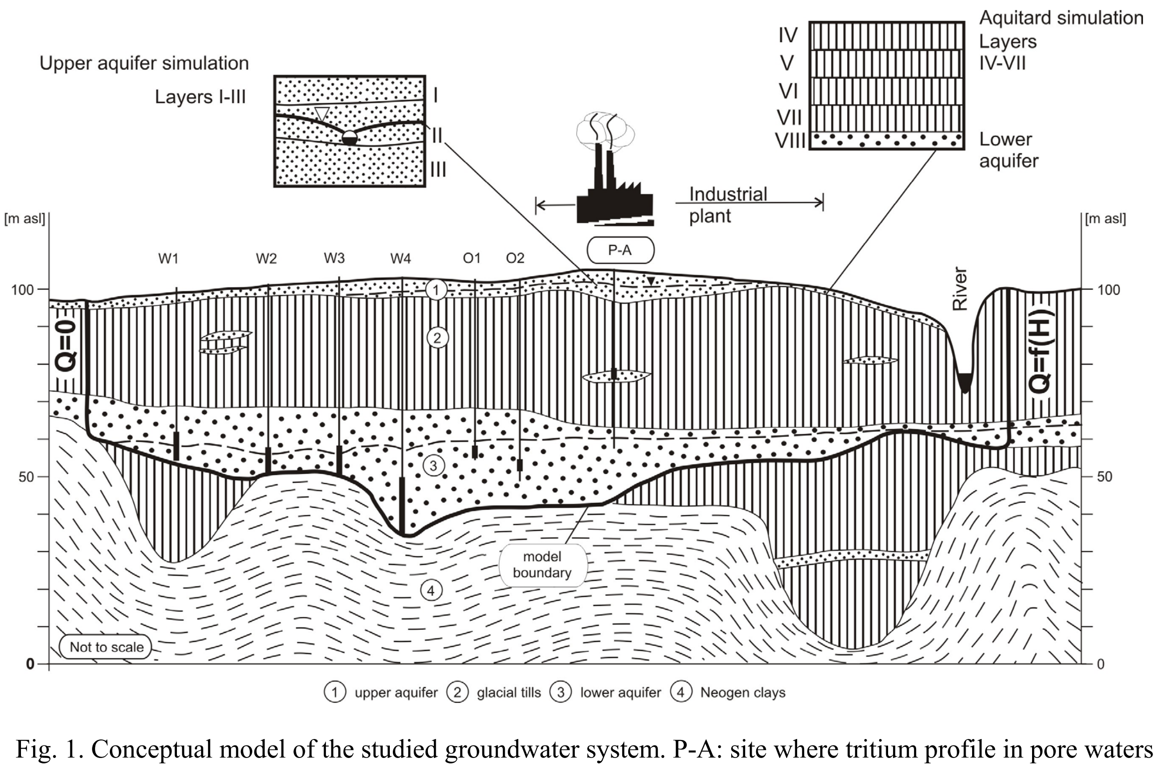


Fig. 1. Conceptual model of the studied groundwater system. P-A: site where tritium profile in pore waters was measured; W1-W4: exploitation wells; O1-O2: observation wells.

The observed tritium profile (Fig.2) can be identified beyond any doubt with the passage of bomb-tritium through the aquitard. Identifying the peak of tritium concentration in the pore waters at 27.5 meters with the 1963 peak of bomb tritium in precipitation, one can derive average leakage velocity through the aquitard in the order of 42 cm/year. If one takes into account the delay of tritium in the upper aquifer which is in the order of 2-3 years, the calculated effective leakage velocity will increase to ca. 45 cm/year.

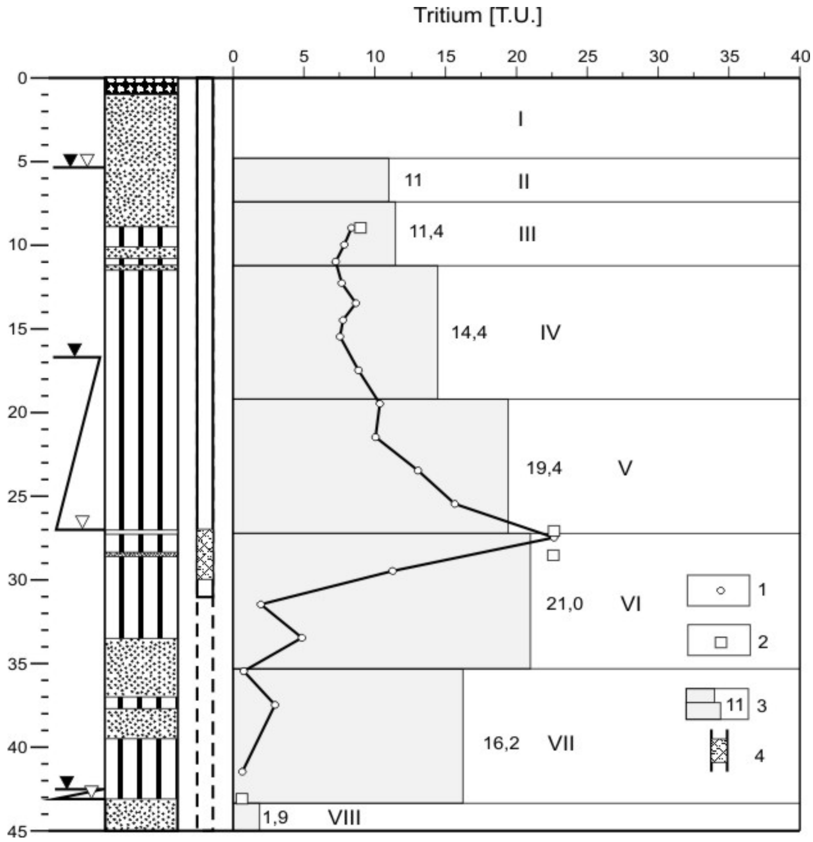


Fig.2. Tritium depth profiles in special borehole P-A. 1 - tritium content in pore waters; 2 - tritium content in water samples; 3 – tritium content in model layers I-VIII simulated by MT3D flow and transport model; 4 – screen of the observation well installed after drilling operation; open triangle – incident water level, full triangle – stabilized water level.

Figure 2 shows also the tritium concentrations simulated by the numerical MT3D transport model in the prescribed lateral layers (from II to VIII). The simulated tritium content increases from 11.4 TU in layer No. III to 21.0 TU in layer No.VI and then decreases again to 1.9 TU in layer No. VIII. The measured tritium profile reveals relatively low hydrodynamic dispersion when compared to the model. This is partly understood in the light of poor vertical resolution and the resulting excessive numerical dispersion in the model.

The peak of tritium concentration in the model seems to be located deeper when compared to the measured maximum. Since the model was calibrated with the hydrodynamic data, this difference, if real, should be used for subsequent verification of the model

Keywords: Hydrogeology, contamination, tritium, modelling

Towards a technology-aided water cycle to overcome drought periods in stressed watersheds

[1] Sandra JENNI, [2] Bob WILL, [3] Michelle YEH, [4] Jean-Pierre DELHOMME

[1] Schlumberger Water Services, 1 Cours du Triangle 92936 Cedex France, sjenni@slb.com
[2] Schlumberger Water Services, 2520 Venture Oaks Way, Suite 430 Sacramento Ca 95833 USA, rwill@sacramento.sl.slb.com
[3] Schlumberger Water Services, 2520 Venture Oaks Way, Suite 430 Sacramento Ca 95833 USA, myeh@waterloo.water.slb.com
[4] Schlumberger Water Services, 1 Cours du Triangle 92936 Cedex France, JDelhomme@la-defense.water.slb.com

ABSTRACT

In many countries ranging from temperate to Mediterranean climates, water is often abstracted from the hydrographic network or from the underneath aquifers, in a manner that is regardless of the existence of a strong coupling between surface and groundwater. For example, the discharge decrease of streams below an acceptable threshold or the complete dry out may be caused by an over-extraction from aquifers.

A number of solutions are now being studied, or being implemented, to overcome drought periods in many regions. When the solution proposed is to release water from dams into the rivers, the interaction of streams with groundwater (e.g., the existence of gaining or losing reaches, or of a bank storage effect) is, very often, not acknowledged enough. The decision for a solution to proactively manage water resources requires an integrated approach, taking in account all aspects, including the hydrogeological ones.

The idea that aquifers could be used to supplement base-flow to streams during summer could be further developed (e.g. by recharging the aquifers in relation with the streams). Surface water can, itself, be a significant source of this recharge water, stream water being diverted to nearby aquifer recharge facilities, so as to augment the natural recharge, during the wet season. This water could be treated before injection, utilizing surplus treatment capacity that exist during winter in many regions, e.g. in coastal areas.

Such an integrated water management strategy requires a global watershed model (coupled surface and groundwater flow) to understand how the downstream part of the watershed will be affected by the fact that “excess” surface water is now used for aquifer recharge in the upstream part. A quantitative model of the water cycle is needed to predict the likely impact of the recharge schemes. It requires knowledge of various natural processes that operate in the subsurface and at surface and of how they could be managed so as to optimize the system performance, ensure a healthy recovery of the recharged water to gain public acceptance and minimize any potential harm to the environment.

An ongoing study, using fully coupled surface- groundwater model, is presented so as to illustrate the approach described above.

Water and heat flow through uplifted metamorphic highs in the basement of the Pannonian Basin

[1]Tivadar M.TÓTH, [1],[2]Balázs KOVÁCS, [1]István VASS, [1]János SZANYI

[1]Dept. of Mineralogy, Geochemistry and Petrology, University of Szeged, Hungary, mtoth@geo.u-szeged.hu
[2]Department of Hydrogeology, University of Miskolc, Hungary, kovacs.balazs@gama-geo.hu

ABSTRACT

Fractured fluid reservoirs are of key importance in the recovery of water and hydrocarbon supplies or geothermal energy. These rock bodies are especially important in Hungary, where numerous hydrocarbon reservoirs and geothermal fields occur in the fractured crystalline basement of the Pannonian Basin.

The basement consists essentially of different gneiss and amphibolite types of the Variscan age. These lithologies define a rather complicated fracture network in the basement due to their various rheologic properties as well as complex brittle evolution. As a result of the selective uplift history during the Neogene basin formation, the topography of the basement at present is characterized by exhumed metamorphic domes (500 to 2000 m below surface) and deep sub-basins (down to 8000 m) among them. Sedimentary cover also differs in these two situations significantly. In the sub-basins sandy and pebbly sediments occur, which are covered by a thick layer of impermeable lacustrine marl. This is the main stratigraphic reason for the significant overpressure that can be measured in the basin areas. As metamorphic basement highs usually are at higher topographic position, they are not covered by the impermeable formation (Fig. 1).

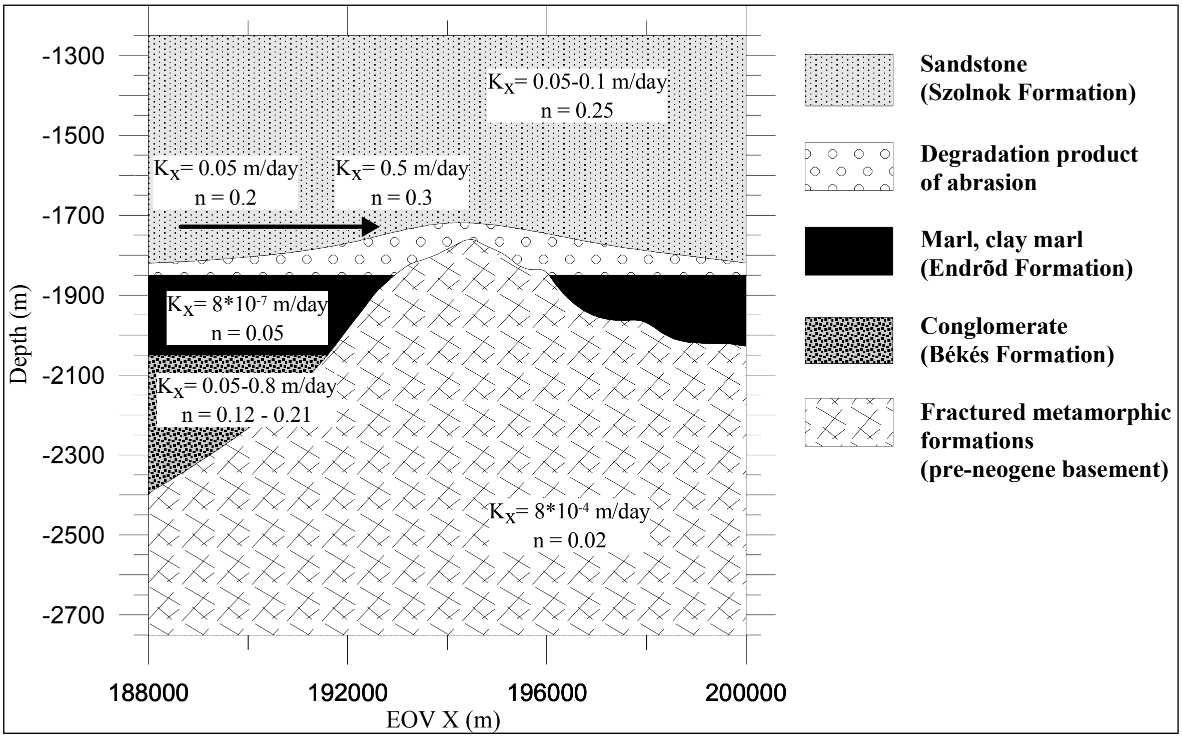


Fig. 1. Schematic geological cross-section of a metamorphic dome with hydraulic conductivity (K_x) end effective porosity (n)

Regarding both fluid migration and storage capacity, the fracture network of the basement rocks has a key role and has been studied in great detail in many cases. To simulate a 3D fracture network for both near well regions and at reservoir scale, a fractal geometry based DFN (discrete fracture network) modelling system (REPSIM) was used. For modelling we measured the most essential geometric parameters of the fractures (length distribution, orientation, spatial distribution of fracture midpoints, length – aperture relationship) using well-log data, rock specimens, CT images and thin sections. Using the simulated 3D fracture network, essential hydrodynamic parameters, like fractured porosity, the 3x3 permeability tensor, sizes and spatial positions of communicating fracture sub-systems and REV (representative elementary volume) were computed.

Based on ten independent runs on the same input data set we can state that there is a significant difference in fracture parameters in the amphibolite and gneiss dominated portions of the basement, amphibolite having a denser network with longer fractures. As a consequence, in addition to large-scale fault zones, amphibolite layers store the most fluid and are responsible for water and heat flow through the basement rocks.

To investigate the heat (energy) and water balance of the area of interest, a numerical model was built using Processing SHEMAT and later the SUTRA2D3D codes. Based on the spatial information of geophysical prospecting, the geometry of the basement and the covering sediment structures was determined. Upon these data a simplified hydrogeologic scheme of the investigated area was established. The hydraulic behaviour of the fractured metamorphic units was described by the parameters resulted by the REPSIM code. The thermal properties of the investigated region are originated from the geothermal database of the country and based on several deep drillings of the site. The modeling environment therefore is partially stochastic (because of the several realizations of permeability tensor and porosity by REPSIM) but also has some deterministic features.

Using the model, several runs were performed in order to analyze the natural (primer state) heat transport and hydrodynamics of such regions. Since these highs of the basement rocks possibly will be used later for geothermal energy production, the effect of heat production and injection doublets on the thermal energy balance is also to be investigated.

Results of modelling suggest that because of their rather special stratigraphic and structural position, the uplifted basement highs govern heat transfer and fluid flow like a chimney (Fig. 2) and so many formations are found prospective for further geothermal investigations.

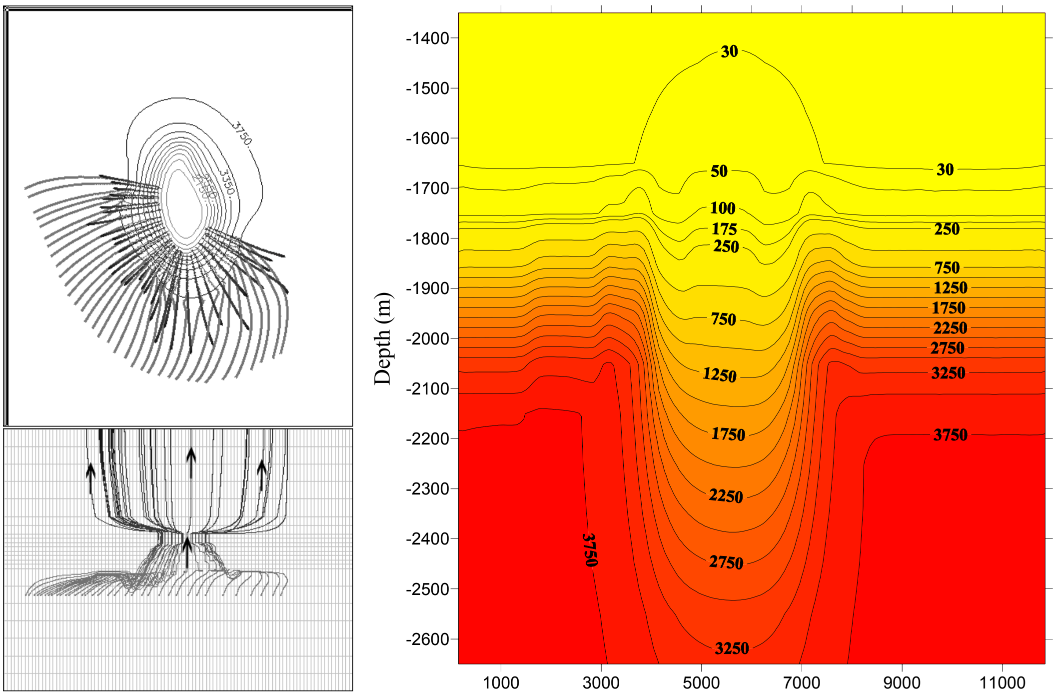


Fig. 2. Groundwater flow pathlines and hydraulic head distribution nearby the investigated basement „chimney"

Keywords: 3D fracture network, representative elementary volume, heat transport

What can transport modelling predict without validation in the field?

[1]Branka BRAČIČ ŽELEZNIK, [1]Brigita JAMNIK, [2]Barbara ČENČUR CURK

[1] Public water Supply company JP Vodovod-Kanalizacija d.o.o., Vodovodna cesta 90, 1000 Ljubljana, Slovenia, e-mail:bzeleznik@vo-ka.si, bjamnik@vo-ka.si
[2] IRGO – Institute for Mining, Geotechnology & Environment, Slovenčeva 93, 1000 Ljubljana, Slovenia, e-mail: Barbara.Cencur@irgo.si

ABSTRACT

Human activities in the area of the Hrastje water field threaten groundwater quality. A numerical groundwater flow model was established for the wider area of the Ljubljansko polje aquifer. A lack of experimental data on solute transport leads to unreliability in the transport model and its prediction of pollution scenarios. The transport model needs to calculate reliable scenarios of pollution dispersion, which can only be achieved with the application of real transport parameters.

This was provided by tracer experiments performed in the Ljubljansko polje aquifer. Two multi-tracer experiments (potassium bromide, uranine, eosine, microspheres and tinopal CBSX) were conducted near the water field. The latest was done in an urban area, from where the groundwater flows in direction to the water field. Tracer test design considered differences between pollutant spreading in the unsaturated and saturated zones of the aquifer. Therefore, the tracer injection was performed by spreading on the surface (injection to the unsaturated zone), as well as injecting directly into the saturated zone through observation wells.

Results of the multi-tracer experiment improved the flow and transport model. All together, this will yield better knowledge of the hydrodynamic conditions in the Ljubljansko polje aquifer, which will result in more effective measures for waterworks protection.

Keywords: tracer tests, drinking water management, alluvial aquifer

TOPIC 13

Groundwater modelling: deterministic and stochastic approaches

A short term numeric model for the aquifer response understanding in the Rio Galeria basin (Rome, Italy)

[1]Matteo ROSSI, [1]Giuseppe SAPPA

[1]Dept. Hydraulics, Transportations and Roads, University "Sapienza" of Rome, Italy,
e-mail: matteo.rossi@uniroma1.it, giuseppe.sappa@uniroma1.it

ABSTRACT

The Rio Galeria basin is located near the city of Rome and it is part of the bigger Tevere river one. Many important activities with a high environmental impact have sprung up in the last twenty years on its large area like waste landfills, incinerators and large factories.

For these reasons, monitoring environmental policies on air, soil and water sectors have a relevant importance to safeguard the local ecosystem.

Concerning the water environment, the first step is to understand the particular hydrogeological systems and their response to external natural and human disturbances.

This study is a first step in order to build a numerical flux and transport model to monitor possible environmental impacts of these activities on surface and groundwater.

It starts with the elaboration of a piezometers net data, collected daily on 16 different points over two years 2005 and 2006, in part of the basin (Fig. 1).

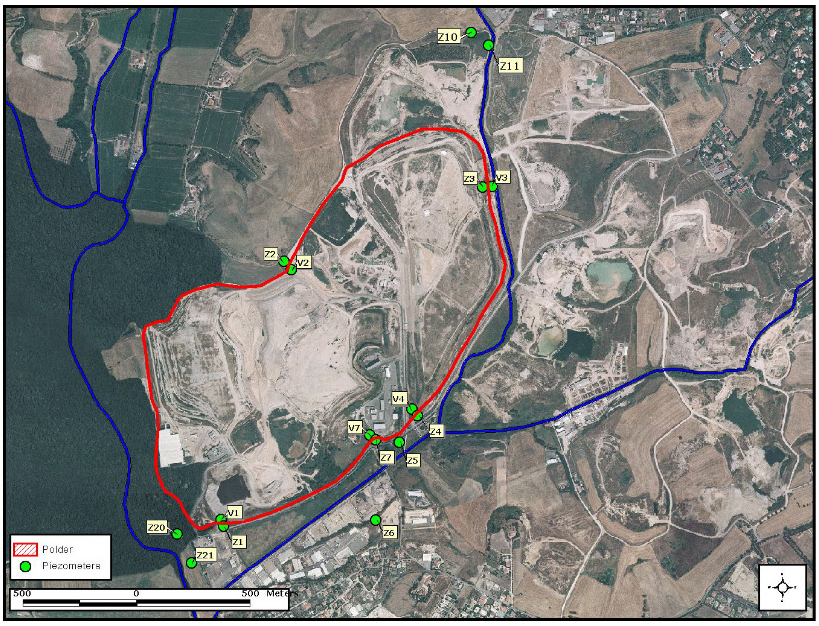


Fig. 1. Piezometers net in part of the area under study

Comparing daily potentiometric level fluctuations with local rainfall precipitation values, a first conceptual model of the aquifer response to direct recharge in terms of response times has been studied; this helped in spatial permeability distribution determination and to the formation of a local aquifer conceptual hydrogeological model.

In order to test the aquifer conceptual model, the aquifer involved in Rio Galeria basin activities has been modeled by the finite difference numerical code implemented by Modflow.

The code was applied to an area of about 30 kmq, separated into a 250 square grid, refined in the dumping area to 50 meter cells. In order to consider the vertical potentiometric variation, 2 different layers were used, to simulate both pyroclastic and sedimentary deposits housing the aquifer (Fig. 2).

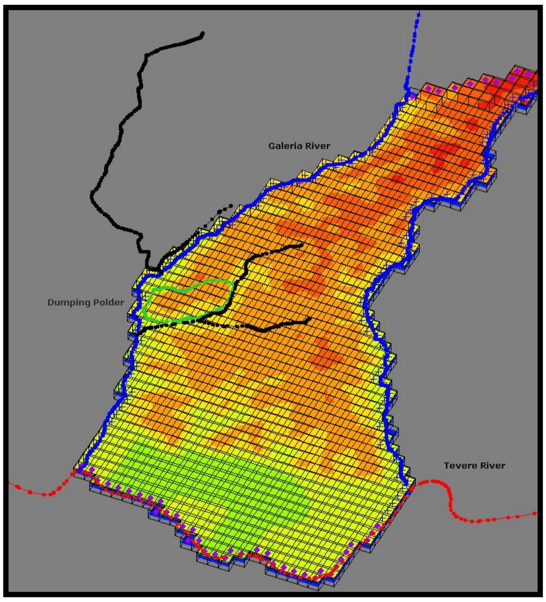


Fig. 2. Finite Differences Grid for the groundwater model

A first steady state model has been implemented to simulate the spatial distribution of hydraulic conductivities; based on an inverse model helped to automate the calibration using the measured hydraulic heads.

Then, a transitory model on a monthly base has been implemented in order to reproduce the local model of aquifer response to rainfall precipitations (Fig. 3).

Year 2005 piezometers campaign data have been used for the automated calibration with direct rainfall recharge in order to refine the simulated head values in the dumping proximities.

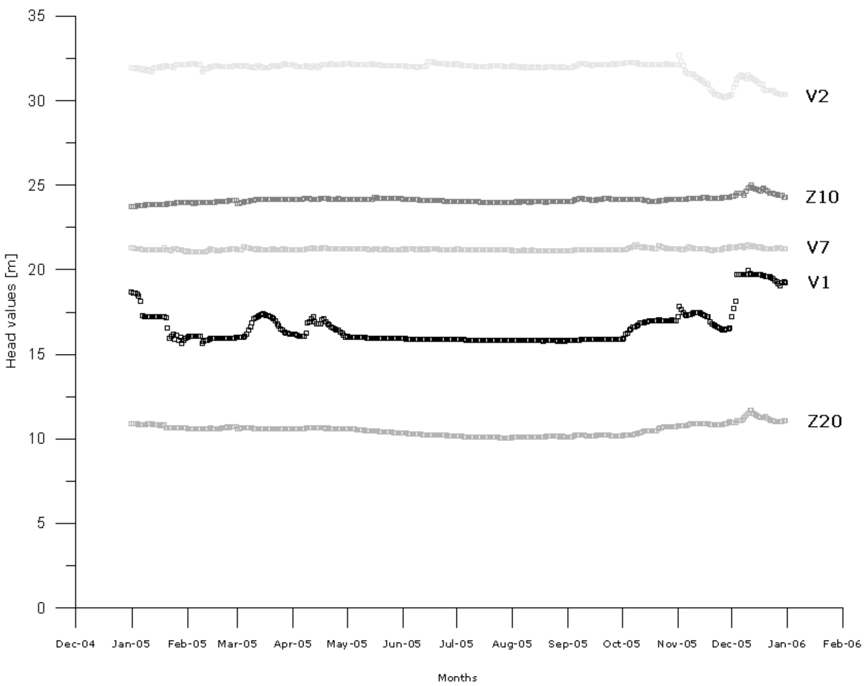


Fig.3. Daily potentiometric fluctuation in monitoring piezometers during 2005

The final groundwater flux numerical model is a valid and basic instrument is very useful on a medium scale to test the appropriate transport model to follow in detail the possible relation between human activities and groundwater or to implement different land management scenarios in order to support groundwater policies decision making.

Keywords: groundwater modeling, finite differences, potentiometric fluctuations

The application of a hydrodynamic model on groundwater source "Sava I" (Serbia): protecting the groundwater source

[1]Dušan POLOMČIĆ, [1]Veselin DRAGIŠIĆ, [1]Miroslav KRMPOTIĆ,

[1]Rudarsko-geološki fakultet, Đušina 7, Belgrade , Serbia, e-mail: dupol2@gmail.com, v.dragisic@rgf.bg.ac.yu, kornat@eunet.yu,

ABSTRACT

The groundwater source "Sava I" is used for the water supply of the Ruma community in Serbia. Recent explorations suggest the possibility for the simulation of groundwater source exploitation and source protection zones around the groundwater source. The simulation model to be used is a hydrodynamic model based on 3D groundwater flow simulation. The model set-up involved the following: the basic interpretation of input data, the schematization of the porous medium, flow field streaming and model forming and measurements. In the selection of basic model parameters, a multilayer model was created with the possibility of producing an automatic streaming field change that is dependent on groundwater flow conditions. In the hydrodynamic model of the groundwater source "Sava I" the following boundary conditions were applied: boundary with a defined (limited) potential (piesometric head), the river boundary, effective infiltration continuum from precipitation and evapotranspiration, and a defined inflow boundary.

The surface streams in this area are the river Sava and the channel Jarčina. Figure 1 shows a diagram of the groundwater level of wells in the aquifer as a function of the water level of the river Sava.

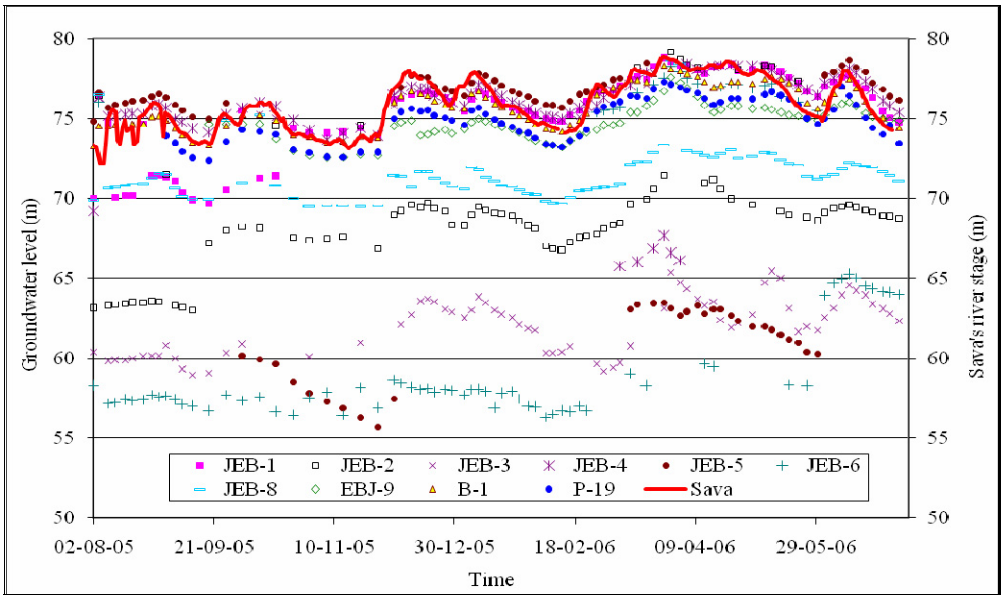


Fig. 1. Groundwater level diagram of wells in the aquifer „Sava I" and water level of river Sava

It is evident that the river Sava has a major effect on the groundwater level of the aquifer while the impact of pumping is confined to narrow zones around the abstraction point. This is the because of the high permeability of the porous media and the strong hydraulic connection between the extensive groundwater source and the surface water of the river Sava.

Groundwater flow in the model is calculated and simulated as real flow under both confined and unconfined aquifer conditions, with separate field descretion. The results obtained from the model were then compared with those obtained from the wells for verification. The analysis of the groundwater balance for the time period over which the simulation took place, showed that the dominant inflow was from the river Sava (92.8%) while the channel Jarčina contributed only 3.7%. Infiltration from precipitation and inflow into the aquifer from the east and the south was almost negligible.

Further analysis of the groundwater source “Sava I” was performed to determine the extent needed for groundwater protection zones near the aquifer. Partical tracking simulations were done at time intersections of 25, 50 (Fig. 2) and 200 days.

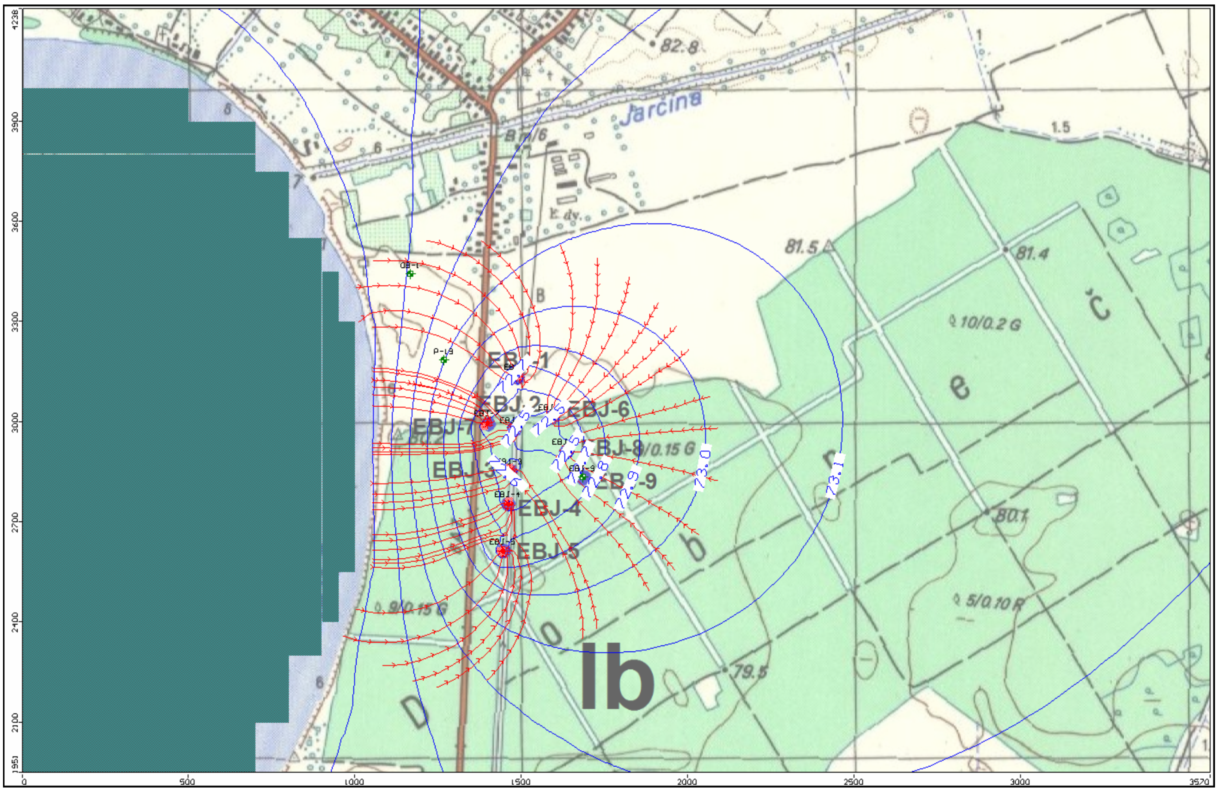


Fig. 2. Streamlines position in zone of exploitation wells of groundwater source “Sava I” which shows distance needed for groundwater movement within 50 days to source.

The hydrodynamic model for the groundwater source “Sava I” resulted in identifying important parameters for aquifer formulation. The most important contributions of this derived analysis of a groundwater source system are the implementation of the aquifer schematization, boundary term definition, quantified groundwater balance and the determination of groundwater protection zones.

Keywords: hydrodynamic model, water supply, groundwater sources, hydrogeology, groundwater protection zones.

Artificial Neural Networks for defining the Water Quality Determinants of Groundwater Abstraction in Coastal aquifer

[1]A. HANI, [1]L. DJABRI, [2]B. AOUN-SEBAITI, [3]S. LALLAHEM and [4]C. LAMOUROUX

[1] Faculté des Sciences de la Terre, Dépt. de Géologie. Université de Annaba, BP 12, 23000 Annaba, Algérie. E-mail: haniazzedine@yahoo.fr
[2] Département de Génie Civil. Université 20 août 1956 de Skikda (Algérie).
[3] Laboratoire de Mécanique de Lille, UMR 8107. Ecole Polytechnique Universitaire de Lille. Av. Paul Langevin 59655 Villeneuve d'Ascq, France
[4] UFR des Sciences de la Terre, UMR Processus et Bilans des Domaines Sédimentaires, Bât. SN5, Université des Sciences et Technologies de Lille, 59655 Villeneuve d'Ascq Cedex, France

ABSTRACT

Authorities responsible for water sustainability in the in the lower Seybouse River basin, eastern Algeria, must recognize the importance of water quantity and quality integration. So, there is a need for a better knowledge and understanding of the water quality determinants of groundwater abstraction to meet the municipal and agricultural uses. In this paper, the artificial neural network (ANN) models were used to model and predict the relationship between groundwater abstraction and water quality determinants in the lower Seybouse River basin. The study area chosen is the lower Seybouse River basin and real data were collected from forty five wells for reference year 2006.

Results indicate that the feed-forward multilayer perceptron models with back-propagation are useful tools to define and prioritize the important water quality parameters of groundwater abstraction and use. The model evaluation shows that the correlation coefficients are more than 95% for training, verification and testing data. The model aims to link the water quantity and quality with the objective to strengthen the Integrated Water Resources Management approach. It assists water planners and managers to better assess the water quality parameters and progress towards the provision of appropriate quantities of water of suitable quality.

Keywords: Seybouse River basin, groundwater, water quality parameters, water quantity, integration, water sustainability, multilayer perceptron network, prediction.

Simple deterministic model of coastal brackish karst springs

[1]Ivana GABRIC, [1]Ognjen BONACCI

[1]Faculty of Civil Engineering and Architecture,
Matice hrvatske 15, 21000 Split, Croatia.
ivana.gabric@gradst.hr, ognjen.bonacci@gradst.hr

ABSTRACT

The phenomenon of coastal karst aquifers and coastal brackish karst springs draws more and more attention from scientists in last decades. They present potential water resources of significant quantities of quality water and have great importance for mostly densely populated coastal areas. Those regions have a tendency for even further development and consequently higher water needs. Therefore, development of coastal karstic springs contaminated by sea water would be of great importance for coastal communities short of fresh water. A prerequisite for the efficient management of these springs is better knowledge of the mechanism of sea water intrusion. To this end, building models which could help to explain the functioning of those springs would be of great importance.

It is well known that groundwater flow in the karst carbonate aquifer is due to the highly non-homogenous characteristics of karst and exceptionally complicated to model. The distribution of fresh water and sea water throughout the coastal karst system is different from that obtained with a simple application of Ghyben-Herzberg law which can be used to locate the interface between fresh and sea water only in the karst matrix but not in the whole karst system. The complex interaction between karst conduits, discrete fractures and the rock matrix results in highly varied hydraulic properties and distribution of sea water in the coastal aquifer. However, in the case of the coastal karst aquifers the dominant influence on the distribution of sea water through the aquifer belongs to the conduits. The general position of these conduits is shown on Fig. 1. The upper primary conduit ends at the outlet of the aquifer (brackish spring) and the secondary conduit is connected to the primary conduit (conduit branching) and the sea. An indicator of the existence of the secondary conduit is the submarine springs which are a common feature in the coastal karst regions. Seawater can flow freely to the spring after entering the upper conduit where there is conduit branching. Though these conduits also cross the zone of karst matrix containing sea water and sea water enters the conduit as a function of head difference between karst matrix and conduit, dominant intrusion of sea water occurs in the conduit branching.

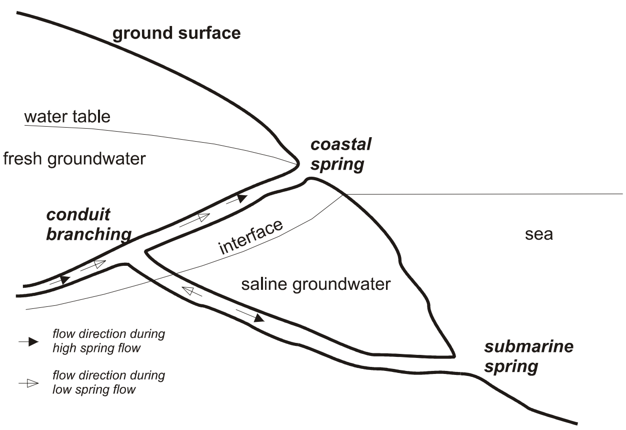


Fig. 1. Coastal spring in a conduit flow karstic aquifer

Described hypothetical spring geometry is used for building a simplified model of the coastal brackish karst springs. In this case the karst system is presented as network of conduits with flow described by the Darcy-Weisbach equation. The location and geometry of karst conduits are generally unknown but can be assumed on the basis of the known geological characteristics and existing knowledge about the hydrodynamic functioning of the aquifer. The input data for the model are measurements of discharge and water level at the brackish spring taken continuously at maximum 1 hour interval. Calculation parameters of the model are parameters of conduits geometry for one or more conduits as it is expected that there are several pairs of primary and lower conduits with branching at different depths. The fitting of the model consists in minimizing the difference between the

measured and calculated component of sea water flow at the spring. Results of this simple model can be used to verify the hypothesis about seawater flow to the spring. This information gives better insight into the process of sea intrusion, and hydrodynamic functioning of the spring. A better knowledge of the whole process is the prerequisite for effective management of coastal brackish springs and planning their development. This simple model is applied on two brackish springs: spring Pantan (Croatia) and spring Almyros of Heraklio (Crete, Greece).

Keywords: coastal karst springs, seawater intrusion, conduit model

Experimental studies and numerical modelling of surface water groundwater interaction in a semi-disconnected system

[1] L. ALBERTI, [2]G. BROGIOLI, [3]G. FORMENTIN, [2]T. MARANGONI, [2]M MASETTI.

[1] Politechnic of Milan, DIIAR Piazza Leonardo da Vinci 32, 20126 Milan, Italy, luca.alberti@polimi.it
[2] Department of Earth Sciences, "Ardito Desio", University of Milan, Via Mangiagalli 34, 20133 Milan, Italy, tomaso.marangoni@unimi.it; marco.masetti@unimi.it.
[3] G.E.CO. snc, Via R. Cuttica 42, 20025 Legnano (MI), Italy, giovanni.formentin@geco-env.it

ABSTRACT

Groundwater and surface water are not isolated components of the hydrologic system, but instead interact in a variety of physiographic and climatic landscapes. Thus, development or contamination of one commonly affects the other. Therefore, an understanding of the interactions between groundwater and surface water is needed for effective management of water resources. This subject presents many difficulties where a vadose zone exists between the surface water channel and the regional water table. Under these conditions the hydraulic connections between the stream and the aquifer mainly occur through unsaturated flow in the sediments of the vadose zone.

In this work experimental data and numerical modelling have been used in conjunction to quantify the water exchange between surface and groundwater and to analyse the main factors affecting it.

The study area has been located in a 2 km long reach of the Olona river in the Milan District (Northern Italy). The stream is characterised by an average discharge of a few cubic meters and yearly flood events with a discharge of 30-35 m^3/s.

Soil type and use in the study area have been mapped at a 1:10 000 scale through the analyses of 11 samples. The soils consist of mainly silty sand with some gravel while both agricultural and urban areas are present, leading to different conditions of infiltration over the area.

Instruments were installed in upstream and downstream sections of the river to monitor the hydrometric levels, for a period of four months, while a series of flow velocity has been measured at different levels to calibrate the roughness coefficient and to derive the two water level-discharge curves. Measured minimum and maximum discharge in the monitoring period has been 2 and 27m^3/s respectively.

The reach has been accurately selected to have a hydrologic condition not influenced by human activities, but some urban drain pipes and one irrigation canal has been found and their discharges calculated.

The balance of inflow and outflow in the river stretch, when river discharge was almost constant, has been estimated at about 6.53E-5 m/s, which can be considered the amount of water loss through infiltration into the riverbed.

A detailed hydrogeological characterisation has been performed and a section passing through the middle of the reach has been chosen to perform a 2D groundwater flow numerical analysis for unsaturated and saturated conditions.

Saturated hydraulic conductivities has been calculated by means of four slug tests and one pumping test, piezometric levels have been continuously measured with an automatic data-logger in a piezometer located 40 m away from the right riverbank.

The Gupta and Larson method and Green and Corey solution have been used to derive the soil moisture and the hydraulic conductivity functions, respectively. Numerical simulations have been performed both for steady state and transient conditions. The first scenario were designed represent a period without rainfall where hydrometric levels have been almost constant for some days; monitored piezometric levels and the calculated loss through the riverbed have been used to calibrate the model. A sensitivity analysis of the main hydrogeological parameters has shown that height and hydraulic conductivity of fine sediments in the riverbed are the main factors controlling infiltration.

During the transient analyses time dependant boundary conditions of hydraulic head has been applied to nodes representing the riverbank to simulate the measured hydrographs. The simulations allow you to check and quantify the temporal variation of infiltration and the formation and extension of the saturated zone, such as an inverted water table, during flood events.

Despite the fact that the aquifer-stream system is mainly connected through infiltration in unsaturated soils, the total aquifer recharge, due to water loss through the riverbed, can have very high values which should always be considered to improve management of both the quantitative and qualitative aspects of surface water and groundwater

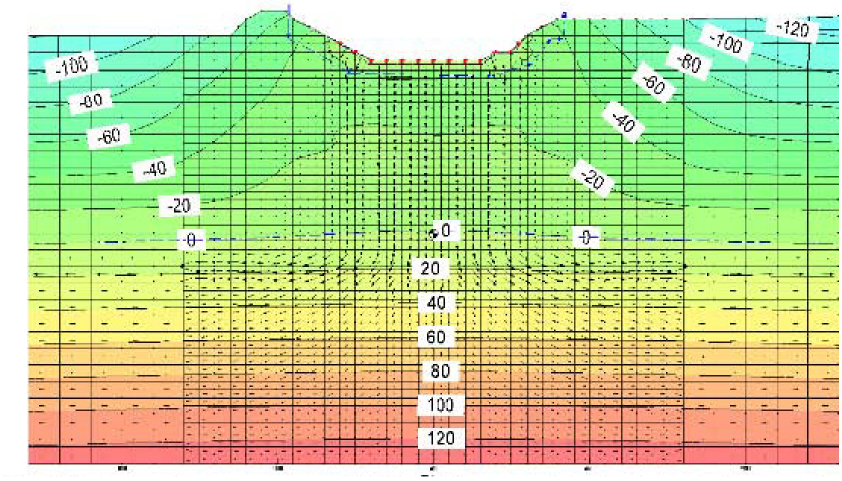


Fig. 1: Distribution of pore water pressures (in kPa) and flow vectors below the river and in the saturated zone

Keywords: Groundwater, surface water, numerical modeling, unsaturated flow,

Geochemistry of Kairouan plain, Tunisia

[1]Rim SAYADI, [1]Rachida BOUHLILA, [1]Mustapha BESBES.

[1]Laboratoire de Modélisation en Hydraulique et Environnement, Ecole nationale d'ingénieurs de Tunis, Tunisie

ABSTRACT

The aquifer of Kairouan, located in the central part of Tunisia, is the main water resource for drinking supply, agriculture and industrial use in the region. It is composed of a shallow and a deep aquifer unit and its main feeding comes from natural recharge in wadiis. Because of the demographic, agricultural and industrial development in the region, the aquifer is increasingly being exploitated with more than 5000 wells and 400 drillings (boreholes). The actual exploitation volume exceeds the aquifer capacity and thus can threaten the water quality there. The main risks are dealing with upwelling of deep saline water and Sebkha water intrusion. Another risk can come from recycling of irrigation water, which can be very saline because of the arid climate of the region.

In this study, we present the main results of a geochemical study of Kairouan aquifer. Major elements were used to identify the water types and a statistical analysis was performed to determine the salinity origin as well as the inter-connection between the surface water and the two aquifer layers.

The over-exploitation of the aquifer is inducing a general and continuous lowering of the static waterlevel over the past years, which will probably result in an early exhaustion of the resource (Fig. 1).

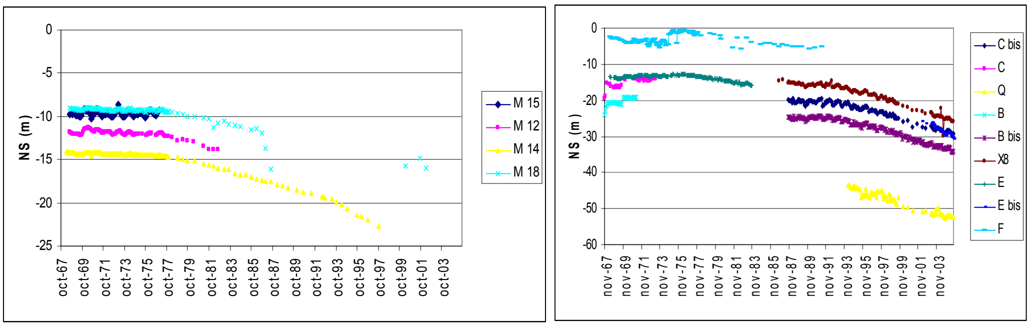


Fig. 1. Static waterlevel evolution from 1961 to 2003 of (a) the shallow groundwater (b) the deep groundwater

The spatial distribution of the groundwater salinity is controlled by the geology of the region (Fig. 2). The two aquifers were divided into three principle areas regarding the salinity distribution:

- Area with salinity ranging between 0-2 g/l in the Merguellil Wadi region,
- Area with salinity ranging between 2-3 g/l in the Zeroud Wadi region
- Area with very high salinity > 5g/l towards the Sebkhas and in the south area of the plain.

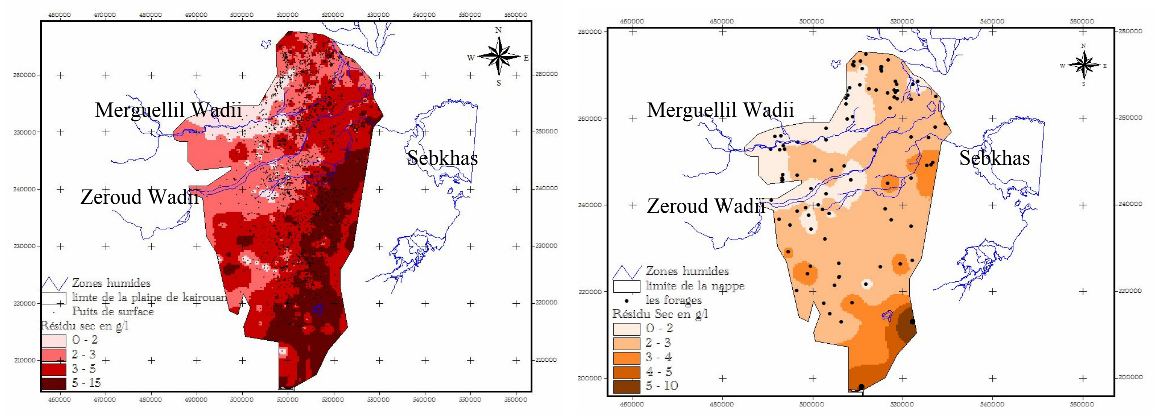


Fig.2. Spatial distribution of (a) shallow groundwater salinity (b) deep groundwater salinity

Figure 2 shows a similar response for both aquifer units. The water type is mainly Na-Cl and is regionally the same as is shown by the Piper diagrams (Fig. 3). This can lead us to conclude that the two aquifers are strongly connected and mainly recharged by the two principal Wadis, Zeroud and Merguellil.

The statistical study shows that salinity is mainly controlled by Na, Cl, SO_4 and Mg elements (Fig. 3).

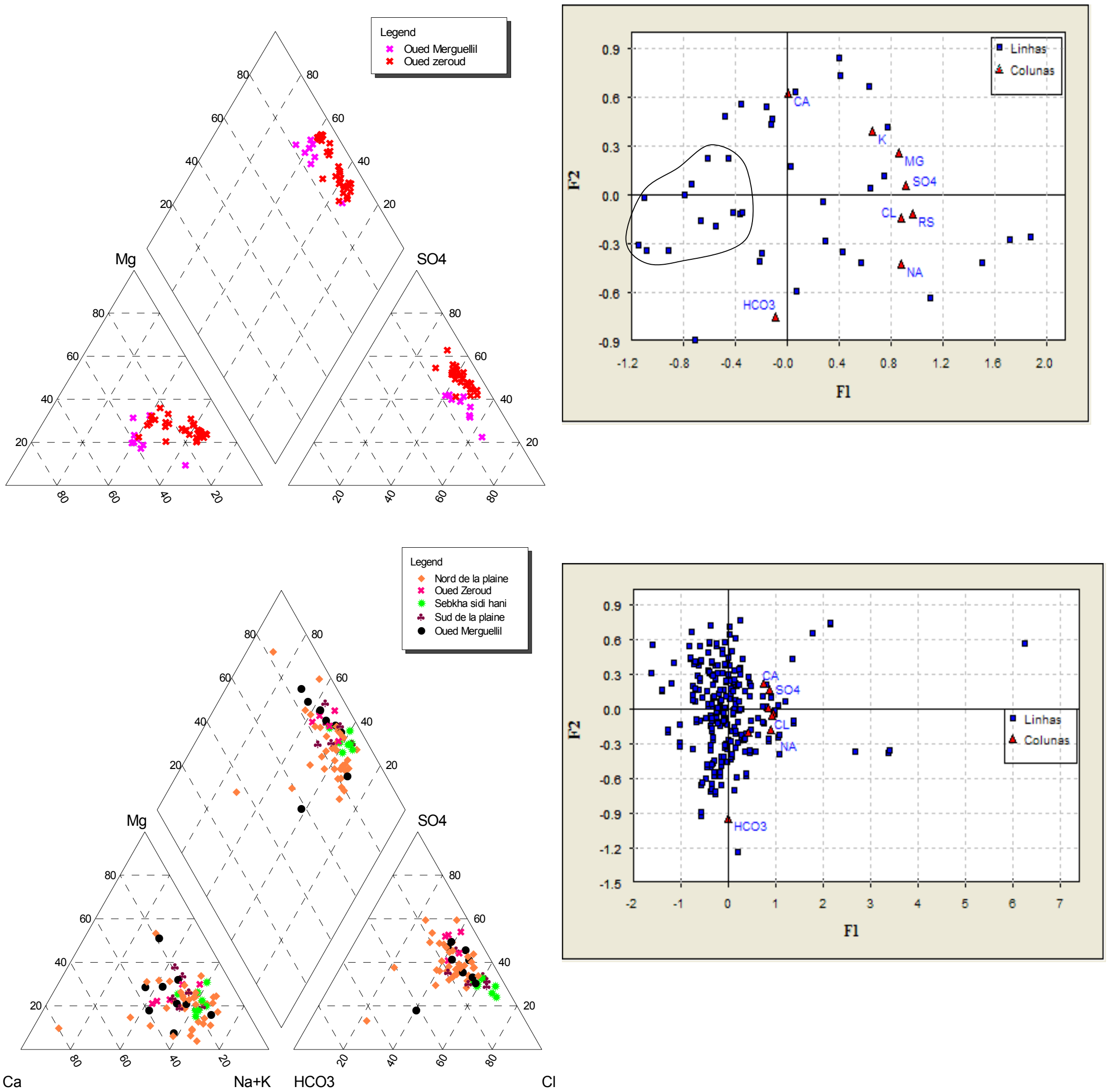


Fig. 3. Piper diagrams indicating chemical groundwater type.

In addition, salinity distribution was mapped for each year from 1971 to 2005. Obtained salinity maps show a stability contrasting with the increase in groundwater exploitation. Indeed, the poor groundwater quality is controlled by the geology of the area. The richness of the mineralization by different major elements has been explained by the probability of rock alteration, meteoric contribution and salt migration in the atmosphere from Sebkhas.

Keywords: geochemistry, surface water, groundwater, salinity, chemical water type.

Groundwater abstraction and subsidence in the Zumpango region, central Mexico

[1] Guillermo HERNÁNDEZ-GARCÍA, [2] Rafael HUIZAR-ALVAREZ

[1] Instituto de Geofísica, Universidad Nacional Autónoma de México, 04510, México,:
e-mail: ghdez@geofisica.unam.mx
[2] Instituto de Geología, Universidad Nacional Autónoma de México, 04510, México,
e-mail: huizar@servidor.unam.nx

ABSTRACT

The lack of control on the groundwater abstraction in Mexico city produces effects that have been linked to severe environmental impacts such as subsidence, inducement of bad quality groundwater and the drying of springs. This uncontrolled groundwater management in the study area implies a possibility that abstraction will produce similar environmental impacts

The Zumpango region covers its water demand of an estimated 17.7 m^3/s with groundwater. This area also partially supplies water to Mexico city and its metropolitan area. The constant population increase and related economic activities in the region result in a steady growth in water demands. The related abstraction rate has produced an average drawdown of about 1.5 m/year in the last two decades. It suggests that present groundwater management needs to be reviewed.

Uncontrolled groundwater management in the study area suggests the possibility that abstraction will produce similar environmental impacts. Consequently, it becomes necessary to study its hydrogeologic functioning to achieve a rational groundwater use in the Zumpango sub-basin. So, the main objectives of this study deal with the geologic structure, the hydraulic characteristics and their integration in a groundwater flow code (MODFLOW) to: 1) analyse the regional behaviour of the hydraulic gradient, and 2) investigate several alternatives of production thickness.

Aquitard response to water abstraction in an underlying aquifer unit implies an expected subsidence increase of 0.30 m/annum to be added to the present rate of 0.40 m/annum. Consequently, for the year 2020 overall additional subsidence will reach approximately 6.0 m. An uncontrolled abstraction increase under actual borehole distribution will trigger additional problems with urban-area infrastructure.

Keywords: Subsidence, groundwater modelling, México

Groundwater modelling results as a tool to sustainable water use.

Stanisław STASKO

Wroclaw University, Institute of Geological Sciences, General Hydrogeology Department
Pl.M.Borna 9 , 50-204 Wrocław, Poland
EM: sstasko@ing.uni.wroc.pl

ABSTRACT

Poland's geological formations includes mostly porous aquifers but also fracture, karstic and crystalline (hard rocks) in the southern part of the country.

One of the main problems regarding groundwater management is available or safe exploitation by water plants especially in big cities and in case of considerable extraction.

The recommended method for groundwater resources evaluation and allowed extraction according to domestic regulation is a numerical modelling approach. Results of groundwater resources assessment in three different geological formations are discussed and illustrated using a deterministic approach. Each case study was followed by hydrologic measurements and mapping survey (wells, spring, current water abstraction etc.). Isotopic and chemical data together with atmospheric precipitation amount and distribution has been collected in order to calibrate the final results.

The first case study covers carbonate aquifer in porous –fracture – karstic water system. This monocline Triassic aquifer form by Muschelkalk limestone and dolomites is the main source of water supply. Fresh water occurrence up to 400 m depth has been recognized. At the same area dewatering of open pit exploitation for lime production creates conflict of interest. Part of an aquifer, manifested on land surface, is at high risk due to agriculture and other activities in the outcrop area. Results of modelling with Modflowe and Feeflow programs allows the evaluation of available water resources and the impact of different forms of water exploitation. What is more important, it provides a tool to the administration for an active policy to protect water resources, according to EU Water Framework Directive. Some complications and limitation of modelling programs related to the above mentioned programmes are discussed. In order to simulate local high flow in karstic systems instead of using Modflow code it is necessary to apply Feeflow. Different scenarios have been developed in order to select the best water intake localization and interaction with other water users.

A quaternary aquifer in porous buried valley up to 160 m depth and glacial deposits near Wrocław City are examples of a typical situation in the low land part of the country. The main goal of modelling was to evaluate a renewable and admissible volume of extracted groundwater as a possible source of water supply for Wrocław City. A three layered model was constructed and evaluated according to detailed hydrologic data. This regional modelling results show good aquifer isolation and high (58 600 m^3/day) available resources.

The third example illustrates fresh and mineral water occurrence and exploitation problems in Carpathian flysch formation. Typical depth of fresh water occurrence is up to 80 m only in sandstone and shales and well productiveness is up to 5 m^3/h. Limited amount of fresh water resources in such an aquifer and increasing water demand create a problem of coexistence of both types of water and safe water exploitation. Long term pumping experience with a detailed field study supported by modelling technique showed limitations and a proposal of the best water use.

These examples illustrates that the modelling technique is an important tool for water management policy and decision support systems. Well designed model could be verified in future when new data are available. Clear statement of the advantages and limitations of such techniques in each case study should be a part of a groundwater resources evaluation process.

Keywords : groundwater, modelling, sustainable use, resources

How to model groundwater flow on the regional scale in hydrogeologically complex regions?

[1]Roland BARTHEL, [1]Jens WOLF, [1]Vlad ROJANSCHI, [1]Johanna JAGELKE, [1]Marco BORCHERS, [2]Thomas GAISER, [3]Wolfram MAUSER

[1]Universitaet Stuttgart, Institute of Hydraulic Engineering, Pfaffenwaldring 7a, 70569 Stuttgart, Germany, Tel. +49- 711 685 66601, Fax +49 711 685 66600, e-mail: roland.barthel@iws.uni-stuttgart.de
[2]Institute of Soil Science, Universitaet of Hohenheim, Germany
[3]Faculty for Geosciences, Ludwig-Maximilians University (LMU), Luisenstr. 37, D-80333,

ABSTRACT

Many water management tasks such as the evaluation of the impact of climate change and the establishment of river basin management plans - as requested by the European Water Framework Directive - require a regional (i.e. river basin scale >10,000 km^2) assessment of the state and future of water resources. Models are important tools that help people to understand systems, to predict changes and to support decisions with far-ranging implications. Since groundwater is a major drinking water source in many parts of the world, the groundwater system and its accurate representation play a major role. Thus far, numerical 3D groundwater flow models are the only means to consider multiple aquifers, to describe horizontal as well as vertical flow, to calculate flow direction and velocity, to quantitatively simulate groundwater discharge to surface waters and, above all, to provide hydraulic heads in different aquifers as a result.

However, to set up a groundwater flow model that can actually provide all the aforementioned results in a meaningful, realistic and useful way is not a simple task. In most cases data required for model parameterization is not available in sufficient amounts in all parts of a river basins, and discretisation must be relatively coarse to result in a reasonable number of elements/cells. Models for hydrogeologically complex areas (i.e. multiple aquifers, complex relief etc.) of more than 10,000 km^2 are relatively scarce. Furthermore the question of whether numerical groundwater flow models of this size and complexity are really an appropriate means to solve groundwater related management problems is definitely one that needs to be discussed thoroughly.

Here we will make an attempt to discuss this question using the example of three regional groundwater flow models (Upper Danube catchment, Germany, 80,000 km^2, Neckar catchment, Germany, 14,000 km^2, and Southern Ouémé Basin, Benin, 11,000 km^2) which were developed within the framework of the integrated management projects RIVERTWIN (www.rivertwin.org) and GLOWA-Danube (www.glowa.org; www.glowa-danube.de). The groundwater flow models are integrated into coupled management models comprised of 10 and 16 individual models respectively. All three models were evaluated with respect to the question of whether the chosen modelling approaches (multi-layered finite difference numerical flow modelling, steady state and transient - MODFLOW) are appropriate in view of the existing management problems in the catchments, the data availability and the hydrogeological and hydrological conditions in the basins.

After introducing the projects GLOWA-Danube and RIVERTWIN, the models and the coupling schemes used, it is shown that neither the models in the well-investigated, data rich basins in Western Europe, with its highly developed water related infrastructure, nor the model in the hydrogeologically less well-known and less developed basin in Western Africa provide results that are fully applicable to the main regional management tasks. In the case of the Ouémé basin, the groundwater related problems are foremost of local character and therefore cannot be addressed by regional models in a meaningful way. Data scarcity and complex, unfavourable geological conditions (crystalline rocks, discontinuous aquifers) support the conclusion that numerical 3D groundwater flow models are currently not helpful to manage groundwater related management problems in the Ouémé basin. A better understanding of regional hydrological surface and subsurface processes is required first. Methods for a reliable estimation of groundwater recharge and subsequently groundwater availability were identified as the most urgently needed tool for meaningful groundwater management in view of climatic, demographic and land use change.

In the Neckar catchment, the results of the analysis are less pronounced; here regional groundwater problems could clearly benefit from a physically based 3D model since the hydrogeological system is strictly stratified with at least 6 important regional aquifers. However, even here, the data availability for model set up and parameterization is low in relation to the complexity of the area. Again, groundwater management problems are predominately local ones, but several regional tasks such as prediction of low flow periods under conditions of climate change are also present.

Lastly, the Upper Danube catchment is particularly difficult to model since it combines a thin intensively distributed and highly efficient drainage network of alluvial porous aquifers, intensively carstic terrains, crystalline rocks and an alpine mountain belt which makes up 30% of the area and receives 50% of the precipitation. Here, it is inevitable that mixed approaches must be employed, i.e. a combination of the deterministic numerical scheme in the stratified regions and conceptual approaches in the complex mountainous areas.

As a general conclusion it can be stated that groundwater flow models on the regional scale in hydrogeologically complex regions are in most cases obviously not the only appropriate method to describe the groundwater system. The question of how to represent the groundwater resources meaningfully with respect to data availability and the management problems to be solved has to be discussed very thoroughly for any modelling area or catchment. Regional modelling concepts seem to be quite unique for each region and therefore difficult to transfer from one basin to another and difficult to integrate in standardized management systems. It is not possible to give a final recommendation on which modelling concept is the most appropriate one in regional integrated modelling and management. Hence, this contribution is only intended to provide a discussion of the aspects that need to be considered in the process of choosing appropriate modelling concepts.

Keywords: Regional Scale, Groundwater Flow Model, MODFLOW, Neckar, Danube

Hydrogeochemical and hydrodynamic processes in post-mining landscapes of the potash mining area Nordharz – Analysis of active leaching and subsidence processes

[1]Antje BOHN, [2]Frank HERRMANN, [3]Christoph JAHNKE, [4]Norbert WALTER & [5]Hans-Jürgen VOIGT

Brandenburg University of Technology, Cottbus, Chair of Environmental Geology,
Erich-Weinert-Str. 1, 03046 Cottbus, Germany

[1]bohn@tu-cottbus.de
[2]herrmanf@tu-cottbus.de
[3]jahnke_christoph@yahoo.de
[4]walter@tu-cottbus.de
[5]voigt@tu-cottbus.de

ABSTRACT

Stassfurt is a small city located in the Federal State of Saxony-Anhalt (Germany) known for the first potash mining worldwide. Since 1861 potash has been extracted in deep mining from the Stassfurt Salt Anticline, partly underneath the urban area of Stassfurt. The mining cavities on the southwest flank of the anticline were drowned by accident during the mining activity. On the northeast flank the shafts were flooded with brine to avoid the post-mining damage. Nowadays active subsidence due to the convergence of mining cavities impair the urban development by the danger of sinkholes and water logging of the surface. Because of a total subsidence of over 6 m in the last 100 years, some parts of the town center are below the natural groundwater level and have to be kept dry by drainage. Apart from the convergence of mines and existing cavities new cavities by leaching processes in and at the salt structure can be formed. This is a crucial boundary condition for the sustained subsidence.

Target of the investigations was to analyze the interaction between the existing saline waters and the minerals of the saline “Zechstein formation” to obtain information about the leaching processes. Therefore, the different waters were characterized regarding their genesis and properties. The calculation of the saturation states of the solutions were performed with the geochemical computer program PHRQPITZ. The different aquifers were examined for their hydrostatic pressure potentials in order to explain the hydrodynamic conditions. Within the different aquifers the determined states of saturation of the waters showed that they are predominantly in equilibrium to the solid mineral phases and therefore no longer have any salt leaching potential. In the complex lower Triassic sandstones however some of the solutions are characteristic for the saline “Zechstein formation” and from the transition to the caprock and “Stassfurt Salt” leaching surface. The distribution of the hydrostatic pressure potentials and the chemical characteristics of some of the solutions found in the complex lower Triassic sandstones indicate a migration of highly saline water from the salt rock into the surrounding rock. The available preliminary results indicate that the underground is an open system and therefore recent subrosion and leaching processes by circulating waters are to be expected.

Further investigations are planned to acquire more data about the geological structure and the current hydrogeochemical situation by a drilling program and groundwater monitoring. For the representation of the geological structures including the mining cavities a 3 dimensional model has to be developed. From this a 3-dimensional hydrogeological model has to be derived as a basis for further hydrodynamical and hydrogeochemical simulations.

Keywords: potash mining, salt leaching processes, subsidence, hydrogeological model, hydrogeochemical and hydrodynamic modelling

Implementation of fault systems into the interpolation of groundwater aquiclude maps using Kriging. A case study for the Marchfeld, Austria

[1]Andreas DARSOW, [2]Maria-Theresia SCHAFMEISTER, [1]Thilo HOFMANN

[1]Department of Environmental Geosciences, Vienna University, Althanstrasse 14, 1090 Vienna, Austria, e-mail: andreas.darsow@univie.ac.at, thilo.hofmann@univie.ac.at
[2]Institute for Geography and Geology, University Greifswald, F.-L.-Jahnstrasse 17a, 17487 Greifswald, Germany, e-mail: schaf@uni-greifswald.de

ABSTRACT

For investigations and modelling approaches of aquifer systems the knowledge of the natural boundaries of the aquifer body is essential. One of the most important boundaries is represented by the aquifer basis. Many aquifers include neo-tectonic structures. Considering this disturbance in the aquifer system by such lineaments, interpolation of geological aquiclude data leads to divergent results under consideration of these geological fault systems. The interpolation of the lithological information gained from drillings is critical.

In this study we considered a set of drilling data obtained from the Marchfeld region in Austria. The Marchfeld region is an intensively used agricultural area covering 1000 km² east of Vienna and one of the most important pore aquifers in Austria. Due to its intensive agricultural use it is a highly sensitive system. The presented study is part of a project aiming at the enforcement of the European Water Framework Directive. Interpolation of the aquiclude map, which accounts for fault systems, is obtained by combining different regionalization techniques: Here we use a combination of Ordinary Kriging and Inverse Distance Weighted interpolation implemented in ArcGIS 9.1.

In order to interpolate the geological data set consisting of lithological information we first apply Ordinary Kriging. After several steps of data transformation to convert the floating point raster from the Kriging interpolation into an integer raster, a point shape file was generated in ArcGIS based on the Ordinary Kriging raster. By generating buffer zones around the lineaments, the data from the point shape file which are lying inside the buffer zones are erased. Afterwards the Inverse Distance Weighted method was used for the spatial estimations because it allows regionalisation by the use of break lines.

The interpolation parameters in the Inverse Distance Weighted method are specified in a way that the Kriging raster only differs within the buffer zones. Following these steps raster are generated which vary with respect to their spatial resolution depending on the number of data points in the investigation area.

This approach leads to a different aquifer model, i.e. an increased aquifer thickness, than that reported by previous geological studies. On the basis of about 1000 borehole-logs a hydraulic contact between the upper Neogen and the Quarternary sediments can be assumed, using the suggested regionalization procedure. This contradicts previous work e.g.by Schuch (1977) which assumes that the aquifer basis is located at Quaternary basis.

Reference

Schuch, M., F. (1977): Beiträge zur Hydrogeologie des Marchfeldes, 31 S. (Amt der NÖ Landesregierung), Wien

Keywords: Hydrogeology, GIS, interpolation, Kriging, Inverse Distance Weigthed

The evolution of groundwater management models: a review

Sandra MARTINEZ[1], Oscar ESCOLERO[2], Stefanie KRALISCH[1]

[1]Postgraduate in Earth Sciences, Instituto de Geologia, Universidad Nacional Autonoma de Mexico, Ciudad Universitaria, Coyoacan 04510, Mexico City, Mexico. seddam2002@yahoo.com.mx, cyprexxa@gmx.net
[2]Departamento de Geología Regional, Instituto de Geologia, Universidad Nacional Autonoma de Mexico, Ciudad Universitaria, Coyoacan 04510, Mexico City, Mexico. escolero@geologia.unam.mx

ABSTRACT

Groundwater simulation-optimization models join are decision support tools to construct decision support systems (DSS) for solving groundwater management problems associated with diverse objectives that include sustainable water supply, cost efficiency or ecosystem protection.

This work presents a review of the application of simulation-optimization models and decision support techniques to complex real world groundwater management problems. The development and change in model approaches in the last decades will be described, with respect to the previous results from a review by Gorelick in 1983.

Gorelick (1983) distinguished two model categories that combine aquifer simulation with management models. The first one refers to models that address the hydraulic aspects of aquifer management problems, like optimal design of well fields of pumping strategies. The decision variables are the water demand and hydraulic heads, they can also be expressed in terms of costs. The second category refers to models for water allocation and the evaluation of groundwater policies. They do not only include hydraulic aspects and costs, but the complex physical, socio-economic and political interactions within the system that are necessary to evaluate management scenarios and planning strategies. Nevertheless, facing the evolution in management concepts and the complexity and great variety of today's model applications it does seem unfeasible to keep this classification. For example, models with exclusively hydraulic variables can still include a variety of other constraints like sector-specific demand and the distribution of water rights, investment costs, or agronomic and ecological considerations.

Deterministic models with linear or quadratic programming have dominated theoretical discussion until the decade of the 1990ties and are still widely applied in practice. Within this framework, traditionally two methods have been used to couple the aquifer simulation model to the optimization process: the embedding method and the matrix response approach (later response functions). Nevertheless, the need for more realistic models and the integration of non-hydraulic variables and objectives has promoted the development of a vast variety of other techniques. During the 90ties, important progress has been made in the following fields:

i) Stochastic modeling techniques have allowed the incorporation of uncertainty of parameters. The analysis of uncertainty may be included directly into the model or using a posterior Monte Carlo analysis.
ii) Dynamic strategies permit the inclusion of the variable time into groundwater management. Some studies for example have used optimal control techniques to determine the optimal sequence of pumping rates in time. Dynamic programming is promising to reduce computation time for this kind of problems.
iii) In discrete methods the objective function is expressed as a mixture of discrete and non-linear variables. They permit the solution of combinatorial problems, as they arise from the complexity of hydraulic systems, the design of monitoring networks and the inclusion of additional factors into an integrated water management. Some of the methods include simulated annealing, branch and bound, local search algorithms, dynamic programming, artificial neural networks and genetic algorithms. Various studies suggest very good results in terms of the obtained solutions and computation time, compared to traditional techniques.

The broad application of simulation-optimization models to real world problems of water quantity and quality management was favored by the development of user-friendly software that requires less time and mathematical knowledge by the user. Some examples for common codes are: MODMAN+LINDO (linear programming), FM2K-GWM (for linear, non-linear and mixed integer problems) or MGO.(genetic algorithm, simulated annealing, tabu search, coupled with gradient-based optimization).

Real world groundwater management cases (e.g. the optimal allocation between different sectors and sources) represent multi-objective and often conflicting problems. There does not exist one single optimal solution, but a set of pareto-optimal solutions. The search for this set can be performed inside an optimization model or with independent techniques of multi-criteria selection. The challenge is in sorting the solutions and integrating the preferences of the decision makers. Whereas this process has been essentially intuitive in the past

or based on purely economic considerations, nowadays, stakeholder participation and the interdisciplinary character of the decisions has gained more importance. Decision support tools (DST) have contributed to find the compromise solution that satisfies the majority of the involved stakeholders. There is a very broad variety of techniques and the development of different interaction platforms is in plain process. Weighting methods allow for the direct intervention of the decision makers, but require a lot of runs to find a solution. The constraint method is frequently used to determine and visualize the trade-offs in curves or pay-off matrices. The evolutive algorithms can find the balance between the different objectives in one run, an example is the NSGA-II (Non-dominated sorting genetic algorithm II).

The development of a truly participative modeling process in aquifer management is a bigger challenge than in surface water systems, where a longer tradition in user participation exists and the control of water rights and actual extraction is somewhat easier.

In the field of practical application, the coupling of simulation models, tools for planning and integrated water resource management (IWRM), as well as geographical information systems, can be seen as the actual challenge. Model selection in a modular way, the design of interfaces and packages, and the modeling of the interactions between the hydrologic, hydrogeologic and socio-economic subsystems at a basin level are the key points in this aspect. The characterization of groundwater resources within available IWRM softwares ranges from being absent to simply being a water pool (eg. WEAP21) or simple physical models (eg. MIKE BASIN or newer versions of RIBASIM).

Generally, it can be stated that the application of integrative models to real world cases does not match the quantity of different techniques and approaches developed. An enhanced practical application would benefit water managers, providing them with an effective tool to develop optimal planning strategies for groundwater resources and to evaluate policy proposals.

Reference

Gorelick, S.M., (1983). A review of distributed parameter groundwater management modeling methods. *Water Resources Research* 19-2, 305-319.

Keywords: Groundwater models, Groundwater management, Integrated water resources management, Decision support system, Groundwater policies.

Refinement of rainfall-runoff characteristics by linking hydrologic and groundwater flow models

[1]Nada RAPANTOVA, [1]Jan UNUCKA, [1]David VOJTEK, [1]Jiri HORAK, [2]Dusan ZIDEK

[1]VSB-Technical University of Ostrava, 17. listopadu, 708 33 Ostrava-Poruba, Czech Republic, e-mail: nada.rapantova@vsb.cz, jan.unucka@vsb.cy, david.vojek@vsb.cz, jiri.horak@vsb.cz
[2] Czech Hydrometerological Institute, K myslivne 3/2182, 708 33 Ostrava-Poruba, Czech Republic, e-mail: zidek@chmi.cz

ABSTRACT

The complex approach to water cycle quantitative solutions within the scale of watershed is limited by computation time and hardware requirements and consequent state of modeling software development. Our team presents approach based on the linkage of models which are usually applied for the solution of particular components of the water cycle. Such attitude was tested within TRANSCAT EU research project "Integrated Water Management of Transboundary Catchments" (http://transcat.vsb.cz/transcat) and is further developed in FLOREON "Floods Recognition on the Net" (http://arg.vsb.cz/msk) project.
Linkage of hydrogeological and hydrologic models is possible as combination with the groundwater flow (MODFLOW) and the rainfall-runoff model (HEC-HMS, HYDROG) or as combination with the groundwater flow and hydrodynamic model (HEC-RAS, MIKE 11).
Both types of such combinations represent reciprocal adjustment of the parameters of the models of particular domain of the water cycle of the watershed (surface water, unsaturated zone, saturated zone).

There is the possibility of the rainfall-runoff model baseflow parameters adjustment and calibration on the level of combination of the hydrogeological and rainfall-runoff model. Parameters of the recession method and linear reservoir method can be mentioned concretely.

Communication of the unsaturated zone within the river channels and inundations can be analyzed by the linkage of hydrogeological and hydrodynamic model. Boundary conditions such as groundwater leakage (MIKE 11) or groundwater interflow (HEC-RAS) can be adjusted and calibrated by this type of model combination. Results are tested on two pilot catchments with different geological, hydrogeological,

Fig. 1. Terrain subsidence due the mining activities on the lower part of Olse watershed

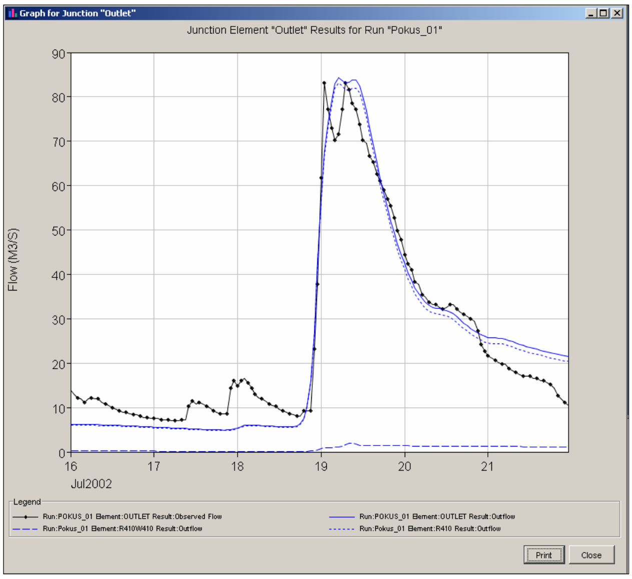


Fig. 2. Simulated (blue curve) and measured (black curve) hydrograph on closing profile of Olse watershed Vernovice

geomorphological and climatic conditions – Olse River and Bela River. Olse River and its lower part of watershed represents catchment with strong anthropogenic impact as a consequence of coal mining. These activities lead to terrain subsidence, closed basins formation, sinks and ineffective flow areas (see Fig. 1). Geomorphological conditions are verified by the LIDAR and radar interferometry terrain scanning. Terrain evolution is predictable pursuant to subsidence forecast by the mining companies.

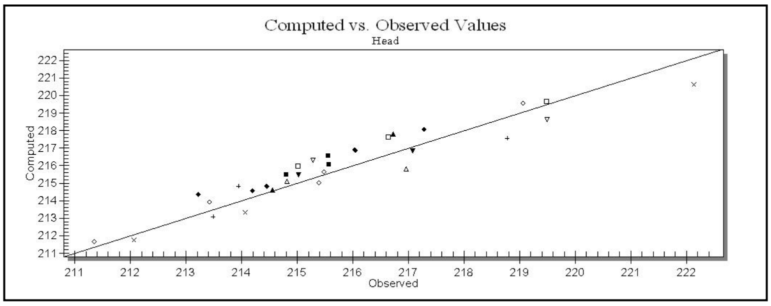


Fig. 3. Comparison of measured and simulated groundwater heads

The contribution of such a complex solution of model linkage is control of water balance on the level of groundwater flow and hydrodynamic models boundary conditions, which is an important element of the model uncertainty decreasing.

Rainfall-runoff model was calibrated on the storm and flash flood rainfall-runoff episodes (Fig. 2). Further model calibration heads towards the episodes with lower extremity. Groundwater flow model was developed for the quaternary fluvial sediments of Olse River and calibrated on 30 calibration targets – groundwater heads (Fig. 3).

A designed solution combined with the theoretical verification of model linkage possibilities brings practical results of water balance and cycle variations within river channel scale. The model is ready to be used for predictions of runoff conditions changes in heavily antropogenously influenced region.

Analyis of Bela catchment is primarily oriented to flood risk protection (Fig. 4). Modeling is complicated by catchment geomorphological and climatic nonuniformity and the lack of dense raingauge station net, which can be particularly improved by the use of the adjusted radar estimations.

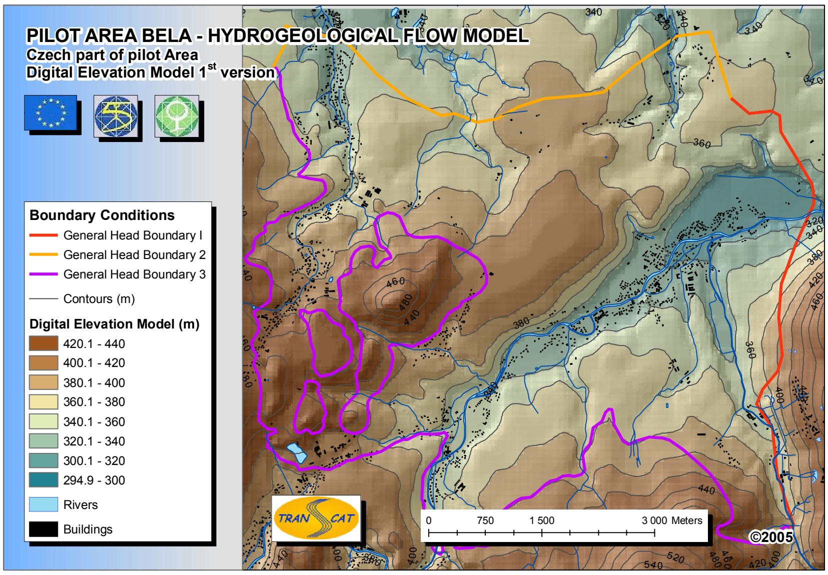


Fig. 4. Bela River Watershed – boundary conditions for groundwater flow model

Keywords: Watershed, modeling, groundwater-surface water interaction

Software Supported Grid-Optimization for the Determination of Groundwater Contamination Using Artificial Neural Networks

Dipl.-Geol. Marc LUDEWIG[1], Prof. Dr. Heinz HÖTZL[1]

[1]Department of Applied Geology, Universität Karlsruhe (TH) – Research University,
Kaiserstraße 12, 76128 Karlsruhe, Germany

ABSTRACT

In the sense of an effective and efficient contamination exploration for decision making reliable information is needed. These decisions depend on the quality of the data and the associated data bases as well as the efficiency of the application-oriented investigation routines. Regarding the use of certain methods, systems are needed, which assist the responsible person in decision in real time. A primary view focuses on the correctness, completeness and reliability of the available data. Typically a lot of advance work is done in order to create a trustworthy basis for the majority of operative as well as dispositive systems. Today, the quality and reliability of decision relevant information are achieved by intelligent data analyses from the existing datapool. They have a huge relevance and thus give impetus to operational and also strategical decisions.

In the recent years, the computical determination of contamination areas in the groundwater bodies has become increasingly important, especially using geostatistical methods implemented by sophisticated software.
In this paper the determination of groundwater contamination in the field by using artificial neural networks (ANN) as an additional method for the exploration of contaminants is presented. In contrast to numerical modelling, which uses assumptions to build the model, artificial neural networks are implemented only with real world data. Input data to the neural networks can be every parameter which influences the dispersion of the contaminations, mainly the hydrogeologic data like the permeability, the thickness of the aquifer or the groundwater recharge. The output of the neural network is the total contaminant concentration in the relevant area.

From several recent test areas the artificial neural networks show a high grade of reliable predictive accuracy and therefore offer an adequate method for the successful determination of contamination areas.

The focus in the development of a grid-optimization can diverge depending upon the question, and vary from a pure selection of new measuring points for an optimization of the sampling raster up to the statement of the expansion of contamination ranges. However, the actual question might be, the goal of the grid-optimization is not to allow a certain number of samples. The resolution lies rather in presenting, mainly in visual form, reliable statements about the complete location situation, as well as recommendations with the expected problem zones**.** Additionally, a further approach lies in the avoidance of misinterpretations of measured results.

Keywords: Artificial Neural Networks, Groundwater Contamination, Grid-Optimization, Field Screening

Study on flood analysis in Izushi River and investigation of river improvement measure

[[1] Kuniko ISHIMORI, [2] Mitsukuni TSUCHIYA

[1] 460-1 Kamisatori-cho, Maebashi, Gunma, 371-0816 Japan, e-mail: umbrella_925@yahoo.co.jp
[2] 460-1 Kamisatori-cho, Maebashi, Gunma, 371-0816 Japan, e-mail: tsuchiya@maebashi-it.ac.jp

ABSTRACT

I. INTRODUCTION

In late years unpredictable abnormal weather due to global warming or desertification causes damage in the human living environment in many parts of the world. Recently, local heavy rain in the city area and flood disasters caused by typhoons, are frequent in Japan. A radical review of river improvement / disaster prevention measures is carried out. In the Maruyama river basin that suffered from typhoon 0423 of 2004, river improvement measures such as river channel maintenance, embankments, inner water measures, and maintenance of a flood prevention reservoir until 2014 are carried out now. In addition, in the Maruyama River nature revival plan, maintenance of the river environment to encourage the return of storks is carried out with a flood control management, too.

In this study, we simulate the flooding due to typhoon 0423 in the Izushi River that is a branch of the Maruyama River, and examine directionality of river improvement measures and river environment maintenance.

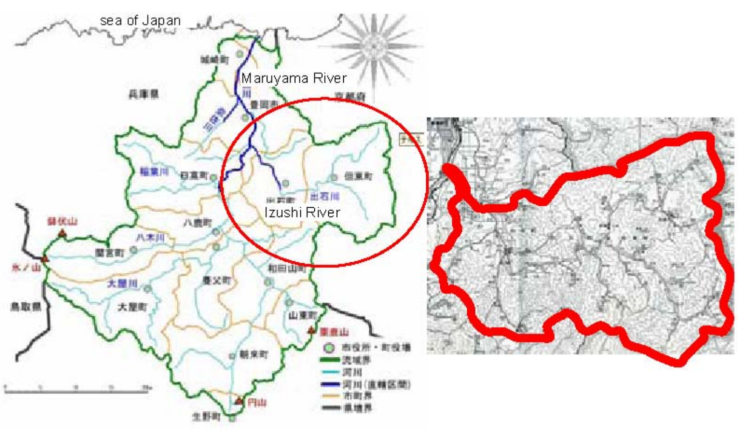
II. SUMMARY OF IZUSHI RIVER

The river extension of Maruyama River rises from Asago, Maruyama Ikuno-cho Hyogo prefecture, and branch river of 97 such as Yagi River, Izushi River, and Nasa River joins it, and flow into the Sea of Japan, Maruyama river is the first-grade river which river length of river channel is 68km, basin area is 1300 km^2. Izushi branch River has a river length of 35 km, and also basin area of 220 km^2. (Fig.1)

The river bed slope is slow because of the neighbourhood of river mouth of Maruyama River, a damp ground where drainage is bad spread out from old era**.** In Roppou River which is a branch, the inundation damage occurs in particular almost every year. Because Roppou river basin area surrounded by Maruyama River, Izushi River levee and mountains, in other words it is an inner water area. However, A wet land formed by a flood to be often caused is a perfect biotope for storks.

III. RAIN ANALYSIS

Using two days greatest precipitation data of 106 years from 1899 to 2004 in Tatsuno point, we performed rain analysis. It became clear that a heavy rain in typhoon 0423 was equivalent to probability for 46 years. (Fig.2).



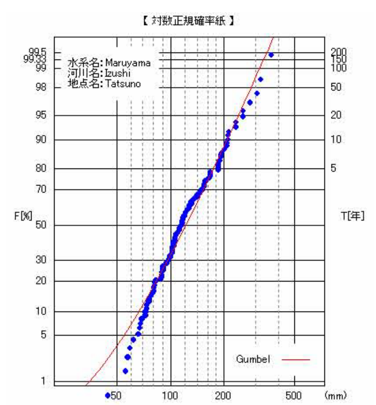


Fig. 1. Izushi River basin

Fig. 2. Result of rain analysis

IV. FLOOD ANALYSIS

We applied flooding simulation software "MIKE FLOOD" developed by DHI and calibrated an inundation area in typhoon 0423. MIKE FLOOD is the flooding simulation model that unified two-dimensional model -MIKE21 of flood plain and one-dimensional model -MIKE11 of a river channel.

We performed one-dimensional unsteady flow calculation in Izushi River by MIKE11. At first, we inserted 45 places of section data with 200m sections (Fig. 3). In addition, we input discharge of the best upstream point with observed value and calculated at Torii spot, junction of Maruyama River discharge using kinematic wave method, and input it on each spot.

Fig. 5 shows runoff analysis results of each inspection spot by MIKE11. It was shown that the peak flow of Torii Bridge point was 1600m^3/s which was section of levee crevasse.

In MIKE21, we used digital map information 50m mesh data of Geographical Survey Institute publication and modelled a flood plain as Fig. 4. We set a broken levee place and unified both models and calculated.

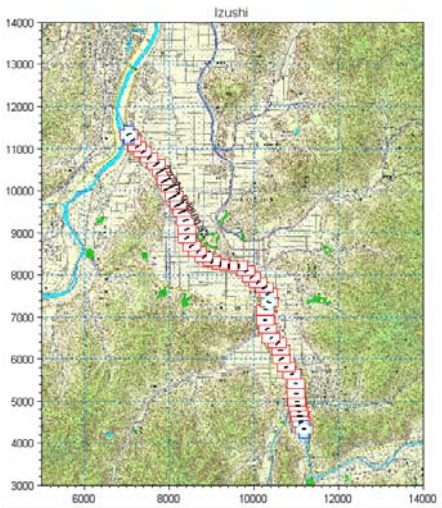


Fig. 3. Izushi river network

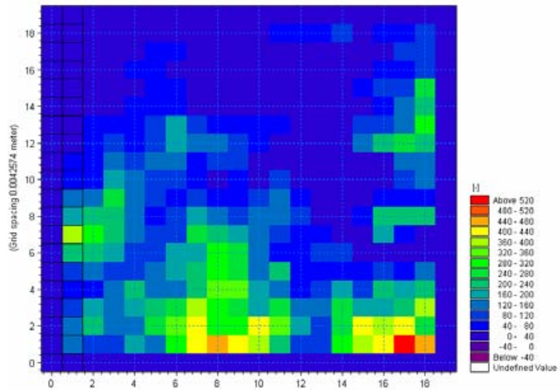
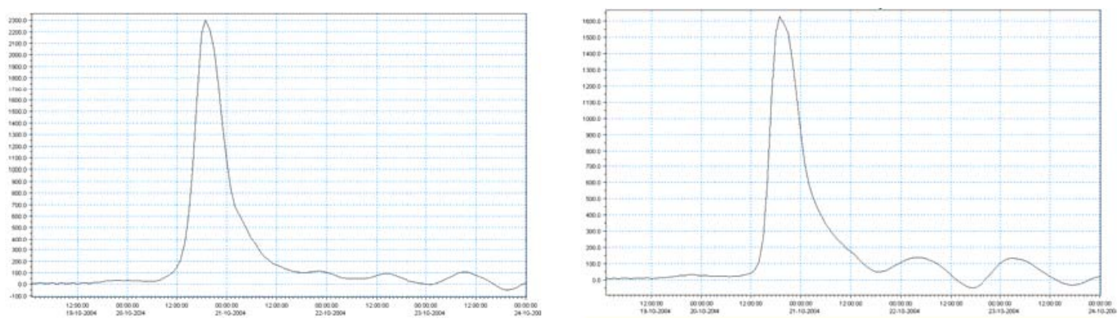


Fig. 5. 50m mesh elevation



(a) Junction of Maruyama river *(b) Torii spot*

Fig. 4. Runoff analysis results by MIKE11

V. CONCLUSION

As a result of having analyzed the flooding at typhoon 0423, we were able to reproduce the inundation results. We will simulate a flooded area incorporated flood management functions such as the establishment of a flood prevention reservoir, the reinforcement of ability for drainage pump in a model and it, and will examine a reduction effect of an inundation area.

Keywords: river improvement measure, flooding simulation, inner water measures, flood plain

Studying of dynamic of groundwater intruding at working off gas deposit using mathematical modeling (the south part of "Medvezhiya deposit).

Irina POLSHKOVA

Water Problems Institute, Russian Academy of Sciences, 3 Gubkina str., 119333 Moscow, Russia,
e-mail: irpol@aqua.laser.ru

ABSTRACT

This mathematical model is focused on studying the dynamic of head decrease in intruding ground water flow, while the rise of gas-water contact occurs during working off gas deposit.

In this case the process of head decreasing cannot be considered as a result of water withdrawal during the exploitation of water supply systems that often is specified on the model as boundary conditions of the second type with determined negative discharge. Thus, the studying of groundwater penetration occurs in two steps.

In the first step the process of movement of gas-water contact was reproduced. As criteria for the model adequacy with reference to the studying process the following factors were controlled:

- The rate of gas-water contact rise;
- The volume of intruded water including total and annual.

Due to negligible values of plane flow, the rise of gas-water contact can be described by the following equation:

$$(Z_b - H)G_{III} = \hat{\mu}\frac{\partial H(x,y)}{\partial t},$$

where $Q = (Z_b - H)G_{III}$ is an annual intruding water volume (this volume is a result of vertical flow affluent, assigned on the model by the boundary condition of the third type); G_{III} is the hypothetical parameter of conductivity, received by solving of the inverse task. The data of absolute values of the surface of gas-water contact seams to be more reliable whereas the second parameter is a calculated value. So, only the order of such value can be reflected in the model but not its exact value.

In the second step the head decreasing process was reproduced. It occurred as a result of the filling of empty underground area by confined groundwater flow during gradual gas-water contact moving. Negative capacity flows for each calculated time-step, being received as a result of the modeling on the first step, were determined as a boundary condition of the second type. The adequacy of the model to the reproducing process was controlled according to regime data by observations wells situated below initial gas-water contact. This modeling was carried out by the use of author's special software "Aquasoft".

Keywords: groundwater flow, gas-water contact

Tank Experiments, Numerical Investigations and Stochastic Approaches of Density-Dependent Flow and Transport in Heterogeneous Media

[1]Manfred KOCH, [1]Robert BRAATZ

[1]Department of Geohydraulics and Engineering Hydrology, University of Kassel, Germany,
e-mail: kochm@uni-kassel.de, robert.braatz@uni-kassel.de

ABSTRACT

Tank experiments and numerical investigations are keys for the understanding of density-dependent flow and transport in heterogeneous media. At the hydraulic laboratory of the University of Kassel density-dependent flow experiments in a Plexiglas tank with dimensions of 9.8_X by 0.1_Y by 1.225_Z m have been performed over recent years, with the objective to analyze macrodispersive effects across a fresh-/saltwater interface within a heterogeneously packed sand structure of given stochastic properties.

Experiments of three representative realizations of stochastic heterogeneity with predefined variances σ^2 ranging from 0.25 - 1.5 and correlation lengths λ_x , λ_z of 0.2 - 0.4 m and 0.05 - 0.2, respectively, of the $Y=ln\ k$ logarithmic permeability field have been carried out so far. These experiments investigate the hydrodynamically stable case of a layer of saltwater of different concentrations underneath a layer of de-ionized water. The anisotropic sand structures are packed in 2401 blocks (each 0.2_X by 0.025_Z m) with eight different pre-sieved classes of chemically pure industrial quartz-sands per stochastic realization. Depending on the latter, the hydraulic conductivities of the sand range from K = 10^{-2} to 10^{-5} m/s (i.e. a permeability of k = 10^{-9} to 10^{-12} m^2).

Numerous experiments with saltwater (chemically pure NaCl-solutions) concentrations ranging from C_0 = 250 (fresh water) to 100000 ppm (brine) and flow velocities ranging from v = 1 to 8 m/d are carried out in each sand pack. About 150 sampling ports vertically distributed along nine columns at the side walls of the tank allow an almost complete in-situ probing of the electric conductivity (respective solute concentration) in the major x-z flow plane. Depending on the flow velocities, steady-state conditions for the transport are reached after one to three weeks. By then, the interface zone has attuned to steady-state conditions over most of the tank.

All experimental results are compared with numerical simulations using the SUTRA density-dependent flow and transport model. As for the boundary conditions (BC), a pressure difference p_{in} - p_{out} between the in- and outflow boundaries of the tank and of $C=C_0$ at the inflow boundary for the concentration are specified to mimic the corresponding tank experimental conditions. The choice of the proper outflow BC for C poses somewhat a problem, as this value normally varies through the course of the experiment. Instead of using a natural (free) BC at the outlet, a first type BC $C=C_{MIX}$ is taken, where C_{MIX} is half of the input concentration C_0 at the saltwater inlet. With this choice of the BC the numerical model appears to much better able to simulate the tank experiments.

The results of both the deterministic numerical models and of the experiments are complemented by Monte Carlo (MC) simulations, using stochastic realizations with predefined variance σ^2 and correlation lengths λ_x , λ_z of the $Y=ln\ k$ permeability field that are representative of the stochastic packing of the tank. From moment-analyses of the width of the simulated saltwater plume, variances of the transversal dispersion are calculated as a function of the horizontal distance from the tank inlet. Using simple square root regression analysis of these variances, representative expectation values for the apparent vertical (transversal) (macro)-dispersivity A_T are computed. For most of the MC-random field families, the numerical models were able to provide an asymptotically stable value for A_T already after approx. 100 realizations for density-independent, and approx. 30 realizations for density-dependent simulations. In addition, the sensitivities of the computed A_T to the various parameters describing flow and transport (i.e. v and C_0) and the porous media (i.e. σ^2 , λ_x and λ_z) are investigated and used in a multiple linear regression to establish a functional relationship between these and A_T.

For calibration and validation purposes, the experiments and numerical models (SUTRA) have recently been accompanied by numerical simulations using the FEFLOW flow and transport model which appears to allow for a better representation of the intricate concentration outflow boundary condition mentioned above. Together with additional tank experiments of different stochastic porous-medium representation, the present analysis will complement the earlier work of Starke (2005) with regard to this scientific topic, namely, an exhaustive characterisation of density-dependent vertical macrodispersion in stochastically heterogeneous porous media.

Keywords: Tank experiments, density-dependent transport, macrodispersion, stochastic heterogeneous media

Three-dimensional Flow Simulation in a Volcanic Sedimentary Aquifer: La Aldea Aquifer (Gran Canaria, Canary Islands)

[1]T. CRUZ, [1]M. C. CABRERA and [2]J. HEREDIA

[1] tcruz@becarios.ulpgc.es & mcabrera@dfis.ulpgc.es Department of Physics, University of Las Palmas de Gran Canaria 35017 Las Palmas de Gran Canaria (Spain)
[2] j.heredia@igme.es Geological Survey of Spain. Ríos Rosas, 23. 28003 Madrid (Spain)

ABSTRACT

Introduction

La Aldea Valley is located on the Western side of Gran Canaria (Canary Islands, Spain) (Fig. 1). In the lower part of the La Aldea-Tejeda ravine, the valley presents a flat bottom surrounded by high mountains, where intensive agriculture of tomatoes and cucumbers take place. Irrigation water supply comes mainly from three dams situated upstream, although there are more than 370 large-diameter wells which provide the necessary water for the crops in dry seasons.

The hydrogeology of the area has been studied since 1994, with the development of several Projects in order to improve the hydrogeology knowledge of the La Aldea aquifer, and a PhD Thesis has been developed characterizing the aquifer functioning. These works have been used to make the mathematical model of the aquifer, based on a 3D conceptual model of hydrogeology flow which was later on numerically implemented through the use of MODFLOW code. The main objective is to get a better groundwater knowledge of the area and to develop a management tool for the future.

Hydrogeologic Framework

The insular aquifer has been conceptualized as a stratified, heterogeneous unique body of groundwater. The recharge takes place mainly at the top of the island, with groundwater circulating towards the coast. The discharge takes place to the sea and to groundwater works (wells and groundwater galleries). Within this framework, the study area represents a discharge area to the sea.

Four hydrogeologic domains have been defined: Alluvial conglomerates, Screes, Las Tabladas (a residual relief with volcanic and sedimentary materials) and Miocene Basalts (Fig. 1). The aquifer is unconfined and the limits of the study area are defined by the high mountain chains (North and South), the waterproof material of the intra-caldera area (East) and the coast line (West). The permeability of the alluvial conglomerates is 26-85 m/day and specific yield values are 0.03-0.1, of the Basalts is 0.03 m/day and specific yield values are 0.005-0.01.

Groundwater Modeling and Results

The modeling area comprises 45 km^2 and was tridimensionally discretized as cells of 50 x 50 m and vertically in 3 layers. The superficial layer comprises the sedimentary material (Alluvial and screes) and some meters of the altered basalts located below, while the other two layers are Basalts, divided in two layers due to the existence of different permeabilities. The model has been running in stationary state for the year 1992 and in transitory state for the period of 1992-1999.

The boundary conditions used correspond to the real physical boundaries of the aquifer. The limits of the North, South and East areas have been defined as null flow boundary conditions (waterproof edge). In the West area, the coast line has been defined as constant level (elevation: 0 m). The East limit is marked by a Volcanic Caldera that has been considered impermeable, except in the ravine bed, where a section has been defined as a constant flow, representing the contribution from the high part of the island towards the study area through the alluvial conglomerates. The top surface boundary condition corresponds to the rain recharge, irrigation returns and supply network leaks. The bottom surface is defined as a null flow condition in the limit between the alterated Basalts and the basalts without alteration. A drain condition has been imposed in the ravine and the extracting pumping wells have been considered with the available data.

The simulation results indicate that:

a) The calibrated parameters (permeability and recharge) present a high sensibility to the model.
b) The transitivities obtained in previous works present the same order of magnitude than the obtained in the model.
c) The recharge obtained for the groundwater balance agrees with the final recharge values obtained in the model.

d) Fig. 1 shows the levels for the stationary state simulation for the year 1992. Groundwater flows toward the alluvial outside of it and from East to West within it, according to the conceptual watertable elevation map.
e) The calculated levels are in good agreement with the observed levels measurements (Fig. 2).

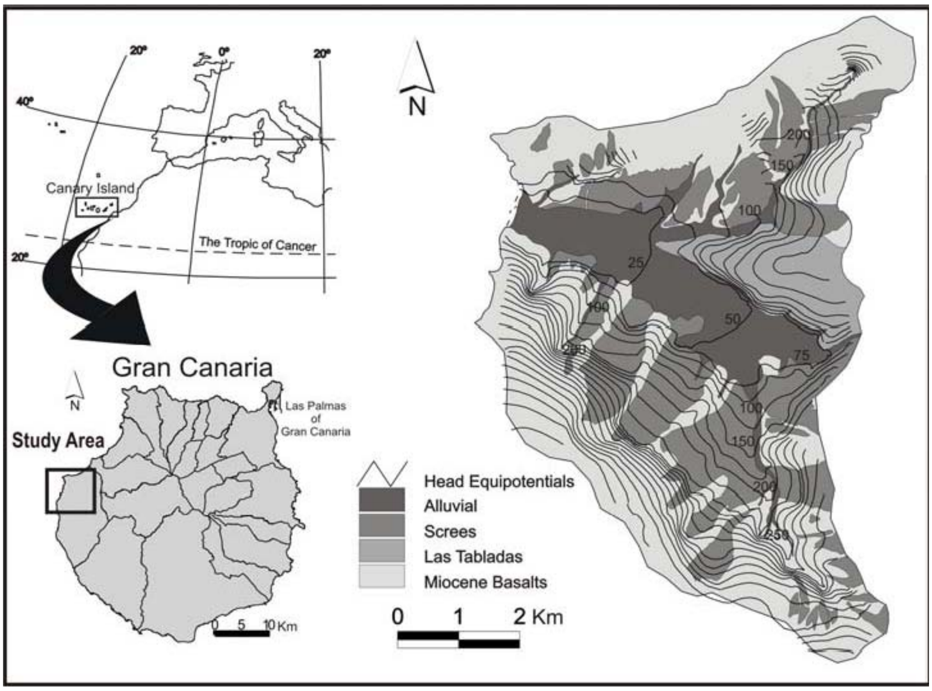


Fig. 1. Location of the study area and results of the simulation in stationary state for 1992.

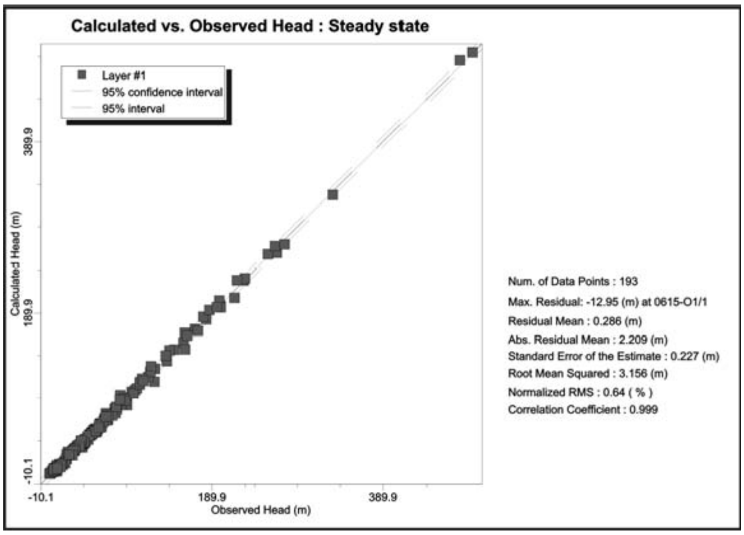


Fig. 2. Results from the model calibration in stationary state for 1992.

Keywords: Volcanic aquifer, conceptual model, numerical simulation, Gran Canaria.

Two-dimensional modeling of groundwater flow and reactive transport of solutes in the Salar de Atacama

[1] Carlos VÁSQUEZ, [2] José Francisco MUÑOZ

[1] José Joaquín Pérez 7223 – Cerro Navia, Santiago de Chile, e-mail: cvasquez@ing.puc.cl
[2] Vicuña Mackenna 4860 - Macul, Santiago of Chile, e-mail: jfmunoz@ing.puc.cl

ABSTRACT

For the Salar de Atacama (2nd Administrative Region, Chile), Fig. 1, several existing studies provide hydrogeologic and chemical descriptions, but few refer to numerical modeling of groundwater flow, and these few do not consider geochemical processes explicitly. The work reported herein uses SHEMAT code (Clauser, 2003) to advance the development of a numerical model to incorporate aspects of geochemistry and reactive transport of ions in the groundwater flow model.

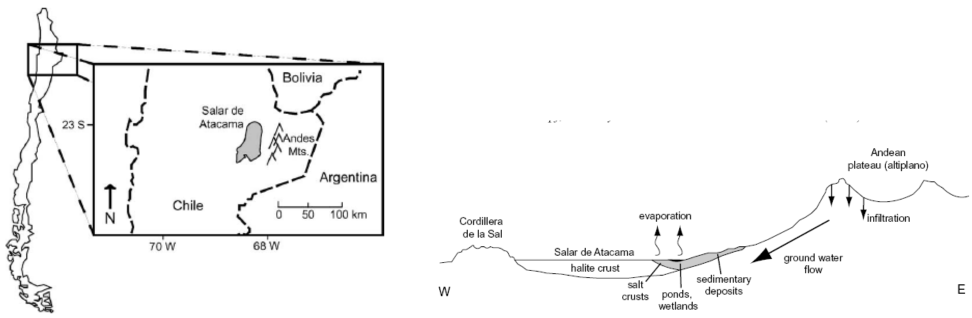


Fig. 1. Location of the study area.

The two-dimensional vertical numerical groundwater flow model proposed (Fig. 2) uses the solutions to equations for flow, ion reactive transport and geochemical processes associated with the formation of minerals in a saturated porous medium with highly concentrated fluid and variations in density, viscosity, porosity and permeability.

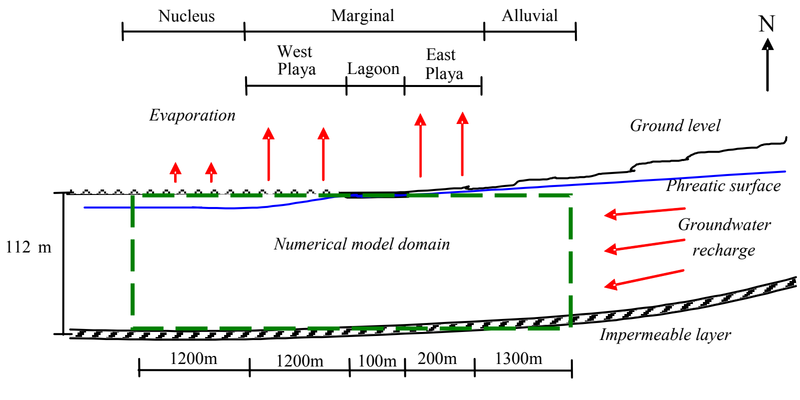


Fig. 2. Idealized profile and schematic of numeric model.

The study area is an idealized profile of the eastern boundary of the Salar de Atacama and includes three zones of relevance for the system: alluvial, marginal and nucleus. Using a rectangular domain of 1,440 cells, boundary flow conditions were determined for the flow associated with evaporation, recharge, lagoons and impermeable strata and, additionally, for the flow of solutes associated with the contribution from recharge or evaporation. The initial conditions of evaporation, recharge, fluid composition and soil type (homogenous) were assigned according to information from the available literature.

The model uses a linear relation of density with chloride concentration. In addition, it assumes the existence of three characteristic minerals only, representative of sodium chloride (halite), calcium sulfate (gypsum) and calcium carbonate (calcite). Regarding chemistry, it uses a scheme of Pitzer virial coefficients in acid-base, complexation and precipitation-dissolution chemical reactions, all in equilibrium. Finally, it assumes that permeability varies with porosity according to the Carman-Kozeny relation, which changes with the precipitation and dissolution of minerals.

Several important results were obtained from running long-term simulations (over 10,000 years). First, a saline interphase was verified to exist in the marginal zone as a result of density differences in the fluid (Fig. 3). Second, the chemical zonation of salts in the marginal zone and the nucleus was reproduced, thus defining in turn sectors of particular chemical characteristics (Fig. 4). Finally, the formation of minerals, such as halite, gypsum and calcite, as a result of flow and evaporation conditions has an influence on flow conditions, principally by forming zones of low permeability (Fig. 5).

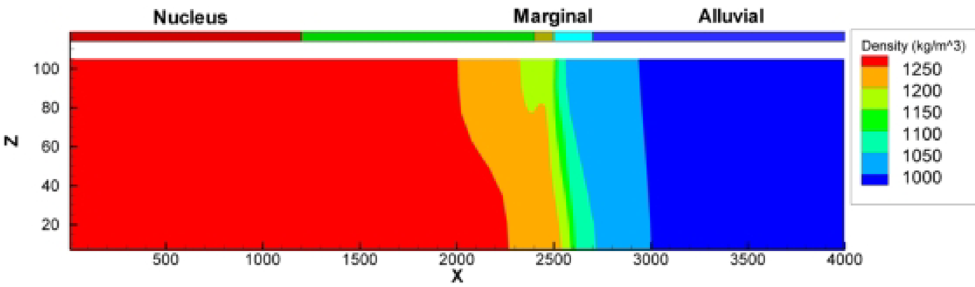


Fig. 3. Spatial distribution of density (kg/m^3)

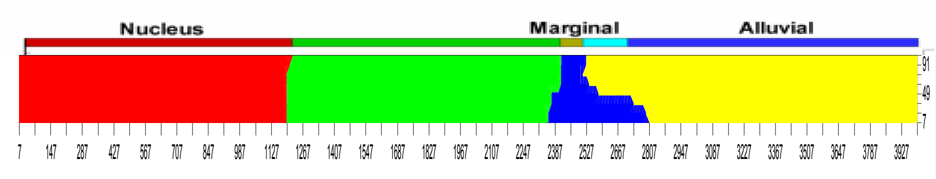


Fig. 4. Chemistry zonation (diagram of predominance of minerals). Red: halite; green: gypsum; blue: calcite; yellow: none.

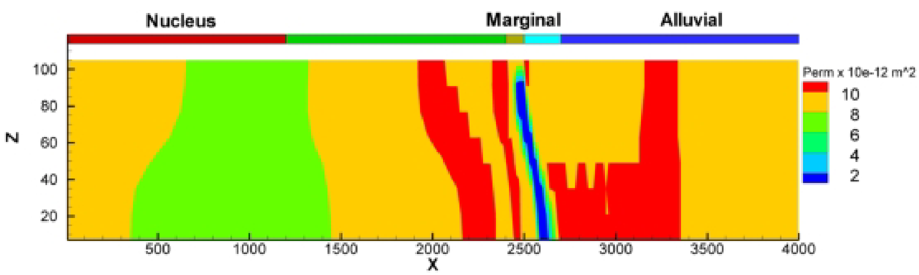


Fig. 5: Spatial distribution of permeability (m^2).

This work shows the feasibility of building groundwater flow models for systems such as the Salar de Atacama using computer codes such as SHEMAT to incorporate geochemical and reactive solute transport processes. In addition, the results of this work, which provide additional information on the fluid, soil and implications on flow, reveal the importance of these processes in the system studied.

Keywords: Geochemical model, brine, salar, SHEMAT.

Use of groundwater models to evaluate the effectiveness of phytoremediation systems: an example from southeastern Brazil

[1]Eduardo Reckziegel de SOUSA, [2]Brent USHER, [3]Cyro BERNARDES JR.

[1]Golder Associates Africa, South Africa, e-mail: edesousa@golder.co.za
[2]University of Bloemfontein, South Africa, e-mail: UsherB.SCI@mail.uovs.ac.za
[3]Ambconsult, Brazil, e-mail: cbernardes@ambconsult.com.br

ABSTRACT

Phytoremediation is defined by the set of technologies used to clean up soil, surface water or groundwater through the use of plants. This technology has been developed in the last 20 years and is a great interest to the environmental agencies, consultants and researchers. The interest in phytoremediation relies essentially in the fact that it has low costs compared with other remediation technologies, it is a relatively well accepted technique by regulatory agencies and most of time avoid waste disposal and the use of other aggressive remediation techniques.

Although big efforts has been made in order to research the potential of phytoremediation, there are still some difficulties regarding the evaluation of effectiveness, specially when phytoremediation is used as a hydraulic barrier and, thus, changes in the hydrogeologic regime play a major role.

The main objective of this work was to evaluate groundwater modelling as tool in the evaluation of phytoremediation effectiveness. A groundwater model was built for a phytoremediation site from southeastern Brazil, where phytoremediation effectiveness was evaluated, essentially in terms of imposed drawdown and evapotranspiration rates of the phytoremediation area.

The phytoremediation system was implemented in August 2000 in an industrial site contaminated essentially by benzene and chlorinated compounds (mostly chloroform) with the objective to promote a last barrier for the dissolved phase before groundwater discharge reaches an artificial lake located approximately 200 meters down gradient from the contamination source. Chemical oxidation using peroxide was conducted in the source areas and therefore only remnant contamination was expected to reach the phytoremediation area.

The studied site is located near the 22o latitude. A-pan evapotranspiration rates ranges from 25 mm in the colder months up to 150 mm/month during the summer. Average Annual rainfall rates range between 1100 and 1200 mm/year. Plants from mesophytic tropical wet forest and from Cerrado climate were selected for the phytoremediation system, with a total of 179 trees planted in an area of approximately 2175 m2. The contaminated aquifer is composed essentially by the weathering horizon of the volcanic and sedimentary outcropping rocks of Serra Geral formation and Tubarão group. This aquifer has an unconfined behaviour and an average thickness of 20 metres, overlying a basalt sill which occurs locally in the site and act as a barrier to deeper vertical migration.

A groundwater model using the USGS MODFLOW-2000, version 1.15.01 was used in order to provide estimates of drawdown, changes imposed in the groundwater flow direction and evapotranspiration rates in the saturated zone. The simulated period started in August 2000, prior to the phytoremediation implementation, up to July 2002, two years after the implementation. A 3 step calibration approach was used in order to conduct steady-state calibration with average water level measurements, transient calibration without evapotranspiration rates in areas not affected by the phytoremediation, and transient calibration of the evapotranspiration rates using the monitoring boreholes located within the phytoremediation area. Calibrated parameters showed hydraulic conductivities ranging between 0.1 and 0.5 meters/day, specific yields of 0.3 and a recharge rate of approximately 6% of the monthly rainfall. The conceptual model indicated a possible delay between rainfall and effective recharge, which was confirmed by the model calibration and showed a delay time of approximately 90 days.

The calculated evapotranspiration rates ranged from 0 to 190 mm/month, which equates to abstraction rates between 0 to 190 m3/month. Higher evapotranspiration rates are observed only from July 2001, one year after the phytoremediation was implemented. This can be explained by the fact that the root system of the phytoremediation trees was not deep enough to abstract water from the saturated zone in the first year of implementation. A graph illustrating the recharge and evapotranspiration rates is presented in Fig 1. Calculated drawdown values ranged from 0 to 40 centimeters, with maximum values occurring between the intermediate and up gradient monitoring boreholes (Fig 2.). Drawdown higher than 15 centimetres only occurred from September 2001 and it is also related to the fact that phytoremediation root system probably was not reaching the saturated zone.

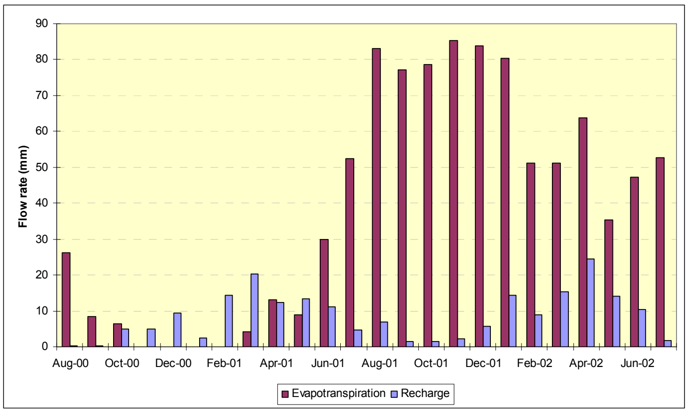


Fig. 1. Simulated evapotranspiration and recharge rates.

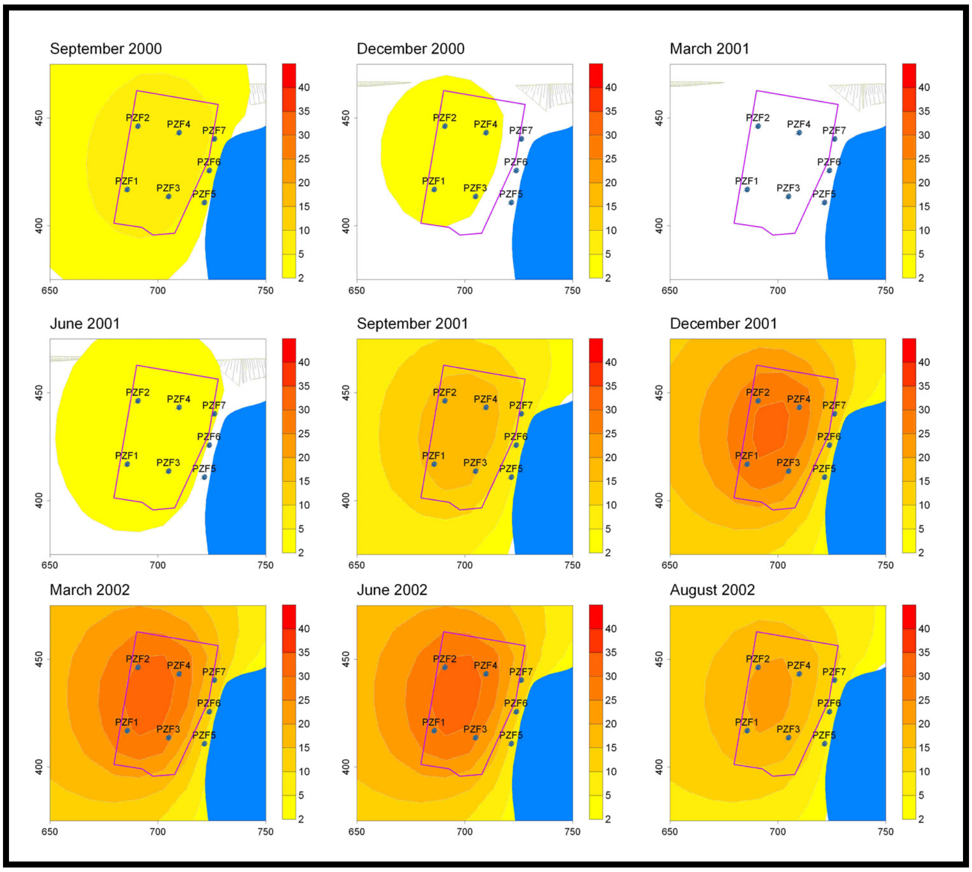


Fig. 2 Simulated drawdown contours (centimeters)

The groundwater modelling results showed, therefore, that the phytoremediation system was not effective as a hydraulic barrier, as the evapotranspiration rates were not enough to provide significant drawdown and, thus, changes in the groundwater flow direction. However the contamination scenario could have been worse if the phytoremediation was not implemented, since favourable biodegradation parameters, such as dissolved oxygen and redox, were kept to favourable levels (high dissolved concentrations and oxidant redox) throughout the phytoremediation levels, probably related to the biochemical effects of the phytoremediation root system.

Keywords: Hydrogeology, groundwater modelling, phytoremediation, recharge estimation, evapotranspiration.

TOPIC 14

Isotopic methods to assess groundwater dependent ecosystems

A contribution to the characterization of a deeply confined carbonatic aquifer in Úbeda (Southern Spain) from a reinterpretation of existing geological and geophysical data and new data on environmental isotopes

[1]Javier RODRÍGUEZ, [2]Elena PÉREZ, [1]Javier HEREDIA

[1] Geological Survey of Spain, Spain, e-mail: jra@igme.es
[2] Centre for Experiments of the Ministry of Public-Works, Spain, e-mail: elena.perez@cedex.es

ABSTRACT

Groundwater abstraction has increased in the last decade in the aquifer “Carbonatado de la Loma de Úbeda” (050.010), where one of the largest areas of irrigated olive trees in Andalucía (Southern Spain) extends. This aquifer is composed mainly of some 90 m thick Jurassic dolomites and limestones. It extends over some 875 km^2; about 250 km^2 of this groundwater body is unconfined and outcrops in the North, while Miocene marls reaching a thickness of some 700 m confine the other 625 km^2 at the South (Fig. 1). The basement of the aquifer is constituted by Paleozoic siltstones and quarcites, covered by Triassic silts, sandstones, and layers of gypsum at the top. Triassic sediments constitute an aquifer in some areas, where the exploitation wells reach to them.

Two rivers cross the area from NE to SW. The Guadalimar River that crosses the unconfined aquifer parallel to the contact with the overlying marls; and the Guadalquivir River that coincides with the southernmost limit of this groundwater body in its confined part. Uncertainties about the geometry and the conceptual model for groundwater flow still remain in this aquifer due to fact that it is confined, and therefore hidden from direct observation; and to the lack of precise information from boreholes, drilled for exploitation purposes and not for research. There are also problems in the understanding of the groundwater-surface water interaction because information about groundwater levels pre-pumping is limited.

Previous studies, aimed at a general characterization of this system, yielded the following results: 1) recharge derives mainly from infiltration of precipitation over the unconfined aquifer, 2) flow takes place mainly from North to South, 3) the chemical evolution and the age of the groundwater in the confined part suggest that there is a cul-de-sac in its Southern limit (no point of natural discharge was identified), 4) the Guadalimar River could recharge the aquifer in the future, if water levels are depleted enough due to extensive exploitation.

The present study has been concentrated in the confined and more extensive part of the aquifer. A review of the existing geological and geophysical information about this area have resulted in a better definition of the geometry of the aquifer and the confining formations, showing a geologic structure more complex than previously assumed. The contact between Jurassic and Triassic sediments defines a sinclinal with an axis in NNW-SSE direction, which causes a depression of some 50-200 m in the central part of the aquifer. More importantly, a series of ENE-WSW faults have been identified in geophysical studies. These faults have throws from 30 to more than 200 m, always leaving the downthrown block to the South. This complex structure conditions the flow of groundwater, facilitating some more rapid circulation in the upthrown blocks and impeding the circulation in the downthrown blocks. Four sectors can be distiguised in this confined aquifer:

- A central sector in the strip closest to the Guadalimar River, where the Jurassic is located at a lower depth, and the thickness of the overlying Miocene sediments is smaller;
- A sector located to the South of the preceding one, limited by ENE-WSW faults, in which the depth to Jurassic and the thickness of the overlying Miocene increase abruptly from some 100 to 700 m. A narrow depression is shown by the geophysical studies in the vertical of Torreperogil where the thickness of the Miocene reaches a maximum;
- An Eastern sector, E and S from Villacarrillo, probably affected by the nearby structure of nappes of the Cazorla mountainous region; and
- A Western sector, between Sabiote, Úbeda and Torreperogil, in which an overlying aquifer composed of calcareous sandstones is located at the top of the Miocene series.

The identification of these sectors in this aquifer is important for better understanding of the groundwater-surface water interaction and to define an adequate groundwater resources management plan. Results of hydrogeochemical and isotopic characteristics of groundwater (see Fig. 1) are consistent with this division:

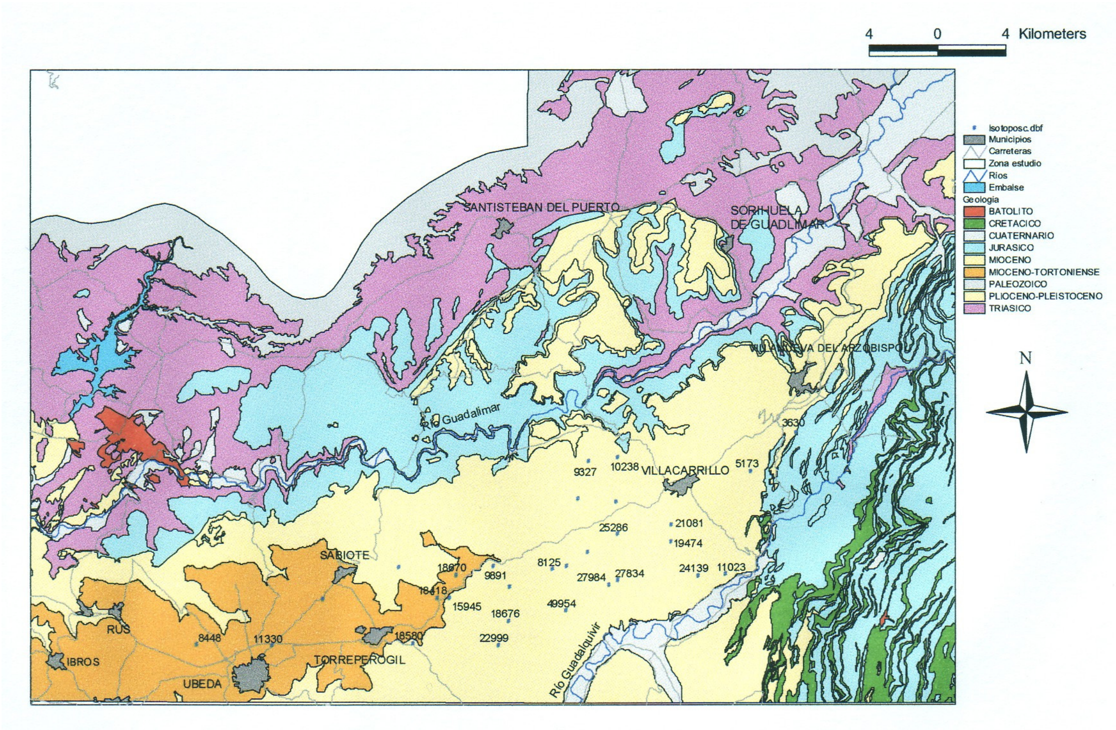


Fig. 1. Geology of the area and spatial distribution of radiometric ^{14}C ages in the confined aquifer

a) In the unconfined sector of the aquifer, calcium-bicarbonate waters of low salinity and pHs between 7.4 and 8 are found. Stable isotopes contents are more or less constant, with $\delta^{18}O$ values between -5,9‰ and -6,6‰, and δD between -40‰ and -45‰. Tritum concentrations show that these groundwaters are modern.
b) In the first strip of the confined sector (South of the Guadalimar River), concentrations of Cl^- and Na^+ increase as the confining unit becomes thicker. $\delta^{18}O$ values are slightly lower than in the unconfined aquifer, from -5,2‰ to -5,9‰, and δD from -38‰ to -42‰. Groundwater flow seems to go from the Jurassic ocutcrops located at the North of Villacarrillo (in the East) and Úbeda (in the West) to the South recharging the confined aquifer.
c) In the central and inner part of the confined aquifer, an increment in the temperature and in the concentrations of Cl^- and Na^+ is observed, particulary in the area where the major depths of the wells are found, coinciding with the mentioned depression found in the bottom of the aquifer bellow Torreperogil. Close to this sodium chloride waters, inmedately at the East, the oldest waters are found. These data suggest that the Guadalquivir River may have functioned as a discharge area of the system in the past. These ages are being further corrected in order to take into account possible aditional dilution of ^{14}C due to sulphate reduction.
d) The Eastern sector, at the South of Villacarrillo, shows the highest concentrations for sulphate. Values for $\delta^{18}O$ fall between -6,0‰ and -6,5‰, and δD between -41‰ and -45‰. The radiometric ages increase from East to West, suggesting some flow in this direction, recharging in the Eastern boundary.
e) The Western sector shows Cl^- concentrations increase rapidly from 90 to 200-300 mg/l towards the East. Stable isotopes contents indicate enriched waters, with $\delta^{18}O$ values from -5,2‰ to -5,9‰, and δD frrom -34‰ to -40‰, probably due to partial recharge from the surficial Miocen aquifer.

The review (reinterpretation) of the hydrogeological and geophysical information, and the interpretation of additional information about the hydrogeochemical and environmental isotopic characteristics (^{18}O, ^{2}H, ^{3}H, ^{13}C and ^{14}C) of groundwater in the confined aquifer of Úbeda, is aiding the formulation of a conceptual model of groundwater flow that may in turn aid in the management of the ground-water resources in this area.

Keywords: confined aquifer, geological model, environmental isotopes, dating.

A multi-technique approach to trace the impact of snowmelt as a source of groundwater resources at Serra da Estrela high mountain area (Central Portugal)

[1] Jorge Espinha MARQUES, [2] José M MARQUES, [3] Paula M CARREIRA, [4,9] Hélder I CHAMINÉ, [5] Paulo E FONSECA, [6] Fernando A MONTEIRO SANTOS, [6,7] Eugénio ALMEIDA, [6,7] Rui GONÇALVES, [4] José MARTINS CARVALHO, [8] Pedro G ALMEIDA, [9] José TEIXEIRA

[1] Depart. de Geologia da Univ. do Porto, R. do Campo Alegre, 4169 - 007 Porto, jespinha@fc.up.pt
[2] Inst. Sup. Técnico, Tech. Univ. of Lisbon, Av. Rovisco Pais, 1049-001 Lisboa, jmmarques@mail.ist.utl.pt
[3] Inst. Tecnológico e Nuclear, Estrada Nacional nº 10, 2685 Sacavém, carreira@itn.pt
[4] Inst. Sup. de Engª do Porto, R. do Dr. António Bernardino de Almeida, 431, 4200-072 Porto, hic@isep.ipp.pt
[5] Depart. de Geologia da Univ. de Lisboa, Ed.C6, 2º Piso, Campo Grande, 1749-016 Lisboa, gpetfons@fc.ul.pt
[6] Centro de Geofísica da Univ. de Lisboa, Ed. C8, 6º Piso, 1749-016 Lisboa, fasantos@fc.ul.pt
[7] Inst. Politécnico de Tomar, Quinta do Contador, Estrada da Serra, 2300 Tomar, epalmeida@ipt.pt
[8] Univ. da Beira Interior, Rua Marquês d'Ávila e Bolama, 6201-001 Covilhã, galmeida@ubi.pt
[9] Minerais Industriais e Argilas, Universidade de Aveiro, 3810-193 Aveiro, jose.aa.teixeira@sapo.pt

ABSTRACT

Groundwaters should be considered one of the most important georesource at the Serra da Estrela Natural Park (Fig.1), not only because it is a fundamental necessity for life, but also because Caldas de Manteigas Spa is one of the most important foci for local and regional development.

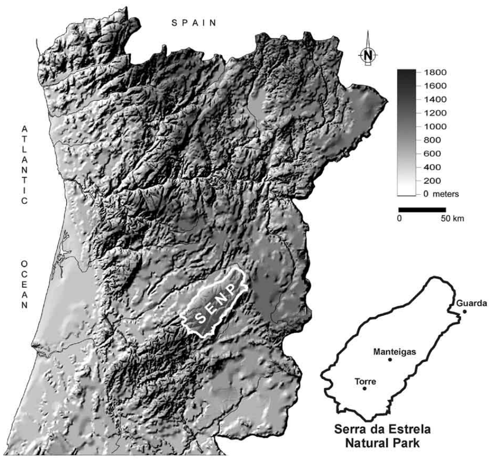


Fig. 1. Morphological features showing the location of Serra da Estrela Natural Park (Central Portugal).

In this paper, special emphasis will be placed on high mountains, in an attempt to understand the i) recharge and discharge processes and ii) role of snowmelt as a source of groundwater resources at Serra da Estrela region. The study area corresponds to the Zêzere river drainage basin upstream of Manteigas village (Fig. 1), which corresponds an area of 28.04 km^2.

Water samples for geochemical and isotopic studies were collected from river waters, shallow groundwaters (spring waters - "*normal*" waters) and from Caldas de Manteigas thermal waters. Fieldwork was done in order to obtain a physical, chemical, geochemical and mineralogical characterisation of the soil zone. The analysis of the satellite image obtained by the SPOT and LANDSAT satellites and aerial photo maps has also been performed. Preliminary geophysical studies (a 600 m dipole-dipole profile with a dipole distance of 10 m) were carried out in order to investigate one of the main potential recharge areas. Hydrological modelling (computer code VISUAL BALAN V2.0) was used to evaluate water resources in the basin.

The assessment of snowmelt contribution to stream and groundwater flow by isotopic fractionation during snow formation, accumulation, ablation and phase change during melt is complex. For this reason, comprehensive sampling of meltwater, instead of snow, is generally recommended for hydrological studies.

The seasonal variation of the stable isotopic composition of precipitation is reflected in the comparatively low δ-values in the snowfall, which will also be reflected in the $\delta^{18}O$ and $\delta^{2}H$ contents of meltwater. This shift provides a very useful tracer signal for hydrogeological studies in mountainous areas.

Fig. 2. Serra da Estrela: (a) important granitic peaks and (b) the Nave de Santo António area, covered with snow during the winter season.

At Serra da Estrela, winter precipitation is usually accumulated in the upper zone of the catchment as snow from November to March. At the end of March snowmelt often becomes more intense. However, the temporal evolution of the $\delta^{18}O$ and ^{2}H content of the shallow cold dilute groundwaters collected at the end of the winter season (April) does not show a significant depletion in heavy isotopes when compared with the data from the end of the summer season (September). This trend seems to suggest the mixing of different water bodies, with the tendency of homogenization of the isotopic composition of the groundwaters.
The multitechnique approach was used to outline a preliminary hydrogeologic conceptual model for the region (Fig. 3). The hydrogeologic systems existing in the river Zêzere basin comprises three main types of aquifers: i) shallow unconfined aquifers, hydraulically connected to the vadose zone; ii) shallow semi-confined aquifers; iii) a thermal aquifer at depth. Waters from types i) and ii) aquifers have TDS ≈ 40 mg/L, pH ≈ 6 and temperature ≈ 10ºC whereas thermal waters have TDS ≈ 160 mg/L, pH ≈ 9.5 and temperature ≈ 42ºC.

The recharge of the shallow aquifers seems to take place mostly in the plateaus (an additional part of the recharge may occur in the slopes of the Zêzere valley and its tributaries). The discharge areas are located in the Zêzere and Candeeira valley-bottoms and in the Nave de Santo António (Fig. 2b) col. The recharge of the thermal aquifer seems to take place on the more permeable zones of the granitic massif, associated to the main NNE-SSW tectonic structures. These recharge areas, consisting of a sedimentary layer of alluvium and quaternary glacial deposits overlying tectonised granite, receive water influx from both vertical infiltration of precipitation (rain and snowmelt) and lateral flow from the local shallow aquifers. Most of the snowmelt could be mainly transformed in surface runoff rather than in direct infiltration into the shallow aquifers. Hydrogeological modelling information seems to support this hypothesis.

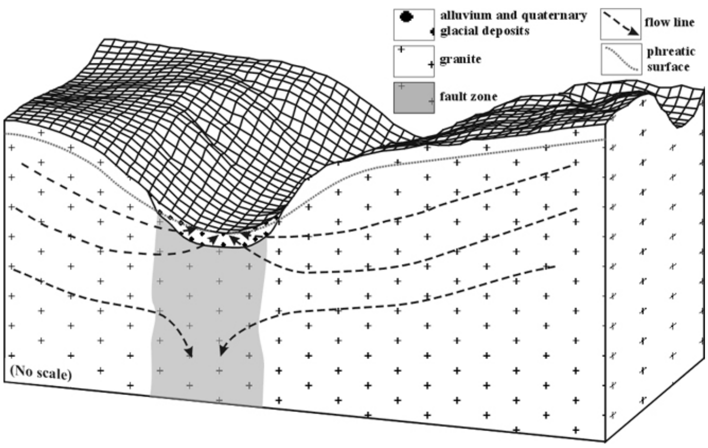


Fig. 3. Scheme of the thermal aquifer recharge: a conceptual hydrogeological model.

Keywords: Geochemistry, isotopes, geophysics, tectonics, high mountain areas hydrogeology

Chemical and isotopic composition of groundwaters in fractured aquifer in two neighbouring catchments

[1]Jerzy JANKOWSKI

[1]Sydney Catchment Authority, Level 2, 311 High Street, Penrith NSW 2750, AUSTRALIA,
e-mail: jerzy.jankowski@sca.nsw.gov.au

ABSTRACT

Water-rock interaction with geological material and fracture-filling minerals developed chemically and isotopically distinct groundwaters in two neighbouring catchments in the Southern Tablelands of New South Wales, Australia. The geology of the area consists of fractured, quartz-rich Ordovician sediments of marine origin. The Dicks Creek catchment belongs geologically to lower Ordovician Pittman Formation and the Williams Creek catchment represents the Acton Shale Member of upper Ordovician unit. The Acton Shale Member is down-faulted against the Pittman Formation in Dicks Creek by movement along the Sawpit Creek Fault, which is a northward extension of the regional Sullivan Line Fault Zone. This fault zone forms the high ridge between the two catchments and produces the lithological and mineralogical variation. Lithologically the Dicks Creek catchment consists of quartz-rich sandstone, siltstone and shale with associated pyrite, and minor albite and chlorite, while the Williams Creek catchment contains black siliceous shales with pyrite and chlorite present as the main accessory minerals. These contrasts in geology, lithology and mineralogy between both catchments are clearly indicated in chemical and isotopic composition of groundwaters, hydrogeochemical processes and the chemical evolution of groundwaters.

Borehole records demonstrate that the major groundwater bearing zones occur within fractures in the fresh rock zone of the Ordovician sediments. This indicates that an aquifer system occurs from the base of the weathered layer down into the deeper fractured fresh rock. Groundwater recharge occurs from direct infiltration where the fractured bedrock crops out on the hills. Groundwater flow then occurs through the intersecting network of deep fractures and veins in the bedrock. Interconnection of fractures has been demonstrated by pumping tests. The groundwater system in the fractured aquifer is therefore considered to form a coherent aquifer. Groundwater discharge in the valley floors is impeded by the presence of the Pleistocene silts and clays. The Sullivan Line Fault, located between the Dicks Creek and Williams Creek catchments, subdivides the regional flow system and creates local flow systems in the Dicks Creek and Williams Creek catchments. The fault acts as a hydraulic boundary to flow between the catchments and indicates that significant recharge occurs along the ridge between the two catchments. The fractured aquifer is semi-confined on the middle and lower slopes and confined on the valley floors by the presence of colluvium deposits.

Chemical and isotopic compositions as well as chemical processes and evolution of groundwaters in both catchments have been assessed on the basis of recharge waters, and recharge and discharge groundwaters. Recharge waters are fresh with low electrical conductivity (EC) content (44 – 98 μS/cm), slightly acidic (pH 5.3 – 6.9), oxidised with positive Eh values and relatively high concentrations of dissolved oxygen. Chemically these waters are dominated by sodium (5 –17 mg/L) and chloride (5 – 22 mg/L). Concentrations of other ions are low with HCO_3 concentration higher than SO_4 and Mg concentration higher than Ca. Chemical composition of these waters originates from rainwater chemistry, evaporation and interaction between surface run-off and surficial sediments.

Groundwater chemistry is strongly influenced by geology and mineralogy of the aquifer, and is dependent on the rate of chemical reactions during water-rock interaction. Infiltrating waters flow through fractures and veins and alter chemical composition of recharge groundwaters. Recharge groundwaters in bedrock outcrop areas are fresh with EC ranging from 490 – 770 μS/cm, slightly acidic and low in dissolved oxygen. Dominant ions in these waters are Mg-Na-SO_4-Cl. Both sodium and chloride are supplied by rainwater with an additional source being from the leaching of rock matrix. Weathering of Na-feldspar and chlorite are the main sources for Na and Mg. Dissolution of carbonate minerals bounded in calcareous sandstone add bicarbonate and calcium to the groundwater system. Oxidation of pyrite is a main source for SO_4 and elevated concentration of iron in reducing and oxygen-depleted groundwaters. Protons produced by the oxidation reactions are used for dissolution and weathering reactions. From recharge to discharge zones significant changes in groundwater chemical composition, pH, Eh and oxygen concentrations are observed. Due to slightly different mineralogy and geology between catchments, two different pathways of groundwater chemical evolution occur.

The chemical composition of Dicks Creek groundwaters results from a series of complex chemical reactions during water-rock interactions. These groundwaters often flow under artesian pressures. The presence

of organic material has significant influence on the rate of chemical reactions. Concentrations of major elements increase as groundwater flows into deeper part of the aquifer. Chloride originates from the aquifer matrix of marine sediments. Sodium is supplied from two sources; the primary source being the dissolution of soluble salts stored in pore spaces and the minor part being derived from the weathering of albite. Continuous supply of HCO_3 and Ca comes from calcium carbonate minerals as all groundwaters are undersaturated with respect to calcite. Magnesium is delivered from the weathering of chlorite and biotite. Oxidation of FeS_2 is rapidly removing available oxygen and because the reduction of SO_4 is incomplete in the fractured system, SO_4 is still present together with reduced sulphur. In the presence of organic matter discharge groundwater are dominated by the Mg-Na-HCO_3-SO_4 chemical type. Due to redox reactions oxygen is depleted, waters are strongly reduced, and interaction with organic matter shows pH buffering between the H_2CO_3/HCO_3 couple and concentration of HCO_3 exceeds 600 mg/L.

Groundwater in the Williams Creek catchment differs in both chemical composition and evolutionary pathway from the Dicks Creek catchment. These waters are more saline and acidic, and oxygen is still present in these groundwaters. Two dominant elements are SO_4 and Mg comprising up to 70% of the total ionic content. Higher concentration of Na and Cl in Williams Creek catchment is attributed to reactions with grain boundaries by acidic waters. The dominant type of waters is Mg-SO_4 where organic matter is absent. If organic material is available waters have a higher concentration of HCO_3.

The sequence of hydrogeochemical reactions from recharge to discharge zones in the two catchments can be best described as two pathways of separate hydrochemical processes. Groundwaters in the Williams Creek catchment flow in the fracture system containing traces of organic matter, and pyrite and chlorite. Oxidation of pyrite produces high concentrations of SO_4 and generates protons, which are responsible for reaction with chlorite developing Mg-SO_4 rich waters. The Dicks Creek groundwaters are rich in HCO_3 and have much lower concentration of Mg and SO_4. The chemical differences between both groundwaters can be explained either by less pyrite available for oxidation in the Dicks Creek or the same amount of pyrite present in both catchments but a much higher concentration of organic matter in the Dicks Creek causing development of strongly reducing environment and removal of SO_4.

Groundwaters from both catchments contain ferrous iron, with concentrations of up to 40 mg/L in the Dicks Creek catchment and up to 20 mg/L in the Williams Creek catchment. Higher concentration of Fe(II) in the Dicks Creek is attributed to the presence of organic matter and much more active redox reactions as well as lack of dissolved oxygen. Presence of organic matter and depletion of oxygen suppress oxidation of pyrite causing reduction of SO_4 to S^{2-}. Concentration of reduced sulphur in the Dicks Creek groundwaters is up to 6 mg/L.

Stable isotope data indicate that groundwaters are of meteoric origin and plot close to Local Meteoric Water Line. Oxygen-18 values for Dicks Creek groundwaters range from –6.2 to –7.9‰ and deuterium range from –44.8 to –49.8‰. Groundwaters from the Williams Creek waters catchment have similar stable isotope values, oxygen-18 and deuterium values ranging from of –6.2 to -7.4‰ and –41 to -47.4‰, respectively. Carbon-13 values are similar in both catchments and range from –15.8 to –20.6‰. More depleted values of ^{13}C signatures in the Williams Creek catchment indicate rapid groundwater flow and limited reactions with carbonate minerals. More enriched carbon-13 signatures in the Dicks Creek catchment show that the dissolution of carbonates using CO_2 delivered from reduction of organic matter are more pronounced processes affecting carbon isotope.

Keywords: Fractured aquifer, groundwater chemistry, hydrogeochemical processes, stable isotopes

Genesis of CO_2-rich mineral waters (N-Portugal) inferred by geochemistry and isotopes ratios in water and gas phases

[1] Paula M CARREIRA, [2] José M MARQUES, [3] M Rosário CARVALHO, [4] Giorgio CAPASSO, [4] Fausto GRASSA, [5] Manuel ANTUNES da SILVA, [2] Maria J MATIAS

[1] Instituto Tecnológico e Nuclear, Estrada Nacional nº 10, 2686 – 953 Sacavém, Portugal carreira@itn.pt
[2] Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal, jmmarques@mail.ist.utl.pt
[3] Faculdade Ciências de Lisboa, Ed. C6, 3ºP, Campo Grande, 1749-016 Lisboa, Portugal, mdrcarvalho@fc.ul.pt
[4] Ist. Naz. Geofísica Vulcanologia, Via U. La Malfa, 153, 90146 Palermo, Italy, g.capasso@pa.ingv.it
[5] Unicer Águas, S.A., Apartado 1044, 4466-955 S. Mamede de Infesta, Portugal; antunes.silva@unicer.pt

ABSTRACT

The study of the origin of carbon dioxide Earth degassing and associated CO_2-mineral waters is one of the key issues to increase knowledge of important geological processes. Na-HCO_3/CO_2-rich mineral waters (which could be fresh to saline, alkaline to acid, often showing moderate to high Cl content) have been described and studied in different countries. Several hydrogeological studies focused on the geochemistry and isotopic signatures of this type of waters, have been performed in the Northern part of the Portuguese mainland (Fig. 1). Recently, the R&D Project "*DISGAS – Dissolved gases in subsurface hydrology – CO_2-rich thermomineral waters (N-Portugal)*" was initiated. In the study region (Fig. 1), the hot (78ºC) and cold (17ºC) CO_2-rich spring and borehole mineral waters, occur along the so-called "*Chaves Depression*", which is a graben structure showing a NNE-SSW axis, parallel to the major regional fault trends within the Galicia- Trás-os-Montes area.

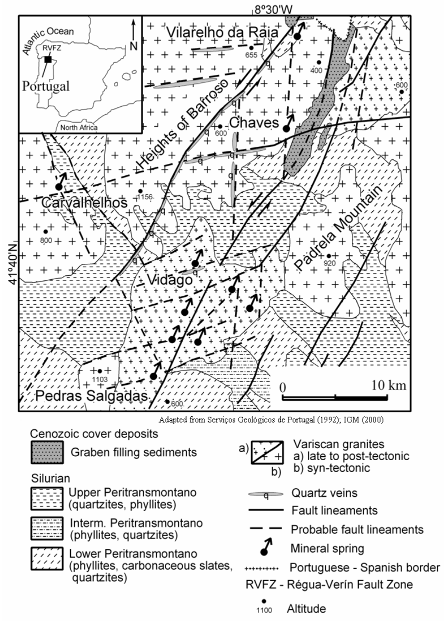


Fig. 1. Geological sketch map of the research region. Location of the main water and gas sampling sites.

Along this tectonic lineament occur, not only the Chaves hot (78ºC) waters (the hottest mineral waters on the Portuguese mainland), but also numerous emanations of cold (17ºC), saline, CO_2-rich mineral waters (*e.g.* Vilarelho da Raia, Vidago and Pedras Salgadas) which are used in the local Spas. This study presents the interpretation of new data on the chemical and isotopic characteristics of the above mentioned mineral waters, with a special emphasis on the associated gas phase. Water and gas samples were collected in order to characterize the geochemical and isotopic composition of the associated gas phase (CO_2, H_2, CH_4, N_2, CO, O_2, Ar, He, Ne, ^2H, ^3H, ^{13}C, ^{14}C, ^{18}O, $^3H/^3He$, $^3He/^4He$, $^{40}Ar/^{36}Ar$ and ^{15}N). The aim was to identify the genesis of the gas phase and the possible contribution of deep crustal and mantle volatile components ascribed to the local tectonics.

The region is located in the Ante-Mesozoic Hesperic Massif, consisting mainly of Hercynian granites and Paleozoic metasediments (Fig. 1). Inserted within the schistoid complex, bands of carbonaceous slates are found well-displayed in the Chaves area. The most recent formations are the Miocene-Pleistocene sedimentary series, showing their maximum development along the central axis of the Chaves graben (Fig. 1).

The studied Na-HCO_3/CO_2-rich mineral waters present pH values between 6 and 7. The total dissolved CO_2 can reach values of up to 6000 mg/L. The δ^2H and $\delta^{18}O$ signatures of these CO_2-rich mineral waters indicate meteoric waters which have not been subjected to surface evaporation. No evidence of water-rock interaction at high temperatures (oxygen-18 shift) has been observed in the Chaves thermomineral waters. The isotopic enrichment found in ^{18}O and ^2H in some of the mineral waters seems to be related to different recharge altitudes. Most of the groundwater samples do not have tritium content, pointing to a deeper circulation path and/or a longer residence time (*e.g.* Chaves thermomineral system).

The circulation of the cold CO_2-rich mineral water systems, takes place at shallow depths in the upper crust, as indicated by the low outflow temperature of these waters. The circulating waters are mineralised by water-gas-rock interactions in a low-temperature environment that favoured a high CO_2 content. The analysis performed on the free dissolved gases, as well as on the associated isotopic composition (^{13}C, ^3He and ^4He), enabled the identification of the genesis of the gas phase associated with these mineral water systems. The results obtained are found in Table 1. The isotopic ratios of carbon and helium ($\delta^{13}C$, $^3He/^4He$) and the geochemical composition of the gas phase ascribed to the CO_2-rich mineral waters were used to identify contributions of deep crustal and mantle volatile components associated with the *"Chaves Depression"* tectonic accident.

Table 1 – Gas phase composition, $\delta^{13}C$ and $^3He/^4He$ isotopic ratio of the studied CO_2-rich mineral waters (b.d.l. stands for below detection limits).

Ref.	Gas Phase composition Free Gases								Isotopic ratios $\delta^{13}C$		$^3He/^4He$
	He (ppm)	O_2 (%)	N_2(%)	CO(ppm)	CH_4(ppm)	CO_2(%)	Ne (ppm)	Ar(tot.)	CO_2(g)	CITD	R/Ra
P.Salg. AC25	195.9	0.02	1.8	0.6	783	97.45	0.150	330.6	-5.3	-0.88	2.68
P.Salg. AC17	229.6	0.31	2.99	b.d.l.	600	95.66	0.126	283.3	-5.2	-0.92	2.50
Vidago AC16	334.0	0.66	5.24	2.2	469	92.31	0.416	711.9	-5.1	-2.32	1.90
Vidago AC18	149.3	b.d.l.	0.9	b.d.l.	41	97.44	0.243	239.4	-6.2	-0.10	1.34
Vid.Areal 3	1061.0	b.d.l.	5.54	b.d.l.	1021	94.41	0.417	965.9	-7.2	-2.20	1.26
Chaves AC1	105.1	0.04	1.72	1	500	97.42	0.150	232.0	-5.8	-2.43	0.89
	Dissolved gases (ccSTP/g)										
V.Raia ACP1	1.23E-1	4.42E-2	2.32E+1	2.19E-4	2.10	318.600	1.25E-4	n.m.	n.m.	-4.81	0.5

The $^3He/^4He$ ratios found in the gas phase of the mineral waters varies between 0.89 and 2.68 times the atmospheric ratio (Ra), at Chaves and AC25 Pedras Salgadas respectively. These ratios are higher than that expected for a pure crustal origin (~0,02 Ra), indicating that 10 to 30 % of the gases originates from the upper mantle. The $\delta^{13}C$, varying between –7.2 and –5.1 ‰ *vs* PDB, and the $CO_2/^3He$ values, from x108 to x109, are typical of MORB fluids. The ^3He contribution is higher in the Pedras Salgadas gas phase than in the Chaves, i.e., the gas mantle signature decreases from S to N, indicating higher ^4He crustal contamination to the North (Fig 2). ^3He in excess of that expected for radiogenic production has been found in fluids from seismically active areas in extensional regimes. Decompression during diapiric rise of mantle material will result in deep partial melting and may lead to crustal underplating. Geo-pressured mantle volatiles, such as CO_2 and helium, released during partial melting, may be focused through weak zones in the ductile lower crust that are associated with the roots of the fault system.

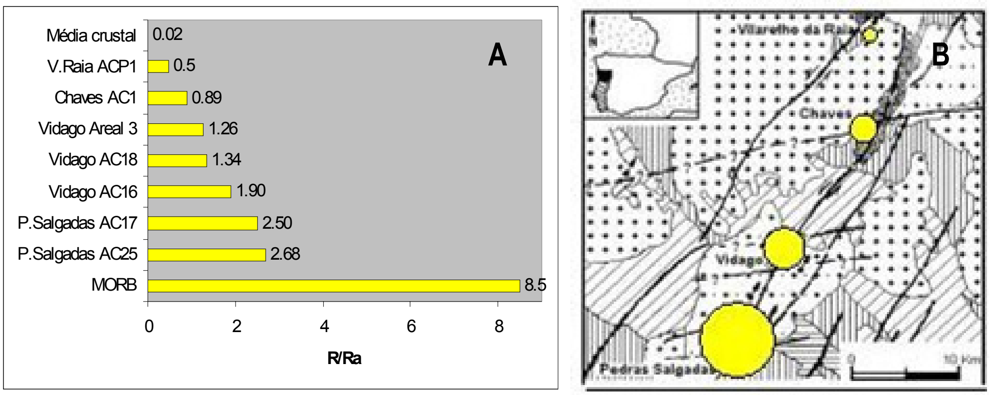


Fig. 2 – (A) The $^3He/^4He$ ratio values observed in the gas phase of the CO_2-rich mineral waters. (B) Spatial variation of the $^3He/^4He$ ratios in the gas phase.

Keywords: CO_2-rich mineral waters, gas geochemistry, isotopes, volatiles origin, N-Portugal

Geochemistry and isotopic composition ($\delta^{18}O$, δ^2H, $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$) in the groundwaters of French Guiana as indicators of their origin and interrelations

[1] Philippe Négrel, [1] Emmanuelle Petelet-Giraud

[1] B.R.G.M., Avenue C. Guillemin, BP 6009, 45060, Orléans Cedex 02, FRANCE,
e-mail: p.negrel@brgm.fr; e.petelet@brgm.fr

ABSTRACT

The current use of untreated river water for drinking purposes by the population of French Guiana has important impacts on public health. Consequently, groundwater is of major importance as a possible alternative drinking water supply to reduce these impacts. Since French Guiana belongs to the Guyana Shield, sustainable water management can be expected to depend increasingly on water from fissured aquifers, e.g. mainly hard rocks (crystalline, metamorphic and volcanic rocks). This study reports the dissolved concentrations of major ions, trace elements (Rb and Sr), stable isotopes ($\delta^{18}O$ and δ^2H), strontium ($^{87}Sr/^{86}Sr$) and neodymium ($^{143}Nd/^{144}Nd$) isotopes in groundwaters and surface waters. Groundwater samples were collected from (i) shallow drill holes in the coastal area, which is the only densely populated area in French Guiana, and (ii) deeper wells in the basement around Cayenne and along the Maroni River from which groundwater is pumped from bedrock fractures.

Concerning major ions, Na concentrations in most of the surface waters and groundwaters plot above the seawater dilution line (SWDL), indicating a Na^+ excess with regard to Cl. As for Na, the surface and groundwaters also display a Ca excess; both reflecting the role of water-rock interaction. Some surface waters were isotopically enriched ($\delta^{18}O$ vs. δ^2H) through evaporation, while most groundwaters agree with both local and global meteoric water lines. Recharge from precipitation events occurs in significant amounts during two periods. The first period is from September to January and corresponds to the rainy season (lasting from late December to July) while the second period of recharge occurs in March-April, which corresponds to the middle of the rainy season.

The surface- and groundwater samples from French Guiana plotted in a $^{87}Sr/^{86}Sr$ vs. 1/Sr diagram indicate the existence of at least three end-members: one end-member may correspond to the drainage of the Lower Paramaca (Unit P) of mainly metavolcanic rocks, while the second end-member would correspond to the drainage of the Upper Paramaca (Unit S) with a mainly meta-sedimentary lithology. The third end-member could correspond to the drainage of plutonic granitoid intrusions (granite and granodiorite from the "Guyana plutonism", granitoid, granodiorite and tonalite from the "Caribbean plutonism").

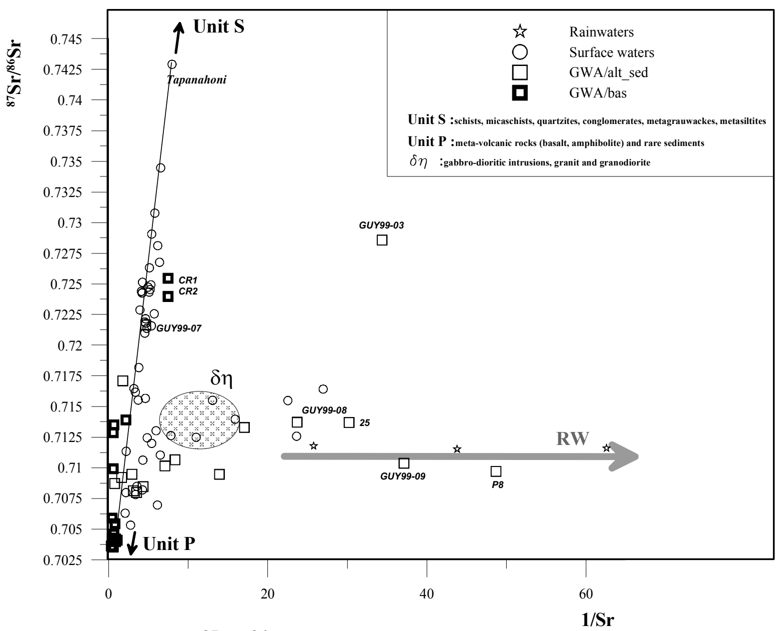


Fig. 1. Relationship between $^{87}Sr/^{86}Sr$ ratios and 1/Sr in waters collected from French Guiana.

In the groundwaters from the extensive sandy-argillaceous terrane and from the alluvia, the dissolved Nd content varies from 39 to 752 $ng.l^{-1}$ together with a broad range in the TDS (10 up to 166 $mg.l^{-1}$). In the groundwaters from deep wells in the basement the dissolved Nd content is lower and varies from 3-4 to 63 $ng.l^{-1}$ with TDS values ranging from 46 to 218 $mg.l^{-1}$. The lowest $\varepsilon Nd_{(0)}$ (which represents -in ε units- the deviation in parts per 10^4 from $^{143}Nd/^{144}Nd$ in a chondritic reservoir) are observed in the groundwaters from the extensive sandy-argillaceous terrane and from the alluvia whereas the highest values are from the groundwaters from deep wells in the basement. The isotopic composition of Nd vs. the $^{147}Sm/^{144}Nd$ ratio for the groundwaters from the extensive sandy-argillaceous terrane and from the alluvia plot between the values measured in the parent rocks and that of suspended matter from the Amazon Basin suggesting a possible influence of sedimentary deposits in the coastal area that originate from the Amazon. On the other hand, some groundwaters from the same area plot in agreement with the field of parent rocks, suggesting that Nd originates from the weathering of the bedrock.

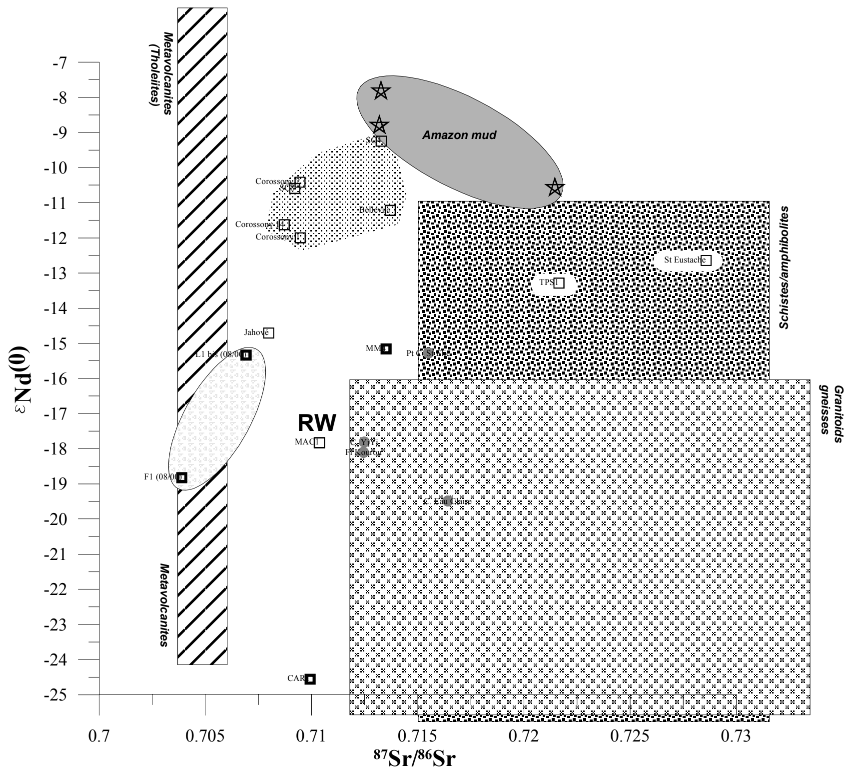


Fig. 1. Plot of $\varepsilon Nd_{(0)}$ *vs.* $^{87}Sr/^{86}Sr$ ratios in surface- and groundwaters collected from French Guiana.

Coupling Sr and Nd isotopes enables the origin and interrelation of groundwaters to be more clearly defined. Some groundwaters are related to the drainage of the metavolcanite rocks of the unit P, others reflect the influence of the isotopic signature from the Amazon Basin, while the remainder of the samples reflect either the drainage of schists from the unit S or the drainage of granitoids.

Present day research has to focus on the increasing use of existing geochemical tools (such as Sr-Nd isotopes) dedicated to elucidating the structure and functioning of the different compartments of hard rock aquifers, i.e. overlying sediments, when they do exist, weathered cover (alterites), weathered-fissured zone, fractured hard rock. This geochemical and isotopic approach on the groundwater in French Guiana has allowed to better constrain the origin and complex relationships between the different compartments of the hard-rock aquifers. This study constitutes a pertinent point of view of the complex functioning of hard-rock aquifers and could be a helpful tool in the framework of the recent European Water Directive (WFD, 2000/60/EC).

Keywords: French Guiana, Strontium isotopes, Neodymium isotopes, Groundwater

Geomorphic controls on groundwater evolution in the arid Cooper Creek system, SW Queensland, Australia: Inferences from element and stable isotope hydrogeochemistry

[1,2]Dioni I. CENDÓN, [2]Josh R. LARSEN, [2]Brian G. JONES, [2]Daniel RICKLEMAN,[2] Gerald C. NANSON

[1] ANSTO (Australian Nuclear Science and Technology Organisation), Menai, NSW 2234, Australia, e-mail: dce@ansto.gov.au, dcendon@uow.edu.au
[2] GeoQuEST, School of Earth and Environmental Sciences, University of Wollongong, NSW 2522, Australia, e-mail: briangj@uow.edu.au, jrl29@uow.edu.au

ABSTRACT

Quaternary climatic changes have had a remarkable impact on the biological and geomorphological evolution of the Australian continent, and in turn can exhibit considerable control on the current hydrological cycle. In the absence of glaciation, changes in precipitation and wind strength have resulted in alternating fluvial, aeolian and lacustrine deposits over much of inland Australia. In the currently arid anabranching floodplain-channel system of Cooper Creek (SW-Queensland), this is manifest as extensive late Pleistocene fluvial and aeolian sand bodies overlain by floodplain and channel mud deposits. The alluvial muds are the result of the much reduced Holocene transport capacity of the Cooper Creek system, and are punctuated at the surface by remnant aeolian sand dunes which are stratigraphically connected to the underlying sand bodies. These Quaternary sand bodies (Chookoo dune-floodplain complex) have in turn become the main aquifers for the region, where the water table is ~10-12m below the floodplain surface.

The presence of shallow groundwater is especially crucial for ecosystems in arid environments because evaporation quickly removes any available surface waters. Considering the importance of this resource, and the fragility of the hydrological cycle in arid zones, the shallow groundwaters in this region have received surprisingly little attention. This study aims to determine the basic recharge/evaporation processes of the Chookoo dune-floodplain-channel system using major and minor element chemistry together with water stable isotopes ($\delta^{18}O$, $\delta^{2}H$) and dissolved sulfate isotopes (sulfate-$\delta^{34}S$ and $\delta^{18}O$). We hypothesise that groundwater recharge predominately occurs as diffuse rainfall infiltration via the dunes while chemical variations also occur through the dunes, modifying the original chemistry of the recharged water. Presented chemical data suggests that the main channel of the creek has little or no hydraulic connectivity with the shallow aquifers except during large flood events when the mud seal over their base is scoured and fresh water temporarily recharged.

Major-element chemistry: All waters are Na-Cl-rich with appreciable amounts of Ca and SO_4. All major elements increase along a transect from the sand dunes to the floodplain within the same aquifer. In general, major element ratios show a marine derived signal for groundwater, while a few surface water samples deviate from marine ratios (Fig. 1A). This difference is interpreted as an event based signature, with most solutes incorporated from dissolution of surfaces salts. Evaporation models also provide evidence of major element evolution (Fig. 1B). Simple evaporation of surface waters cannot reproduce the concentrations found in the groundwater. Only when a mixture of surface and groundwater and/or dissolution of previously precipitated salts along the recharge path are considered, do the evaporation models match with the observed concentrations.

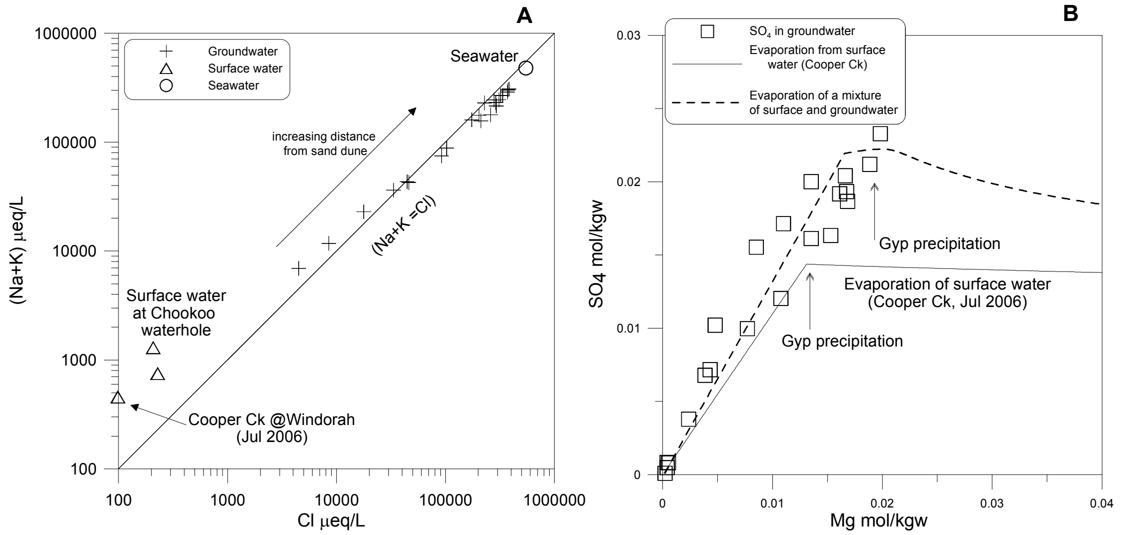


Fig.1. A) Na+K vs. Cl plot. B) Sulfate concentration in groundwater compared to calculated concentrations during evaporation. Sulfate concentrations are plotted against Mg, which is generally conservative in early evaporation stages.

Water stable isotopes (δ^2H and δ^{18}O): The stable isotopes for surface and groundwater in the Chookoo dune region show an offset and slightly flatter trend than the GMWL, which is typical of waters that have infiltration and/or have been subjected to evaporation prior to recharge in arid areas. Extrapolation to the intersection of the Chookoo trend line ($\delta^2H_{H2O} = \delta^{18}O_{H2O}\ 6.23 + 10.99$) with the GMWL reveals that the minimum rainfall δ^2H and δ^{18}O values required for infiltration into the Chookoo aquifer are δ^2H=-82.45‰ and δ^{18}O=-11.47 ‰. When this calculation is compared with the GNIP/ISOHIS record for Alice Springs (1962-1987) it reveals that although there is a large range in the δ^{18}O and δ^2H rainwater values, the highest rainfall events are correlated with the most depleted isotopic values (as low as δ^2H=-84‰ and δ^{18}O=-13 ‰), thus supporting the case for a rainfall-infiltration recharge model for the Chookoo dune-floodplain complex.

Dissolved sulfate stable isotopes (δ^{34}S and δ^{18}O): All groundwater samples show very similar sulfate-δ^{34}S values (+8.33 to +9.23 ‰), while surface water samples from nearby waterholes are more enriched (+10.93 to +12.21‰). This is despite a wide range in total SO_4 concentrations. These ranges are consistent with expected values for precipitated sulfate minerals of inland Australia where sulfate-δ^{34}S values generally become more depleted with distance from the coast. Sulfate-δ^{18}O values display greater variation (+12.01 to 16.25 ‰); revealing the recycling of previously precipitated salt crusts and aerosols in the unsaturated zone.

The data-set supports the interpretation that the porous sand dunes present at the site act as a medium for rainfall recharge and as the agents changing chemical and isotopic signatures. These results have important implications for rangeland management and regional ecology. The retention of surface waters in the channel country of Cooper Creek form isolated wetlands and waterholes on which many aquatic, avian, mammalian and plant species depend. The significant differences in water chemistry and quality between surface and ground waters in this region play an important ecological role in terms of species distribution, for example through differences in species tolerance and dependence on ground versus surface water. This variation could also isolate important local sources for stockwater.

Keywords: Shallow groundwater, evaporates, stable isotopes, desert ecology, Cooper Creek catchment

Hydrogeochemical and oxygen isotope investigations in multilayer aquifer of the Friuli Venezia Giulia plain, north-eastern Italy

Franco CUCCHI, Giuliana FRANCESCHINI, Francesco TREU and Luca ZINI

Department of Geological, Environmental and Marine Sciences, University of Trieste
Via E. Weiss 2, 34100 Trieste (Italy)
Tel.: +39 040 55822052; fax: +39 040 5582048. *E-mail address:* giuliana.franceschini@units.it

ABSTRACT

Groundwater supplies approximately 75% of the European Union's drinking and agricultural waters and therefore knowledge of the quality of groundwater and rate of recharge is fundamental for its protection and management. The Friuli Venezia Giulia Plain, located in the northeastern sector of Italy, hosts a well developed Plio-Quaternary alluvial aquifer. From a geomorphological and hydrogeological prospective this plain is subdivided in two provinces which are separated by a resurgence line. The Upper Friuli Plain is composed of calcareous and dolomitic gravels and hosts a well developed phreatic aquifer. The Lower Friuli Plain is characterized by multi-layered artesian aquifers that are composed of gravels and sands interbedded by clay and silty layers that become thicker in a southwards direction. The constant increase of water demand related to agricultural and industrial activities has resulted in the exploitation of the deeper aquifers without a proper hydrogeological study of the water resource. This has led local authorities to begin an evaluation on a large scale of the hydrological fluxes creating a collaborative project with the GGACI group (Water and Geomorphogical Research Unit) of the University of Trieste. This project combines the systematic analysis of the hydrochemical features of the aquifer with stable isotope investigations ($\delta^{18}O$). Rainfall, surface river waters and groundwater samples were collected in the period 2004-2006. Geochemical analyses on water samples from phreatic and artesian wells were carried out with data from 1996 to 2006. Water temperature, electrical conductivity, pH, anion (HCO_3, NO_3, Cl, SO_4) and cation (K, Na, Mg, Ca) concentrations have been statistically studied and elaborated with GIS to create significant ion concentration regional maps.

In order to characterize the oxygen stable signature of precipitations thirteen pluviometers have been positioned in different areas of the region from September 2004 to present. Weighted mean $\delta^{18}O$ values of precipitation range from –7.7‰ to –10.5‰ (with a mean value of –9.1‰) in the mountain areas and from –6.7‰ to –7.6‰ in the plain (with a mean value of –7.1‰). The calculated vertical isotopical gradient is 0.29‰/100 m in accord with those measured in neighboring countries. Two hundred samples were collected in autumn/winter and spring/summer from phreatic and multilayered artesian aquifers and measured for their oxygen isotope compositions. The phreatic aquifer has $\delta^{18}O$ value that ranges between –6.3‰ to –8.8‰ (with a mean value of –7.8‰), while the shallow artesian aquifers range between –6.8‰ to –10.2‰ (mean value of –8.2‰). These values correspond to a mixing with the isotopic composition of the Region major rivers and with the composition of local precipitations. The water samples collected from the deeper artesian aquifers indicate depleted values ranging from –8.3‰ to –10.5‰ (mean average value of -9.1‰). These waters do not show significant $\delta^{18}O$ seasonal variations whereas the $\delta^{18}O$ values obtained from the samples collected in the phreatic and shallow artesian aquifers exhibit more marked changes during the year.

The deeper artesian aquifers have mean ion concentrations that decrease with increasing depth for Ca, Cl, NO_3 while increasing values have been found for Na, K and no significant changes have been detected for SO_4 and HCO_3. The electric conductivity measured on phreatic and from the shallower artesian aquifers have mean values referred at 20°C of around 440 µS/cm decreasing to 380 µS/cm for deeper confined artesian aquifers. The chemical investigations of the deeper artesian waters have shown that they have a different chemical signature to the shallower waters. This, together with the marked changes in isotopical signal of these deeper waters, indicates that the hydrogeological settings are quite different and that the deepest and therefore oldest waters are separated from the recent ones with little water exchange. The result of this study has indicated that the phreatic as well as the shallow artesian aquifers are fed by local infiltration and by rivers. The deeper artesian aquifers maintain more passive hydrodynamic conditions where the presence of buried structure hinders totally or partially natural groundwater exchange.

The isopleths of ion concentrations and isotopic values have indicated the presence for the phreatic and shallow artesian waters of four different geochemical provinces in the Friuli Venezia Giulia Plain:

1. *Cellina-Meduna Plain*: with high oxygen isotope values and elevated concentrations of HCO_3 and low values of SO_4;
2. *Tagliamento River Plain*: the aquifer have isotopic values similar to the ones recorded in the Tagliamento River, high values of SO_4, low concentrations of HCO_3 and Ca;
3. *Torre e Natisone Plain*: no well defined chemical signatures and isotopical values similar to local precipitations;
4. *Isonzo River Plain*: low isotopic values and high concentrations of Ca.

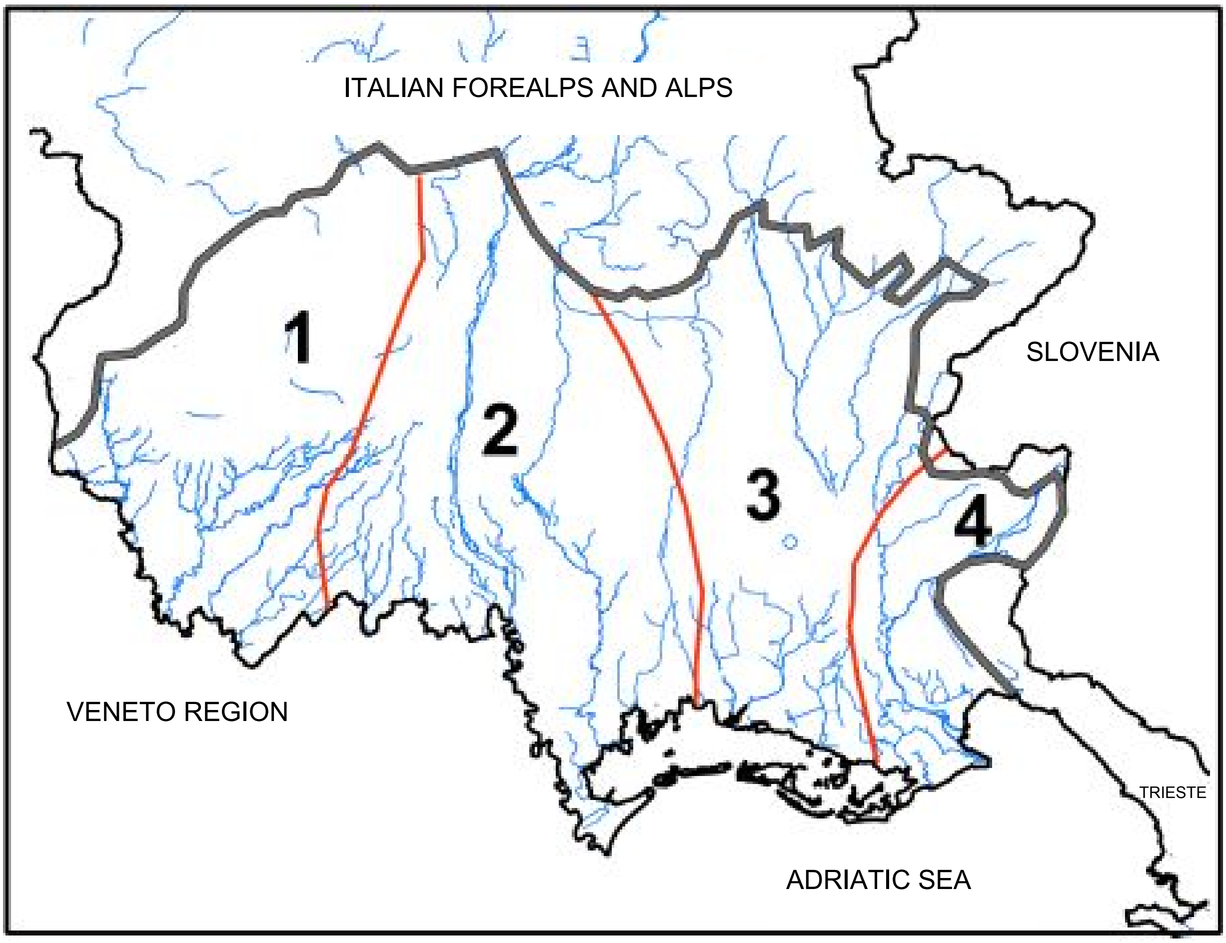


Fig. 1. The four hydrogeological provinces of the Friuli Venezia Giulia aquifer.

Keywords: Hydrochemistry, Isotopes, Groundwater evolution, Aquifers, Italy

Is tritium a useful tool to study the evolutionary trend of groundwater quality affected by diffuse pollution?

[1]Nicole BARAN, [2]Jean RICHERT, [1]Murielle CHABART, [1]Christophe MOUVET

[1] BRGM, 3 avenue C. Guillemin, BP6009, 45060 Orléans cedex 2, France, n.baran@brgm.fr
[2] Chambre d'Agriculture du Bas-Rhin, 2 rue de Rome, BP 30022, Schiltigheim, France, jean.richert@bas-rhin.chambagri.fr

ABSTRACT

The objective set by the Water Framework Directive (WFD - 2000/60/EC, OJEC 2000) is for "all groundwater bodies to achieve good quantitative and chemical status … at the latest by 2015". The Directive demands that European Union Member States not only characterize their levels of groundwater contamination, but also that they study the evolutionary trends of their pollutant concentrations. This means that they must be in a position to explain possible cases of non-achievement. In order to predict future groundwater quality trends, especially after implementation of environmental measures, questions concerning the stock of nitrate or pesticides stored in the unsaturated zone and the infiltration rate of these solutes are paramount.

Tritium is a short-lived hydrogen isotope with a half-life of 12.32 years (Lucas and Unterweger, 2000) that is produced naturally in the stratosphere by cosmic radiation on ^{14}N. Large amounts were produced during the thermonuclear tests of the late 1950s and early 1960s. Both natural and anthropogenic tritium enters the hydrogeological cycle through precipitation. Tritium measurements in the groundwater and in pore water from solids of the unsaturated zone were used to estimate the residence time of the water (Clark and Fritz, 1997; Kolpin *et al.*, 2004) and the water velocity in the unsaturated zone. Largely used during the last decades, tritium is progressively replaced by tools such as CFC or SF6, used to estimate infiltration rate.

In three agricultural sites (loess, chalk, limestone with unsaturated zones of 17, 30, 35 m thickness, respectively) representing geological contexts distributed throughout the world, tritium was measured in the unsaturated zone and/or the saturated zone in order to better understand and estimate the possible evolution of the groundwater contamination by nitrate and pesticides observed in these study sites.

The tritium profiles in pore water from the unsaturated zone enabled us to identify the infiltration mechanisms in the unsaturated zone. In the loess and chalk (Fig. 1), water moved essentially by convection-dispersion whereas in limestone, the profiles revealed, depending on the location in the studied catchment, either a dominant convection-dispersion process or several infiltration which could be due to fractures in the limestone. In case of convection-dispersion in the loess and chalk, a robust transfer rate of water, assuming that the highest tritium peak corresponds to the year 1963, was estimated and an "age" can be attributed to nitrate observed along the depth profile (Fig.1).

The combination of the identification of infiltration mechanisms with the determination of infiltration rate enabled us to explain why, in a catchment with homogeneous nitrate or pesticide loads, water in a given piezometer appeared not contaminated due to anthropic activities (Fig. 2). Nitrate contamination of groundwater increased significantly from upstream to downstream, piezometers located upstream being to date almost free of contamination, a consequence of the combination of the very slow infiltration rate and the great thickness (35 m) of the unsaturated zone. The determination of infiltration mechanisms in the unsaturated zone and the transfer rate also allowed explanation of the high temporal variability of contamination illustrated by monthly analysis of groundwater in a given piezometer.

In the case of loess, a modelling exercise was also conducted. The tritium data measured in the water obtained from solids in the unsaturated zone was used to calibrate the hydrodynamic component of the solute transfer model. In a second step, the nitrogen input and the specific nitrate transformation parameters of this model were somewhat fitted. The good agreement between observed and simulated data (nitrate peak values and depths of these peaks) showed that the approach is relevant and highlighted the importance of hydrodynamic calibration using tritium data.

Based on the three recent studies presented here, it is clear that tritium remains a relevant tool to characterize qualitatively or quantitatively (coupled with a model) the transfer times of water and solutes in the unsaturated zone. The characterization of solutes stocks in the unsaturated zone and of their infiltration rate, for example by using tritium, must be taken into account in the implementation of the Ground Water Directive to explain and predict groundwater quality trends. For example, the slow average rate evidenced by the observed tritium and nitrate profiles and the great thickness of the unsaturated zone suggested that changes in farming practices will not be noticeable in terms of groundwater quality for several decades. These results have to be considered in terms of water management.

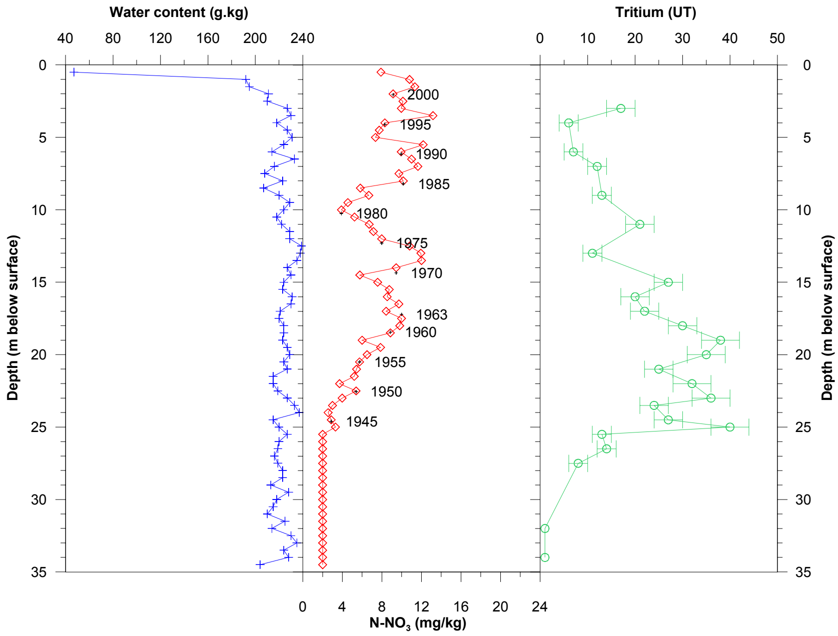


Fig. 1. Measured water content, nitrate and tritium profiles in a chalky unsaturated zone and estimation of the infiltration rate of nitrate based on tritium data

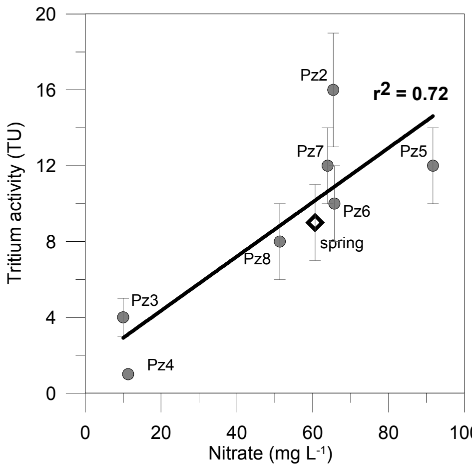


Fig. 2. Nitrate *vs*. tritium (measured value and error) for piezometers and a spring representing the main outlet of the catchment (3 km^2, sandy aquifer overlaid by limestones)

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Keywords: groundwater, trend, diffuse pollution, tritium

Isotope based assessment of recharge regimes and groundwater mixing in the Senegal River delta system

[1]Moctar DIAW, [1]Serigne FAYE; [2]Soulèye WADE, [3]Yves TRAVI,
[1]Abdoulaye FAYE, [1]Cheikh B. GAYE

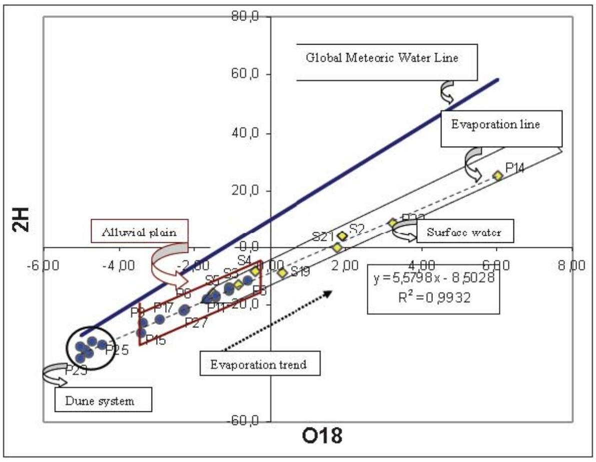
[1] Département de Géologie, Université Cheikh Anta Diop BP5005 Dakar, Sénégal (fayes@ucad.sn)
[2] Institut des Sciences de la Terre, Université Cheikh Anta Diop BP 5693 Dakar, Sénégal
[3] Laboratoire d'Hydrogéologie, Université d'Avignon, 33 rue Louis Pasteur 84000 Avignon, France

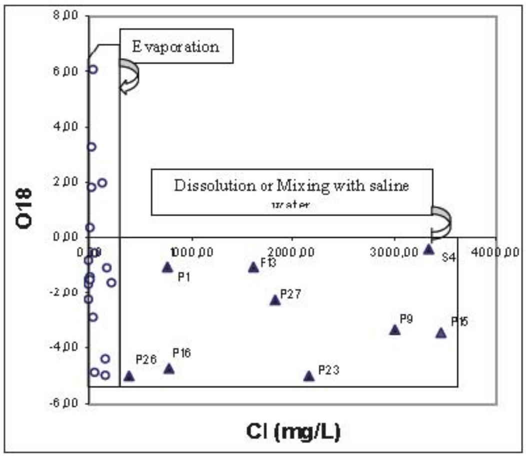
ABSTRACT

The hydrochemistry of major ions and isotopes of the water molecules (^{18}O, ^{2}H, ^{3}H) was utilised to explain the chemical heterogeneity, recharge regimes and hydraulic connectivity between the alluvial aquifer and the wetland areas which characterised the inundation plain. This approach indicates that mineralization processes and the hydrochemistry evolution are mainly controlled by the various processes occurring in different geomorphologic setting (dune and delta) and also processes related to the lithology of the reservoir. Two main groups of water have been identified: the fresh water group with CaMg-HCO_3, Na-HCO_3, Na-Cl, Na-SO_4 and CaMg-Cl water types; and the saline water group with Na-Cl and Ca-Cl water types. Accordingly the TDS vary from 46 mg/L to 6,115 mg/L for most of the sampling wells except in few where values range from 17,815 to 48,105 mg/L. Most of the groundwater sampled during the dry season period are saturated with respect to carbonate minerals (calcite, aragonite and dolomite) and undersaturated to evaporate minerals (gypsum; halite anhydrite). Whereas, saline groundwaters are saturated with respect to these carbonate and evaporate minerals for the two seasons considered.

The $\delta^{18}O$ and $\delta^{2}H$ values for the entire data set are distributed along a line with a gradient of 5.5 (Fig. 1). This type of trend line is observed in most of the sahelian aquifers and the deuterium excess of -8.5‰ shows an evaporated isotopic signature of infiltrating waters instead of rainwater evaporated during storm events. The distribution trend shown in the $\delta^{18}O/\delta^{2}H$ diagram differentiates enriched surface waters (-1.6 to +6.0‰ for $\delta^{18}O$ and -15 to +25‰ for $\delta^{2}H$), waters located in sand dunes which are less evaporated (-5.0 to -4.4‰ for $\delta^{18}O$ and -38 to -32‰ for $\delta^{2}H$) and waters located in the alluvial plain (-3.4 to -0.6‰ for $\delta^{18}O$ and -29 to -11‰ for $\delta^{2}H$). This latter group characterised by a trailing trend seems to result from a mixing between sand dunes waters and the evaporated surface water. This mixing process, which has been evidenced by the hydrogeochemistry seems to be attenuated with depth of the water table and also with to the distance to the adjacent hydraulic axis. By considering the graph chloride contents vs. $\delta^{18}O$ (Fig. 2) which is similar in every aspect to Cl vs: $\delta^{2}H$ (not shown), the two main groups of waters (fresh and saline) are clearly identified and where processes are likely to be evaporation for the fresh water group and dissolution of halite and/or mixing with saline solution for the saline water group.

Concerning the ^{3}H content, the lack of record in precipitation in the region permits only a qualitative interpretation. Its presence in the groundwater indicates at least a proportion of water recharged within the last 40-50 years. However, approximation of the input signal in precipitation can be made by considering value of 3.4-3.5 TU as background level. Tritium contents measured from samples collected in June 2005 range from 3.3 to 4.0±0.7 TU for the surface waters, from 2.3 to 6.4±0.7 TU for groundwater collected in the alluvial plain zones and from 0.9 to 2.8±0.7 TU in groundwater located beneath sand dunes system. By plotting $\delta^{18}O$ against ^{3}H values (Fig. 3); the three main group of waters identified in the $\delta^{18}O/\delta^{2}H$ graph are confirmed with the sand dune groundwater which result from slow rainfall infiltration, the surface water group and the alluvial plain groundwater which result from a mixture of the sand dune groundwater and the surface waters. However; the high tritium content measured in P15 and P 20 located downstream and in irrigation zone seems to be the result of evaporated irrigation water which contribute to the recharge of the system in these areas.





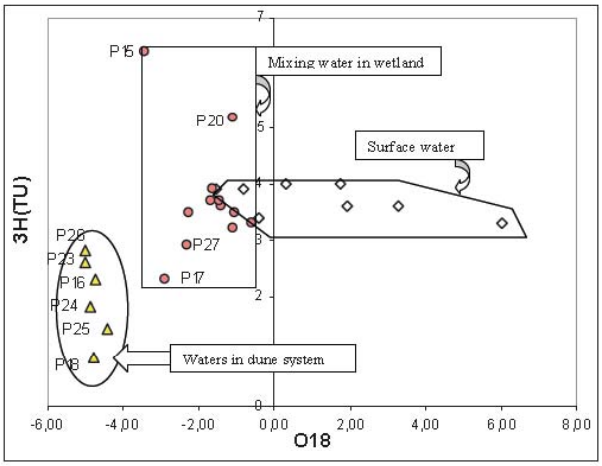


Fig 1: $\delta^{18}O/\delta^{2}H$ diagram

Fig 2: $Cl/\delta^{18}O$ diagram

Fig 3: $\delta^{18}O/^{3}H$ diagram

Keywords: isotopes, alluvial plain, sand dunes, mixing, evaporation

Isotope component characteristics of groundwater in the southern part of Jiangsu province, China

[1] Jiang YUEHUA, [2]Jia JUNYUAN, [3]Xu NAIZHENG, [4]Kang XIAOJUN

[1] Nanjing Institute of Geology and Mineral Resources, Nanjing, China, e-mail: jiangyuehua01@sina.com
[2] Nanjing Institute of Geology and Mineral Resources, Nanjing, China, e-mail: njjjunyuan@cgs.gov.cn
[3] Nanjing Institute of Geology and Mineral Resources, Nanjing, China, e-mail: njxnaizheng@cgs.gov.cn
[4] Nanjing Institute of Geology and Mineral Resources, Nanjing, China, e-mail: njkxiaojun@cgs.gov.cn

ABSTRACT

Suzhou, Wuxi and Changzhou area of the southern part of Jiangsu province is located in the northern plain of the delta of the Yangtze River. Bedrock occurs sporadically and Quaternary system is widespread. The thickness of Quaternary ranges from 80 m to 230 m from west to east and from south to north. From bottom to top the formation is well developed from Pleistocene to Holocene. Based on the study of groundwater isotope（^{2}H and ^{18}O, ^{34}S, ^{15}N, ^{3}H, ^{14}C）the authors discuss conditions of groundwater recharge, runoff and drainage, variation of flow field caused by overexploitation of groundwater and polluted status of groundwater in Changzhou, Wuxi and Suzhou area. The main results are as following: ① The source of groundwater recharge is principally precipitation and partially surface water. Artificial exploitation and evaporation are the main causes of groundwater drainage. The deep confined aquifers (main exploitation aquifers) in Changzhou area and in Wuxi and Suzhou area likely to belong to two different aquifers. The main exploitation aquifers in Changzhou area are not connected with those in Wuxi and Suzhou area, or they are connected but not expedited. The lateral run-off of groundwater is at present characterized by flowing to the exploitation center because of overexploitation of deep groundwater over a long period, but the flowing speed of groundwater is still wondrously slow. The deep confined groundwater is in a close-semiclose state. ② The values of tritium in the samples from deep confined water are less than 3TU and those of $\delta^{18}O$ vary from -6.2‰~-9.0‰, showing that groundwater is in relation to the old recharge and has no relation with the current water. The values of tritium in phreatic & slightly confined water on the whole in Suzhou-Wuxi-Changzhou area range from 19~28 and $\delta^{18}O$ vary from -3.8‰~-6.1‰, indicating that the groundwater is modern water which is related to precipitation and surface water since 1950. ③ The age of deeply confined groundwater varies from 10000a to 38000a on the whole. The nearest exploitation center (along the line of the three cities of Changzhou, Wuxi and Suzhou), showed the oldest age of the groundwater; while the furthest exploitation center showed the newest age of the groundwater. ④ There are obvious differences in the $\delta^{34}S$ value between the shallow groundwater and the deep groundwater in Suzhou-Wuxi area. The high values of $\delta^{34}S$ occur in the samples from deep confined aquifer and vary from 50‰~75‰, while the low values of $\delta^{34}S$ occur in the the samples from phreatic & surface water and vary frome5‰~19‰. The research reveals that the deeply confined groundwater and slightly confined groundwater partially has no pollution on the whole, but the phreatic groundwater and surface water are clearly polluted by acid rain. ⑤ The values of $\delta^{15}N$ of the samples from phreatic & slightly confined aquifers vary from 10.03‰~32.83‰ and those of $\delta^{18}O$ range from 12.50‰~20.76‰, suggesting contamination is due to manure and sewage. The values of $\delta^{15}N$ of the samples from deep confined aquifers are from 2.163‰~6.208‰ while those of $\delta^{18}O$ vary from 17.051‰~23.201‰, suggesting the NO_3^- is derived from precipitation.

Keywords: Groundwater, ^{2}H and ^{18}O, ^{34}S, ^{15}N, ^{3}H and ^{14}C

Mineral waters of northwestern of the Iberian Peninsula: estimation of the mean altitude of recharge areas based on isotopic data

[1]Ana CV OLIVEIRA, [2]Alberto S LIMA

[1] Termas das Caldas da Saúde, 4784-907 Areias, Santo Tirso, e-mail: qualidade@caldas-da-saude.pt
[2] Departamento de Ciências da Terra, Universidade do Minho, 4710-057 Braga, Portugal, e-mail: aslima@dct.uminho.pt

ABSTRACT

Oxygen and hydrogen isotopes of water are widely used as tracers of hydrogeological processes such as precipitation, groundwater recharge, groundwater-surface water interaction, because are affected by meteorological process that provide a characteristic fingerprint of that origin. This fingerprint is fundamental to investigating the provenance of groundwater.

In this work, the mean altitude of recharge areas of 24 mineral waters of the northwestern sector of the Iberian Peninsula is estimated, based on the stable isotopic composition of the precipitation as well as the groundwater isotopic fingerprints (Fig 1). The altitude effect was applied as a tool to calculate the mean altitude of recharge areas from δ^2H and δ^{18}O data.

This sector belongs to the Hesperian Massif, corresponding to an extensive plateau surrounded by a ridge of high relieves, such as the Galician Massif, in the northwestern, the Cantabrian Cordillera, in the north, the Iberian System, in the northeastern, and the Ossa-Morena Sierra, in the southern. The relief is mainly controlled by two fracture systems (ENE-WSW and N-S), that originate fault blocks separated by straight valleys with same directions.

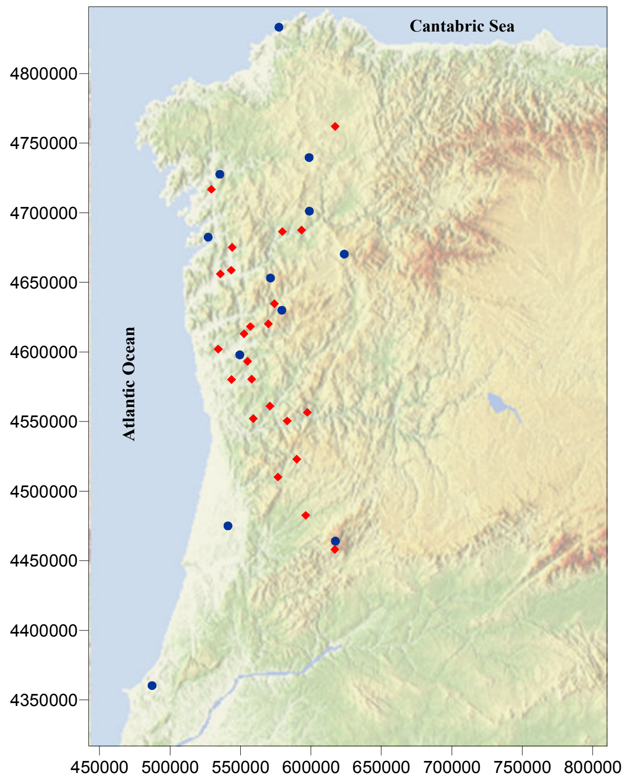


Fig. 1. Distribution of the studied groundwater in northwestern of the Iberian Peninsula (◆ - Mineral waters; ● – Shallow waters).

Data of 36 precipitation stations was analysed and the values of δ^{18}O varies from -7,49‰ to -3,73‰, with a mean of -5,60‰. Relatively to δ^2H, the values are between -54,2‰ and -16,2‰, with a mean of -34,1‰.

A plot δ^{18}O vs. δ^2H defines a straight line according to the equation $\delta^2H = 8{,}09\ \delta^{18}O + 11{,}3$ (r^2=0,89), which is very close to the GMWL - global meteoric water line, $\delta^2H = 8{,}13\ \delta^{18}O + 10{,}8$ (Fig. 2).

The altitude of the stations, its latitude and its distance from coast, together, account for 85% of the isotopic composition of the precipitation of northwestern of the Iberian Peninsula. In this area, as in others studies, was determined an altimetric gradient of -0,2‰ of $\delta^{18}O$ per 100 m of elevation (Fig 3) and a depletion in heavier isotope of 0,6‰ of $\delta^{18}O$ per an increase of one latitude degree. Relatively to the distance from coast, a general gradient of -0,1‰ of $\delta^{18}O$ per 10 Km was estimated. The stations located in the Atlantic coast present higher values of $\delta^{18}O$, when compared with those that suffer influence of the Cantabric Sea. The continental effect is strongly affected by the altitude.

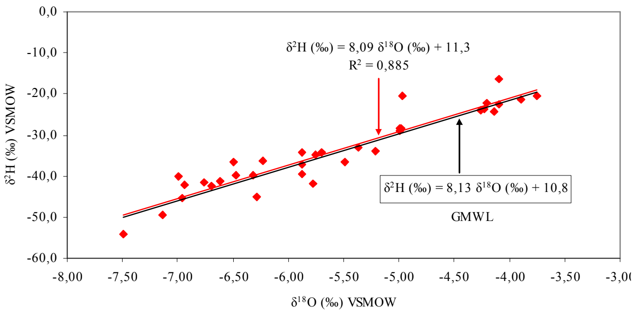


Fig 2. $\delta^{18}O$ vs. $\delta^{2}H$ values of northwestern of the Iberian Peninsula comparative with global meteoric water line (GMWL).

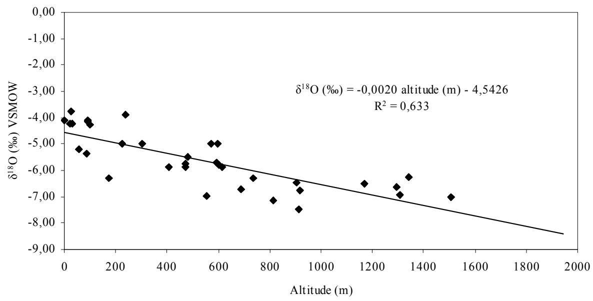


Fig 3. Relationship between $\delta^{18}O$ in precipitation and altitude of the sampling stations.

A group of 36 groundwater samples was analysed, 12 of them are shallow waters and the others 24 samples are mineral waters. The relationship between $\delta^{18}O$ and $\delta^{2}H$ values can be described by the equation $\delta^{2}H$ = 7,257 $\delta^{18}O$ + 7,367, for shallow waters, and the equation $\delta^{2}H$ = 7,808 $\delta^{18}O$ + 10,568, for mineral waters (Fig 4). The main difference between these two equations is due to the deuterium excess. Moreover, the equation of mineral waters is very close to the GMWL, suggesting a meteoric origin for these waters.

Applying the altimetric isotope gradient to the studied mineral waters (Fig 3), the calculated mean altitude of recharge areas ranges from ≈ 150 m to ≈ 1450 m.

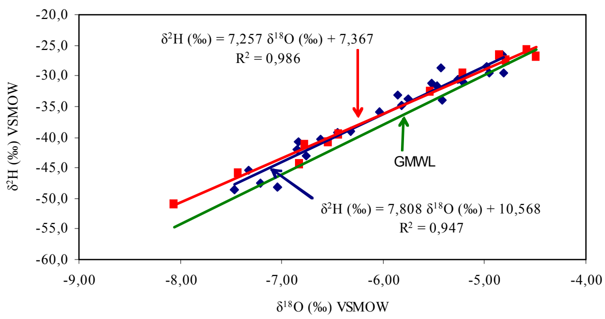


Fig 4. Plot of the isotopic composition of the mineral (◆) and shallow waters (■).

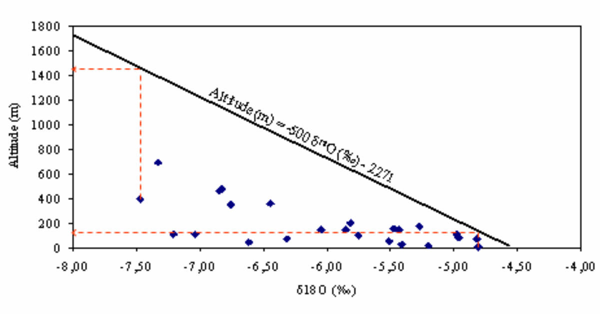


Fig 5. Mean altitude of recharge areas of mineral waters.

Keywords: recharge areas, stable isotope, isotopic gradient, Iberian Península, mineral waters

Sr isotopic tracing of groundwater interactions between different bodies in a small catchment of the Paris basin (Brévilles, France)

[1] Agnès BRENOT , [1] Nicole BARAN, [1] Emmanuelle PETELET-GIRAUD, [1] Philippe NÉGREL

[1] BRGM, Avenue C. Guillemin, BP 6009, 45060 Orléans Cedex 02, France, e-mail: a.brenot@brgm.fr

ABSTRACT

The objective set by the Water Framework Directive (WFD – 2000/60/EC, OJEC 2000) for all groundwater bodies is to "achieve good quantitative and chemical status at the latest by 2015". In this context, European Union member states are establishing monitoring programs to characterize the temporal and spatial evolution of groundwater bodies. With the main constraint of reducing the cost of investigation programs, working from limited observations is a challenge. Data concerning intensive monitoring at a small scale, in terms of distance, may be useful for testing whether larger scale investigation programs are representative or not of the groundwater body as a whole, but this approach has apparently not received much attention. The purpose of the present study is to document spatial and time variation of groundwater geochemistry over a relatively long period (5 years), in a small basin (around 3 km^2) located in an agricultural region where agricultural practices have been well documented and monitored. In this context, the geochemistry of groundwater may be significantly altered by the addition of various components of fertilizers, which have been applied at varying rates in the past. In particular, strontium may be added to fields because it is a trace constituent of major fertilizer components. These anthropogenic inputs are likely to unequally alter natural groundwater composition depending on the water alimentation and the water pathways occurring in the basin. Intensive monitoring of the Cuise Sands Aquifer (Brévilles, France) showed significant disparities for major element concentrations, Sr concentrations, Sr isotopic compositions and tritium values, depending on the groundwater sampling location (Fig. 1a). The first objective of this study was to test if spatial disparities are relevant and if these are related to various controls of lithological and anthropogenic inputs.

Bedrock weathering and anthropogenic inputs related to agriculture are the main potential sources of Sr identified in the catchment. With regard to Ca/Sr versus Mg/Sr (Fig. 1b), the groundwater displays intermediate composition between at least 3 end-members. The Mg/Sr molar ratio discriminates end-member 1 from end-members 2 and 3 whereas the Ca/Sr molar ratio discriminates end-member 2 from end-member 3. Low Mg/Sr molar ratios (<100) (Fig. 1b), associated with low nitrate concentrations, and low tritium values (Fig. 1b) suggest that some sampling points are poorly affected by anthropogenic inputs. On the other hand, sampling points with higher Mg/Sr molar ratios (>250) (Fig. 1b) are positively correlated to higher nitrate concentrations and higher Nitrate/Sr molar ratios (>500) and suggest contribution of Sr from anthropogenic origins. Thus, the Mg/Sr molar ratio was used to discriminate between natural and anthropogenic origin. End-member 1 (Fig. 1b), displaying a high Mg/Sr ratio contribution, constitutes the anthropogenic end-member in the catchment. Various Ca/Sr ratio for piezometers little affected by anthropogenic inputs (Pz1, Pz3, Pz4 and Pz17c), suggest that this ratio discriminates between different natural origins. Thus end-member 2 and 3 (Fig. 1b) reflect lithological control on the catchment. These interpretations are further examined in the light of the Sr isotopic signature since $^{87}Sr/^{86}Sr$ values are capable of tracing anthropogenic sources of dissolved Sr (Böhlke and Horan, 2000).

Contrasted $^{87}Sr/^{86}Sr$ values are observed, groundwater collected in Pz5 and Pz6 (0.70851 to 0.70863) having a higher Sr isotopic signature than groundwater collected in Pz1, Pz3-4 and Pz17c (0.70792 to 0.70850). These two groups of piezometers are also distinguished on the basis of concentrations in dissolved elements and molar ratios. On a $^{87}Sr/^{86}Sr$ versus Mg/Sr diagram (Fig. 1c), groundwater samples lie more or less on a straight line, which clearly reflects mixing between at least 3 end-members. As previously discussed, the groundwater collected in Pz1, Pz3-4 and Pz17c is little affected by anthropogenic inputs and therefore lower $^{87}Sr/^{86}Sr$ values could reflect the main contribution of Sr coming from bedrock weathering. This interpretation is further supported by the low $^{87}Sr/^{86}Sr$ values measured for bedrocks representative of the Brévilles catchment lithologies (0.70747 to 0.70786). Groundwater collected in Pz5-8, Pz10 and Pz19 shows a gradual increase in both $^{87}Sr/^{86}Sr$ values and Mg/Sr ratio (Fig. 1c) from Pz19 to Pz5. Since Mg/Sr ratio discriminates between natural and anthropogenic origin, groundwater should also integrate Sr from anthropogenic origin with a $^{87}Sr/^{86}Sr$ signature higher than the range observed for all piezometers (0.70792 to 0.70863). Thus Sr isotopic investigation of groundwater in this catchment successfully demonstrated the capacity of Sr isotopes to trace fertilizer contribution, which significantly modifies the natural Sr isotopic signature of groundwater.

Furthermore, in Fig. 1b, three trends are observed corresponding to mixing between Sr from a lithological end-member, presenting low Mg/Sr ratio and variable Ca/Sr ratio (included in the range defined by end-members 2 and 3) and Sr from the anthropogenic end-member 1 with a Mg/Sr and Ca/Sr molar ratio higher

than, respectively, 400 and 2000. The lithological contribution in dissolved elements of the groundwater body collected by Pz4 and Pz17c corresponds to end-member 3. Mixing of this lithological end-member with increasing inputs of Sr of anthropogenic origin lead to the composition of Pz6, 7 and 19, whose groundwater compositions lie on the mixing trend 1. For trend 2, the lithological end-member is represented by the groundwater collected at Pz3 and the geochemical signatures of Pz2, 5 and 8 reflect increasing inputs of Sr from anthropogenic inputs. Groundwater collected at Pz1 corresponds to end-member 2. These groundwater geochemical relationships between sampling points are compatible with geophysical investigations that revealed a common hydrological compartment for each of the 3 groups of piezometers (3 trends) (Fig. 1a). Thus specific geochemical signature of groundwater revealed by Sr isotopes, in addition to major and trace element concentrations, demonstrated the partial isolation of groundwater bodies in this catchment.

The main result of this study is that isotopic signatures supply powerful tools to trace water pathways. Such approach, combined with hydrological studies, is of interest to improve the knowledge of the global functioning of aquifers in terms of hydrological and geochemical aspects.

This work is part of Integrated Project AQUATERRA 505428, FP6 European Union, and relate to FLUXES sub-program.

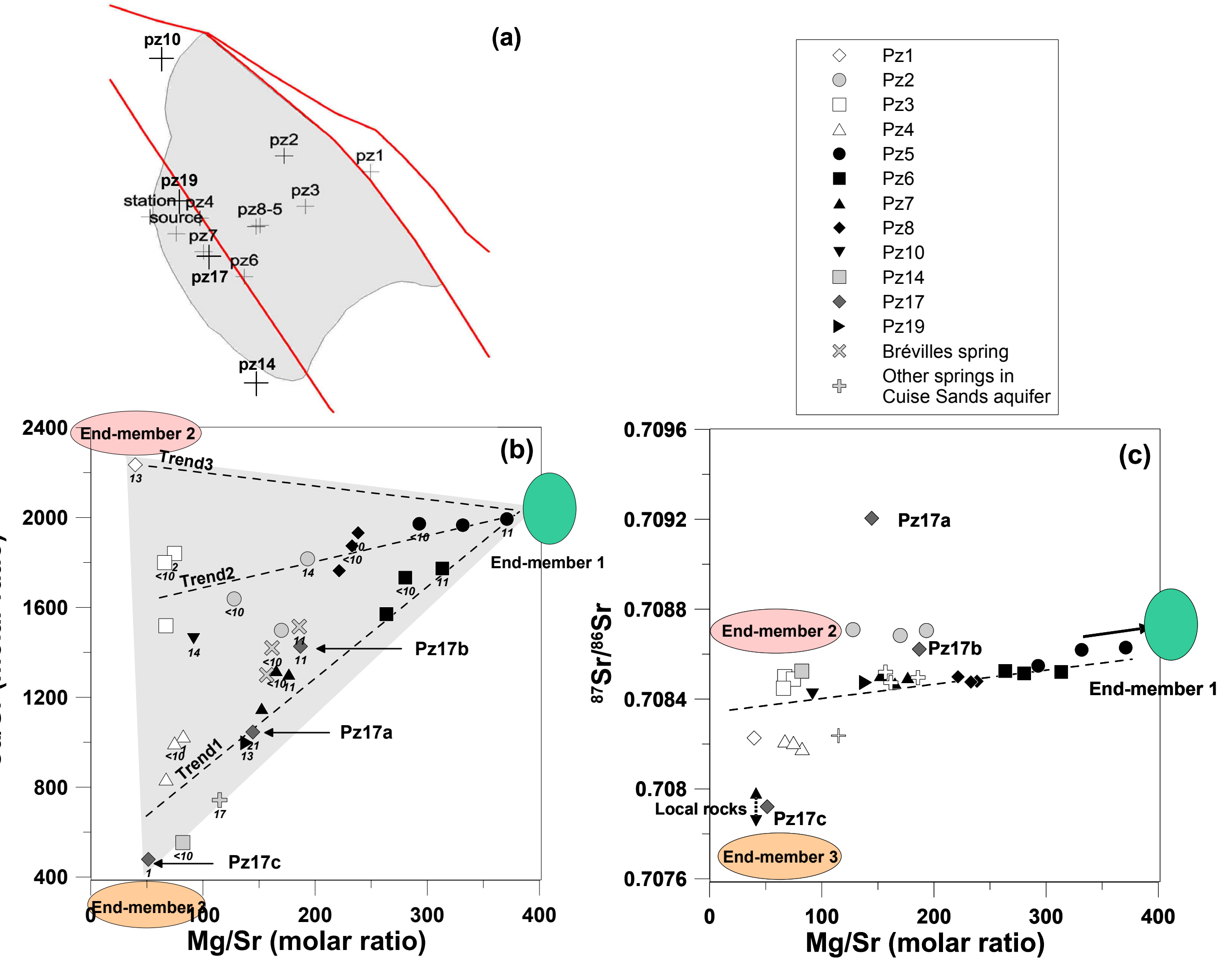


Fig. 1. Sampling points location, in grey the Brévilles catchment, in red the main faults (a) Ca/Sr versus Mg/Sr molar ratio, under script values correspond to Tritium values (b) and $^{87}Sr/^{86}Sr$ versus Mg/Sr molar ratio (c).

Böhlke and Horan (2000). *Applied Geochemistry* 15, 599-609.

Keywords: Sr isotopic compositions; tritium; groundwater; Cuise Sands Aquifer; fertilizers; water pathways.

Sulfur and strontium isotopic compositions of groundwater in the Adour-Garonne district (SW France): constraints interconnection and heterogeneities of water bodies

[1]Emmanuelle Petelet-Giraud, [1]Agnès Brenot , [1]Philippe Négrel, [1]Romain Millot, [1]Stéphane Roy, [1]Philippe Dutartre, [2]Isabelle Fournier

[1]BRGM, Avenue C. Guillemin, BP 6009, 45060 Orléans Cedex 02, France, E-mail: e.petelet@brgm.fr
[2]Agence de l'Eau Adour-Garonne 90, rue du Férétra, 31078 Toulouse cedex, France

ABSTRACT

The main objective of the Water Framework Directive (2000/60/EC) is to prevent further deterioration and protect and enhance the status of aquatic ecosystems in Europe. The success of the WFD will be mainly measured by the status of water bodies. Within the framework of the WFD, the research project Carismeau for multi isotopic and geochemical characterisation of water bodies in the Adour-Garonne district (SW France) is starting jointly between the French Water Agency Adour-Garonne and French Geological Survey (BRGM). Aims of this research project are to provide further characterization of the groundwater bodies which have been identified as being of primary importance and/or at risk in the Adour-Garonne district (1/5 of the French territory). For that purpose, combined geochemical analysis (major and trace elements), and isotopes ($\delta^{18}O$ and $\delta^{2}H$, $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$, strontium, boron, lithium, uranium and lead isotopes) are applied on one demonstrative water body named the Eocene sands aquifer. The ongoing research will set out to demonstrate the role of lateral variation of facies and the interconnections between aquifers. Aim of this contribution is to present the results of $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$.

Eocene sands water body is a multi-layer system composed by sandy Tertiary sediments alternating with carbonate deposits. In details, the Eocene aquifer system is constituted by at least four aquifer systems: Paleocene, Eocene infra-molassic sand, early Eocene, middle Eocene, late Eocene. The deposit sequences characterising the Eocene aquifer system are progradational westward, from detrital deposits to carbonates with evaporites domes (André, 2002). Groundwater recharge may occurs to the east by the edge of the Massif central, to the south by the edge of the Pyrenees and by inflow from the surrounding aquifers (Paleocene and Miocene aquifers). Waters were sampled during one field campaign in May 2006 in different types of borewells used for drinking water, irrigation, geothermal activities or groundwater quantity and quality survey in the frame of the WFD.

First results point out the extreme heterogeneity of water signatures between the selected water bodies but also within a same aquifer. Interpretation of $\delta^{18}O$ and $\delta^{2}H$ isotopes of the water molecule and strontium isotopes described in Negrel et al. (2007) are encouraging. Sr isotopes point out the extreme heterogeneity of water signatures between the selected water bodies but also within a same aquifer with values ranging from 0.7076 up to 0.7118. Present contribution objectives is to further discuss these interpretations in the light of the results of $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$ isotopic signature in order to constraint the origin of the water and the water-rock interactions.

Groundwater sulfates concentrations displayed large variations from 0.41µg/l to 961µg/l. For sulfates concentrations higher than 100 µg/l, the $\delta^{34}S_{SO4}$ values range between 12.6 and 31.3‰ (Fig. 1a). Gypsum values measured locally for upper part of the Eocene sands (mean value = 12.72 ± 1.2‰, André, 2002) and isotopic signature documented for evaporite of Eocene and Paleocene ages (17 to 22‰, Claypool et al., 1980), suggest that dissolution of evaporite layers is probably one of the upmost source of sulfates on the basin. Previous interpretations developed by Négrel et al. (2007) based on $^{87}Sr/^{86}Sr$ ratio also support that weathering of evaporite constitute an important source in dissolved element. The end-member representing evaporites defined by groundwater $^{87}Sr/^{86}Sr$ values around 0.7072 (Négrel et al., 2007) fully agreed with values of marine evaporites from the Eocene age.

Sampling points displaying sulfates concentrations lower than 31 µg/l and $\delta^{34}S_{SO4}$ values lower than 10‰ (Fig. 1a), suggest that other sources than evaporite dissolution occur on the basin. Atmospheric contribution may be a meaningful source as low concentrations in dissolved sulfates were measured. Local isotopic signature of rain water were not documented yet, but measured $\delta^{34}S_{SO4}$ values for groundwater (1.3 to 10‰) are compatible with published values for sulfates originating from atmospheric inputs (Jenkins and Bao, 2006). However, recorded $\delta^{34}S_{SO4}$ values also agree with oxidation of sedimentary sulphur that could be related to the mineralogy of Eocene infra-molassic sands. On Fig. 1a, for similar $\delta^{34}S_{SO4}$ values (1.3 to 10‰), $\delta^{18}O_{SO4}$ values discriminate two groups of sampling points: SIM-4 and SIM-9 ($\delta^{18}O_{SO4}$=2 to 4‰) and EM-1, EM-8 and EM-9 ($\delta^{18}O_{SO4}$=11 to 16‰). These two groups have been previously discussed by Négrel et al. (2007) with regard to $^{87}Sr/^{86}Sr$ ratio. As

illustrated on Fig. 1b, high $^{87}Sr/^{86}Sr$ ratio observed for SIM-4 and SIM-9 can be attributed to silicate weathering. On the other hand, EM-1, EM-8 and EM-9 (0.70836 to 0.70894) are most probably controlled by an end-member with $^{87}Sr/^{86}Sr$ ratio of 0.70900, that may corresponds to weathering Miocene carbonates as suggested by Négrel et al. (2007).

Recorded $\delta^{34}S_{SO4}$ values higher than 25‰ (25 to 39.8‰) suggest that one process controlling dissolved sulfates in Eocene aquifer system may be linked to the process of isotopic fractionation induced by bacterial reduction (Nriagu et al., 1991). Previous study by André (2002) also documented $\delta^{34}S_{SO4}$ values attributed to bacterial mediated sulfates reduction. The positive trend observed between $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$ values (Fig. 1a) and associated decrease of SO_4/Cl molar ratio would evidence that sulfates loss is associated with isotopic fractionation processes. This means that a conservative behaviour of Cl^- is supposed for a restricted part of the Eocene infra-molassic sands.

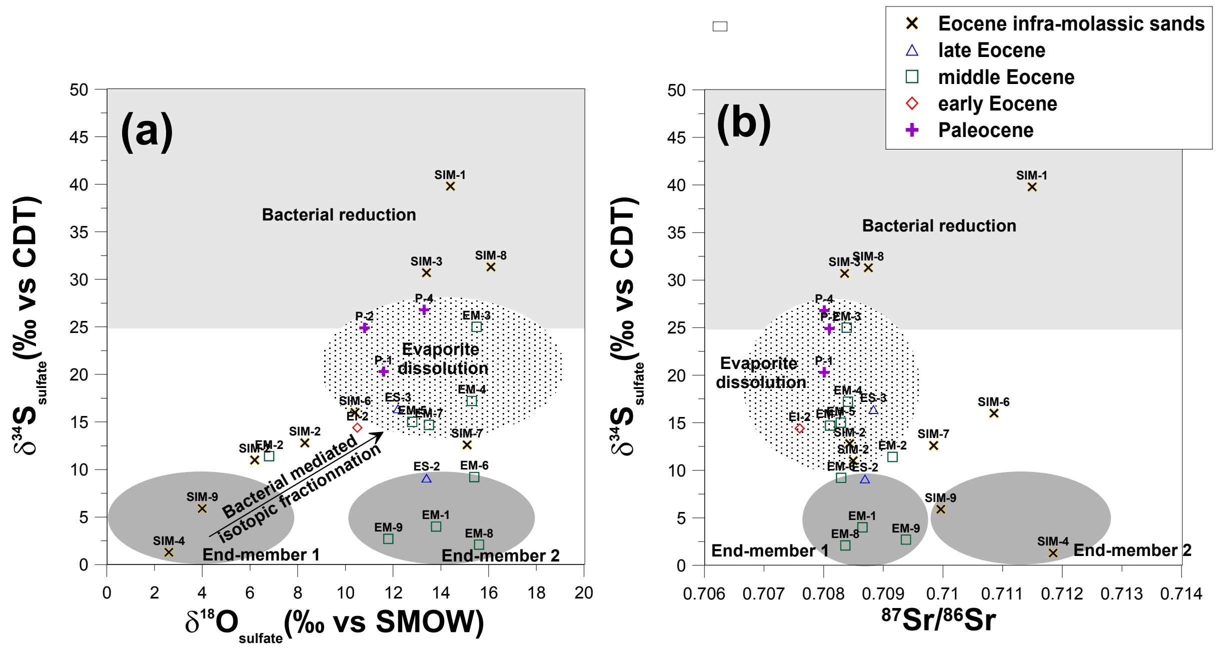


Fig. 1. $\delta^{34}S_{SO4}$ versus $\delta^{18}O_{SO4}$ (a) and $\delta^{34}S_{SO4}$ versus $^{87}Sr/^{86}Sr$ ratio(b).

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Keywords: Sulfate isotopic compositions; strontium isotopes; groundwater; Eocene sands water body; water-rock interactions

The partition of C-O-H-S isotopes in the Hermosillo coastal aquifer (Sonora, Mexico) in relation to natural processes, land cultivation and saline intrusion.

[1, 3]Anna SZYNKIEWICZ, [2]Miguel Rangel MEDINA, [3]Magdalena MODELSKA, [1]Lisa M. PRATT, [2]Rogelio MONREAL

[1] Indiana University, Department of Geological Sciences, 1001 E 10th Street, Bloomington, IN 47408
[2] Sonora University, Department of Geology, Mexico
[3] Wrocław University, Institute of Geological Sciences, Cybuslkiego 30, 50-204 Wrocław, Poland

ABSTRACT

In December 2005 and April 2006, chemical and C-O-H-S isotope analysis was carried out in 28 groundwater samples collected in a same number of wells in the coastal aquifer extending to the west from Hermosillo in the Sonora Desert. The main goals were to describe the origin of the groundwater, the influence of intense cultivation on water quality and the quantitative estimation of contamination by saline intrusion. The coastal aquifer has been extensively cultivated for 60 years. This has caused the formation of a deep depression cone and permanent contamination of groundwater system by marine water, which has penetrated up to 36 km toward the continent from the Gulf of California.

Hydrogen and oxygen isotope analysis showed that groundwater in the coastal aquifer originated from meteoric precipitation, as their H-O isotopic composition follows the general trend of Sonora Meteoric Water Line (SMWL). Sulfur isotope analysis in sulfates allowed us to classify at least three types of waters. Type 1 represents the groundwater sampled in the wells of cultivation area. This water has relatively low values of $\delta^{34}S$, from -2.12 to 3.25 ‰ and the highest O_2 content, average 6.64 mg/l. The relatively low values of $\delta^{34}S$ values in groundwater of type 1 suggests that sulfate isotope composition has been highly controlled by biological processes which might have taken place near or directly on the surface of the cultivated fields resulting from redox processes. This implies that the exchange of water between the aquifer and the pumped water infiltrating back to the ground is relatively fast and the currently pumped water has been already modified by agricultural activity. Before this infiltration to the ground, the pumped water stays on the cultivated fields for several hours. In general, this process involves partial evaporation followed by the increase of δD and $\delta^{18}O$, and the reequilibration of H-O isotope composition with water vapor in the air. Therefore, the groundwater of type 1 is significantly shifted to the right from SMWL and followed by the evaporative line experimentally determined in Apr 2006.

Type 2 is characterized by higher values of $\delta^{34}S$, from 5.21 to 8.71 ‰ and lower O_2 content, average 4.85 mg/l. Type 2 have been found in wells located in the ranch areas and Hermosillo city as well as in the Aconchi hot spring. Type 2 might have been represented by water not being significantly yet altered by agricultural activity as $\delta^{34}S$ of sulfate has shown the moderate values expected from arid environments, slightly enriched in sulfate by contribution of aerosol spray, and their H-O isotope compositions strictly follow the SMWL.

Concentrations of main ions in waters of type 1 and 2 are very diversified, but the observed positive correlations in the systems: SO_4-Cl, Na-Cl, K-Cl and $\delta^{34}S$-$\delta^{18}O$, $\delta^{34}S$ -δD, $\delta^{34}S$-Cl content, may suggest that a new portion of these ions, coming from the aerosol spray and/or the fertilizers, is being introduced to the aquifer. Moreover, the observed the highest percentage variability of cations relative to anions variability suggests that the process of cations exchange has taken place in the freshwater system of the Hermosillo coastal aquifer.

Type 3 represents the groundwater contaminated by saline intrusion, with the highest values of $\delta^{34}S$, from 14.19 to 20.39 ‰ and the lowest O_2 content, average 2.68 mg/l. In these waters the highest concentrations of chloride, sulfate and sodium ions have been observed. The chemical analysis of the main ions in type 3 water has shown that the intensive regular and inverse cations and anions exchange have taken place after contamination by saline intrusion. Based on isotope mass balance, it was calculated that the groundwater of type 3 is contaminated by saline water in a wide range, from 68 to 98 ‰.

Use of stable isotopes and chemical data to evaluate the fate of nitrate associated to an inactive cesspit in the unsaturated zone of the Adamantina Aquifer (Urânia, Brazil)

[1], [2]Claudia VARNIER, [2]Ricardo HIRATA, [3]Ramon ARAVENA

[1]Geological Institute, Environment Secretariat of the State of São Paulo. Av. Miguel Stéfano, 3900, CEP 043301-903, São Paulo (SP), Brazil, e-mail: clvarnier@hotmail.com
[2]Department of Sedimentary and Environmental Geology, Institute of Geosciences, University of São Paulo. Rua do Lago, 562, CEP 05508-080, Cidade Universitária, São Paulo (SP), Brazil, e-mail: rhirata@usp.br
[3]Department of Earth Sciences, University of Waterloo. 200 University Avenue West, N2L3G1, Waterloo, Ontario, Canada, e-mail: roaraven@sciborg.uwaterloo.ca

ABSTRACT

High nitrate concentrations, above the drinking water standard, have been found in several cities in the northwest portion of the State of São Paulo, Brazil. Groundwater is the main source of water supply of these cities and the use of cesspools was common in the past. The present work studied the impact of nitrate from an inactive cesspit on the unsaturated and saturated zones of the Adamantina Aquifer (Urânia, São Paulo), through the hydrogeochemistry of major ions (including the nitrogen series), minor ions, stable isotopes ($^{15}N_{NO3}$, $^{15}N_{N2O}$, $^{18}O_{NO3}$ and $^{18}O_{N2O}$), and gases (O_2, CO_2, N_2O and CH_4). The cesspit, which has been inactive since 2002, was monitored during three years after the construction of a monitoring station. The station consists of a 11.2 m deep dug well, in which 12 tensiometers and 12 suction lysimeters were installed from the surface down to the saturated zone (0.5-9.0 m), and a single monitoring well, at the bottom of the dug well. The chemical analyses of the water indicated high concentrations of nitrate, along the entire unsaturated zone (up to 458 mg.L^{-1} NO_3^--N). The concentrations of gases, isotopes and nitrogen species show a "zig-zag" behaviour, with peaks of concentration at the depths 2, 4, and 6 m. This behaviour seems to be associated with the intercalation of geological material with different hydraulic conductivities that can restrict the access of oxygen- and gases-rich waters along the less permeable material creating reducing zones (microcosms) among oxidizing ones. During humid periods, when the soil water content is higher, these depth intervals would present greater resistance to the leaching of solutes, due to their lower hydraulic conductivities compared to adjacent intervals (Fig. 1). As a consequence, the concentration of gases, isotopes and nitrogen species shows a "zig-zag" behaviour when they are compared to the dry season ones. However, during dry periods, the contaminant is transported away from the microcosms by molecular diffusion. During the wet periods, the contaminants are mixed with the water passing through the unsaturated zone, reducing the concentration of contaminants by dispersion (Fig. 1). A comparison between gas and nitrogen compounds, in association with the coexistence of reducing and oxidizing zones, suggests that N_2O is formed by denitrification. Strongly acidic environments (pH<5) and high nitrate concentrations inhibit the rapid denitrification and tend to hinder the formation of N_2 as the final product. The $^{15}N_{NO3}$ and $^{18}O_{NO3}$ data are also indicative of denitrification. The ranges obtained for $\delta^{15}N_{NO3}$ are from +6.80 to +30.09‰ (wet season) and from +9.54 to +23.25‰ (dry season); therefore, they are more enriched than the isotopic fingerprint expected for regular sewage nitrate (+8.1‰ to +13.1‰). The comparison of the results obtained by this study for $\delta^{18}O_{NO3}$ (-3.60 to 4.50‰), fractionation ratio of these isotopes (b=0.22), regression constant (a=-3.26), and linear regression coefficient (0.60) with the values reported by other authors reinforced the coexistence of denitrification and nitrification in the studied area. The signatures of $\delta^{15}N_{N2O}$ and $\delta^{18}O_{N2O}$ (-16.16 to -11.94‰ and 28.05 to 30.69‰, respectively), compared to values reported by other authors (-37 to -11‰ and -21 to +57‰), indicate that the N_2O detected in the area is produced by denitrification. It is worth emphasizing that the use of $^{18}O_{N2O}$ and $^{15}N_{N2O}$ isotopes is still a very new technique in hydrogeological studies, and more studies are needed to establish the isotopic fingerprints of the nitrification and denitrification processes, considering the different sources of nitrate contamination.

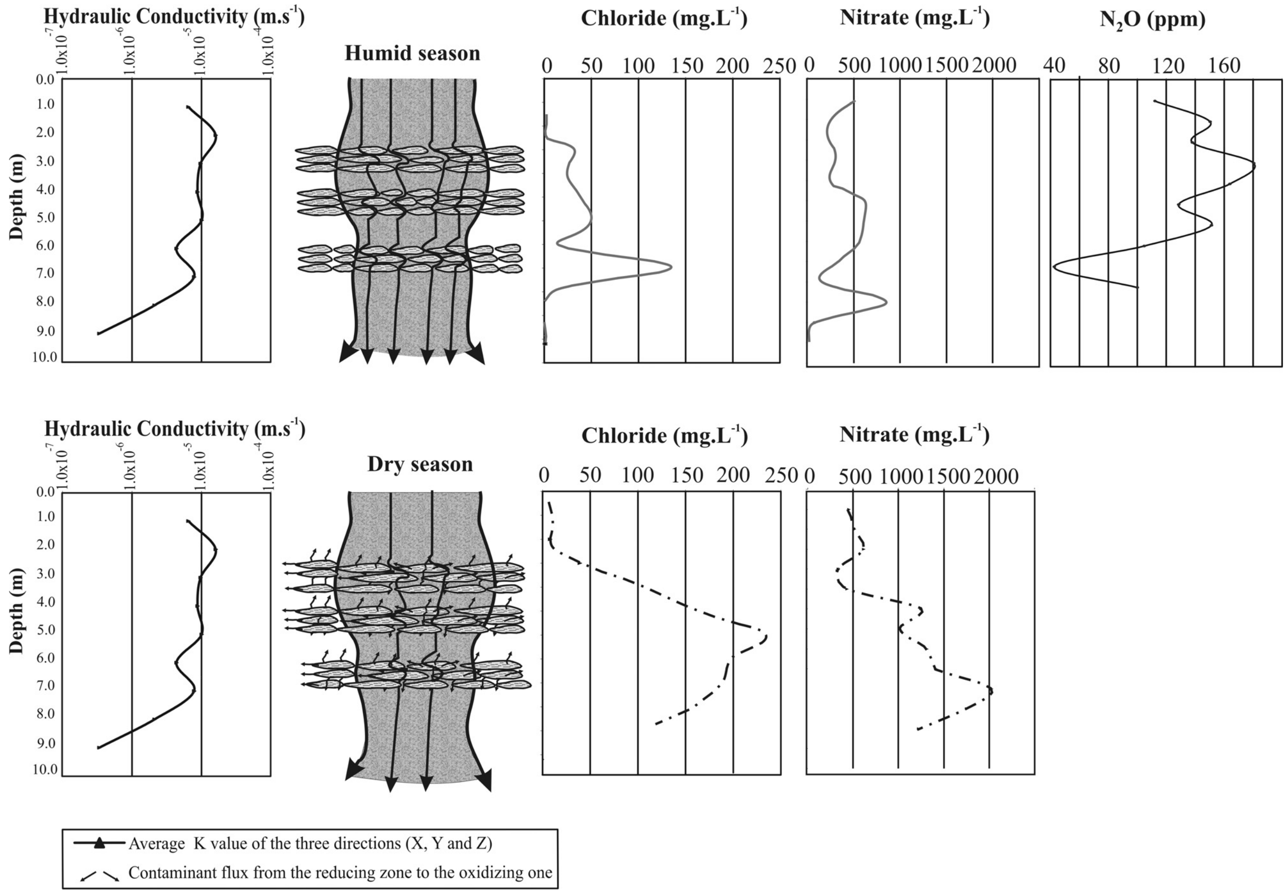

Fig. 1 – Relation between hydraulic data, gas and physico-chemical concentration profiles along the unsaturated zone

Keywords: unconfined aquifer, unsaturated zone, stable isotopes, gases, cesspit, nitrate.

TOPIC 14

Isotopic methods to assess groundwater dependent ecosystems

A study of the hydraulic conexion between different aquifers in Granada (Southern Spain) combining existing geological data with new information on hydrogeochemistry and environmental isotopes

[1]Elena PÉREZ, [2]Javier RODRÍGUEZ, [2]Francisca FERNÁNDEZ

[1] Centre for Experiments of the Ministry of Public-Works, Spain, e-mail: elena.perez@cedex.es
[2] Geological Survey of Spain, Spain, e-mail: jra@igme.es

ABSTRACT

The area under study is located in Andalucía (Southern Spain) and comprises the aquifers “Huéscar-Puebla de Don Fadrique” (050.013) and “Sierra de la Zarza” (070.037). The total surface is 567 km^2, of which 213 km^2 are permeable outcrops (mainly “Sierras”), 170 km^2 in the first aquifer and 43 km^2 in the second one. According to previous studies, these aquifers, composed of Jurassic dolomites and limestones several hundreds of meters thick, form the main mountainous ranges in this area and are independent of each other. Their contact is covered by some 75-80 m of Plio-Quaternary conglomerates, gravels and clays, which extend over an area called “Los Llanos de La Puebla”, where groundwater is used for irrigation purposes. A subdivision of the aquifer “Huéscar-Puebla de Don Fadrique” in two different sectors from West to East, at both sides of the Huéscar River, was proposed as well, based on the different behaviour of the discharges of two springs located in these two sectors. A conflict has risen recently between the use of groundwater in current irrigation plans and the important recreation and socio-economical role that the springs play for the inhabitants of this area.

A review of the existing geological and hydrogeological information about this area, combined with additional characterisation of the hydrogeochemical and environmental isotopic characteristics (^{18}O, ^{2}H, ^{3}H and ^{14}C) of groundwater, has aided better understanding of the geometry of the hydrogeological formations, controlled by the complex contact between the Prebetic and Subbetic structural domains in this area; and to propose an explanation to the similiarities and differences in the chemical (including environmental isotopic) characteristics of groundwater from the different sectors identified previously. The main aim of the study is to build a coherent conceptual hydrogeological model of this groundwater body that may help in the management of water resources in this area.

The area is located in the central part of the Betic Range, in the contact between the Prebetic and the External Zones of the Betics, represented here by the Subbetic covered by the Postorogenic Terrains that filled the intramountainous basins during the Upper Miocene-Quaternary. Based on a review of the geologic information of this area it is important to stress first that the materials that form the “Sierra de La Zarza” have been included in the Subbetic domain, in both the detailed 1/50.000 geologic maps (MAGNA series) and the descriptions made at the scale of the whole Betic Range. By doing so, these materials are distinguished from the Triassic outcrops located at the South of La Zarza, West of Topares, described as part of the Subbetic Chaotic Complexes. This means that the aquifer of “Sierra de La Zarza” may have some lateral and vertical continuity, and may not be as limited as the isolated carbonate blocks associated with the Chaotic Complexes. This observation, in addition to the fact that the mechanic contact between the Liassic and Triassic sediments in this area are subhorizontal, in addition to the limited thickness of the Triassic sheets observed between the Subbetic thrust sheets, allow us to hypothesize that the Liassic calcareous materials are connected hydraulically in N-S and E-W directions in this area. An important observation is that the superposition of the nappes of marls and calcareous materials, which constitute aquifers, gives a multilayered character of the aquifers in this area, reaching a total thickness of more than 1,100 m.

Regarding the sectors of the aquifer lying at both margins of the Huéscar River, the predominant marly composition (low permability) of the thick formation that outcrops in a large area between these two aquifers, as well as the presence of vertical faults located also between both aquifers, may justify some lack of hydraulic connection between these two sectors.

The hydogeochemical characteristics of the groundwater samples taken in “Sierra de La Zarza” are similar to the ones taken in “Los Llanos de La Puebla” and in the Eastern sector of Almaciles, and this supports the hypothesis of a hydraulic connexion between these materials. This conclusion seems to be also supported by the analysis of the hydrometric and piezometric information, as well as by the ^{14}C age of groundwaters found in this aquifer: 800 years for the water from “Bugéjar” spring, the main discharge point in this aquifer.

Regarding the subdivision of the aquifer “Huéscar-Puebla de Don Fadrique” in two different sectors, from the analysis of the waters from the two main springs in the area, the following observations can be made, and these are consistent with the observations made after the review of the geologic information:

- “Fuencaliente” spring, located in the Southernmost part of the aquifer “Huéscar-Puebla de Don Fadrique”, in the surroundings of Huéscar, is a natural discharge of this aquifer, evidenced by the similarities found between the chemical and environmental isotopic composition of the groundwaters and the discharges from the spring. A ^{14}C age of 4,347 years has been obtained for the waters discharging in “Fuencaliente”, similar to the age obtained for the groundwaters in the central part of “Los Llanos de la Puebla”. This is compatible with the existence of a groundwater flow pattern coming from the recharge in the carbonates crops of the “Sierras” of “Jureña”, “Tornajos” and “La Zarza” passing through the central part of “Los Llanos de La Puebla” to discharge in “Fuencaliente” spring.

- “Parpacén” spring waters are different from those of “Fuencaliente”. They have a lower content of total dissolved solids, indicating a lower grade of evolution in the aquifer. Thay are also depleted in ^{18}O and ^{2}H, probably due to precipitation occurring in the Northern mountains of “Sierra de Taibilla”. Tritium contents indicate some contribution frome waters infiltrated before the 50´s., and the hydrometric data show irregularities , highly influenced by the irregular precipitations in the area.

Keywords: hydraulic connexion, geological model, environmental isotopes, dating.

Deep Groundwater Exploration Methods: An Example from the Eastern Cape Province in South Africa

Lebogang NHLEKO

Council for Geoscience
P.O Box 572
Bellville South Africa
lnhleko@geoscience.org.za

ABSTRACT

Shallow boreholes drilled into fractured-rock aquifers throughout the Karoo, South Africa, have been found to be low yielding and sometimes unsustainable. Deep fractured aquifers therefore needed to be investigated for water supply to rural poverty-stricken areas.

Groundwater exploration methods are always changing and being refined. There is a general consensus that the more methods used during the exploration, the better.

For the fractured-rock aquifer case study site at Qoqodala (Eastern Cape, South Africa), several conventional methods and a few innovative ones were used. The area is characterized by the permo-triassic Karoo sediments intruded by Jurassic dolerites. The target was an inclined dolerite sheet proven to induce fractured aquifers also associated with deep groundwater occurrences. However, the hard dolerite has always been a deterrent for drillers and exploration scientists.

Among the methods used were:

- Geological mapping (including lineament and fracture mapping)
- High density airborne magnetic survey
- Geophysical profiling (TDEM)
- Exploration drilling
- Bore hole logging and video camera
- Down the hole geophysics (calipers, sonic etc.),
- Pump tests
- Injection test.

TDEM was very useful in detecting the deep dolerite structure and aquifers, and confirmed the geological cross section (confirmed by drilling).

Very high blow yields were intercepted at Qoqodala linked to the dolerite sill and inclined sheet. Recharge to the groundwater system is from orographic seasonal rainfall and was found to be good. The deepest borehole drilled during the exploration was more than 300m deep. The groundwater system was found to be characterized by deep aquifers that are not only extensive, but connected as well. The sustainability of these aquifers was proven through pump testing. However the vulnerability of the surrounding ecosystems must be taken into consideration.

Environmental isotopes (^{18}O, ^{2}H, and ^{3}H) as a tool in groundwater investigation in the Chad basin

[1]B. Ngounou Ngatcha, [2]F. Guillaume, [2]C. Leduc, [3]J. Mudry, [4]D. Djoret

[1] Department of Earth Sciences, Faculty of Science, University of Ngaoundéré, PO Box 454 Ngaoundéré, Cameroon, E-mail : ngatchangou@yahoo.fr
[2] UMR Hydrosciences, Université de Montpellier II, CC MSE, 34095 Montpellier cedex 5, France
[3] Department of Geosciences, University of Franche-Comte, F-25030, Besançon, Equipe d'Accueil n° 2642 « Déformation, Ecoulement, Transfert »
[4] Department of Geology, University of N'djamena, Chad

ABSTRACT

This paper reviews the available evidence of groundwater recharge in the shallow aquifer of the Chad basin in a semi-arid area. The Chad basin almost exclusively depends upon groundwater as a perennial source of water supply. Economic development of this region depends largely on the Quaternary aquifer. Sustainable use of groundwater must ensure, not only that the future resource is not threatened by overuse, but also that natural environments that depend on the resource, such as aquatic ecosystems, and wetlands are protected. Study of groundwater recharge processes is vital for quantification of total natural recharge to the aquifers, and for proper management of groundwater systems. Recharge mechanisms were investigated using environmental isotopes (^{18}O, ^{2}H, and ^{3}H). The recharge conditions have not changed noticeably since 1960. Direct recharge mainly proceeded from precipitation over the Quaternary deposits. Indirect infiltration occurs from the fluvial network (Logone, Chari) and non permanent rivers (Komadougou Yobe, El Beid, Mayo from Mandara Mountains). In the Chad basin, the rainfall that infiltrates had a weighted mean of –5 ‰ $\delta^{18}O$. The Chari river supports the level of the water table, and its isotopic content at N'djamena is about –2,5 ‰ $\delta^{18}O$. Systematic enrichment in $\delta^{18}O$ and $\delta^{2}H$ of groundwater shows the significant impact of evaporation under the semi-arid climate of the Chad basin. Tritium results in groundwater samples from the Quaternary water table gave evidence for ongoing recharge, with a mean of about 2 mm.yr^{-1}.

Keywords: Chad basin, Quaternary aquifer, groundwater recharge, environmental isotopes (^{18}O, ^{2}H and ^{3}H), aquatic ecosystems.

Groundwater abstraction and dependent ecosystems in Ljubljansko barje, Slovenia

[1]Brigita JAMNIK, [2]Janko URBANC, [3]Jasmina KOZAR LOGAR

[1]VODOVOD-KANALIZACIJA Public Utility, Vodovodna cesta 90, SI-1000 Ljubljana, Slovenia,
e-mail: bjamnik@vo-ka.si
[2]Geological Survey of Slovenia, Dimiceva ulica 14, SI-1000 Ljubljana, Slovenia,
e-mail: janko.urbanc@geo-zs.si
[3] Josef Stefan Institute, Jamova cesta 39, SI-1000 Ljubljana, Slovenia,
e-mail: jasmina.logar@ijs.si

ABSTRACT

Groundwater abstraction in the water field Brest in the immediate southern vicinity of Ljubljana, the capital of Slovenia, is an indispensable part of Ljubljana's drinking water supply. The area, a large wetland on the extreme south of the Ljubljana basin, is called Ljubljansko barje (Ljubljana marshes). By origin, it is a still active tectonic depression, filled by thick quaternary sediments. This unique landscape is a highly diverse and rich ecosystem. The marsh has been inhabited since pre-historic times and is today a cultural landscape, dominated by extensively managed meadows and cornfields. The main river, crossing the area from the west to the east, is the Ljubljanica. It enters the city from the south at its edge, but is not hydraulically connected to the exploited aquifers. Rare fauna and flora species have been found on the area.

This region yields approximately 10% (3.920.961 m^3 in year 2006) of the annual drinking water supply. Increased abstraction is planned in the near future. The area is sensitive to sinking, which can be caused by natural processes, but also other reasons should not be ignored: evenly distributed drainage channels, new settlements and road constructions, as well as groundwater exploitation for public and private usage. A higher abstraction will only be allowed if the research activities show that the influences on the environment are acceptable.

The amount of groundwater abstraction used for public water supply is presently limited to 148,5 l/s from the upper holocene aquifer and to 225 l/s from the pleistocene aquifer situated below the Iška river fan alluvial deposits. The Iška river is one of the main tributaries of the Ljubljanica. According to the present knowledge of the hydrogeological conditions, excessive abstraction from the pleistocene aquifer could be more harmful to the environment than the abstraction from the holocene aquifer. The lowering of the spring base flow at the foothills of the mountains that close the area from the south could be the main indicator of excessive exploitation of the aquifer.

The aim of the research activities that supplement the regular groundwater level measurements and measurement of the ground subsidence and form a data basis for groundwater modelling is to achieve a better understanding of the hydrogeological circumstances and hydrological regime in the area. The result of the long-term groundwater level measurements and geochemical composition will be combined with the recent measurements of the stable isotope composition (oxygen-18, deuterium) of groundwater and tritium content in different subaquifers of the Ljubljansko barje, surface waters and local precipitation.

Keywords: groundwater, stable isotope, tritium, drinking-water

Hydrogeological and Isotopical conceptual model of the groundwater in the Lacustrine area from the MV, Baja California, México.

[1]Enrique PORTUGAL and [2]Julio ÁLVAREZ

[1] IIE, Reforma 113, Palmira, Cuernavaca, Mor. México 62490: portugal@iie.org.mx
[2] Cerro Prieto, B.C., CFE. Carretera Pascualitos km 26.5 B.C., México: julio.alvarez@cfe.gob.mx

ABSTRACT

The ground waters system from Mexicali Valley (MV) is one of the largest aquifers in the northwest arid area of Mexico. Processes of salinization caused by evaporation and mixture with highly saline waters have been recognized, although, the amount of aquifers and their interaction is not well established and understood. The general flow direction is from east to west. Major aqueous species and stable (^{13}C, $^{34}S_{SO4}$, $^{18}O_{SO4}$, $^{18}O_{H2O}$ and D_{H2O}) and radioactive (T and ^{14}C) environmental isotopes have been measured in ground waters from MV; mainly in those located into and surrounding to the Cerro Prieto geothermal field area. The data were used to determine the aquifers and study the processes that affect their compositions. They show a wide range of the chemical and isotopic composition. Here we use a k-medias statistical model to define hydrochemical and isotopical waters grouping. This showed that the low mineralized waters from the eastern part enter the central part, where an older aquifer exists in lacustrine deposits. The low permeability of the area gives rise to a stagnant aquifer, which is at least partly surrounded by an interface zone, where mixing between waters from eastern part and central parts occurs. Tritium data in water of the eastern part support that these waters are modern recharge, whereas radiocarbon method revealed that the waters of the central and western part are an isolated system whose residence time is of 32 ka. The hydraulic, hydrochemical and isotopic data reveal the existence of at least three aquifers. This evidence is supported by the interpretation of the isotopes carbon.

Keywords: Hydrogeology, environmental isotopes, hydrochemical

Isotopic prospection in high vulnerability area of the Milano province (Northern Italy)

[1]Cristina ARDUINI, [3]Andrea DADOMO, [2]Giovanni MARTINELLI, [1]Giovanni PORTO, [3]Roberto SOGNI, [1]Andrea ZELIOLI

[1]Provincia di Milano, Corso di Porta Vittoria, 27 – 20121 Milano, Italy, e-mail: g.porto@provincia.mi.it a.zelioli@provincia.mi.it , c.arduini@provincia.mi.it
[2]ARPA Emilia Romagna, Via Amendola, 2 - 42100 Reggio Emilia, Italy, e-mail: giovanni.martinelli15@tin.it
[3]ARPA Emilia Romagna, Via via XXI Aprile, 48 - 29100 Piacenza, Italy, e-mail: rsogni@arpa.emr.it , andrea.dadomo@gmail.com

ABSTRACT

A hydrogeochemical prospection has been carried out in the Milano province with the purpose to better identify and characterize Nitrogen pollution sources. A network of 90 wells has been considered for geochemical prospection and 37 wells were also considered for isotopic survey. A geochemical stratification both in chemical characters and in isotopic ones has been identified and related to local pollution phenomena. The organic character of Nitrogen pollution phenomena has been identified and related to vulnerability characteristics of surveyed area. The obtained results allow improvement of previous vulnerability mapping methods.

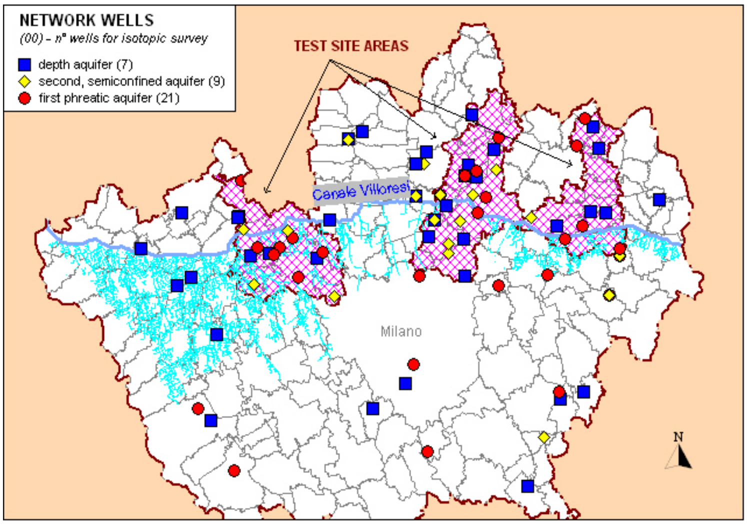

Fig. 1. Province of Milano - Sampling point area

Keywords: Hydrochemistry - Stable isotopes - Northern Italy

Recharge sources and evolution of groundwater in alluvial fan system, North of China: by isotopic and hydrochemical methods

[1,3]Fadong LI, [4]Qiuying ZHANG, [2]Changyuan TANG, [4]Akihiko KONDOH,
[4]Yasuo SAKURA, [5]Guoying PAN

[1]Graduate School of Science and Technology, Chiba University, Chiba 263-8522, Japan, lifadong@gmail.com
[2]Faculty of Horticulture, Chiba University, Chiba 271-8510, Japan, cytang@faculty.chiba-u.jp
[3]Centre for Agricultural Resources Research, Institute of Genetics and Developmental Biology, CAS, Shijiazhuang 050021, China
[4]Chiba University, Chiba 263-8522, JAPAN;
[5]Institute of Resources & Environment, Henan Polytechnic University, Jiaozuo 454000, China;

ABSTRACT

Most of cities in the world have developed an alluvial fan system. With the development of the economy and industry and the increase in population, quality and quantity of groundwater are reduced by over-exploitation. In order to address the problem of realistic assessment of groundwater resources potential and its sustainability, it is vital to understand the recharge sources and hydrochemical evolution of groundwater in alluvial fan systems. In March 2006, groundwater and surface water from local rivers were collected for major elements analyses and stable isotope (oxygen-18 and deuterium) compositions around the alluvial fan system in Xinxiang, northern China in semi-arid and semi-humid eco-environments.

In mountainous areas, the groundwater accepts the recharge of precipitation and is characterized by Ca-HCO3 with depleted $\delta^{18}O$ and δD (mean value of -8.8‰). Along the flow path from a mountainous area to an alluvial plain, the sources recharged into local groundwater become complex with water chemistry of mixed cation – mixed anion type, and heaviest observed were $\delta^{18}O$ and δD (around -8.0‰). Before the surface water, with a mean isotope value of -8.7‰, recharges into groundwater, it undergoes isotopic enrichment in the alluvial plain. Ion exchange and absorption effects are expected to the groundwater evolution in the flood plain. The transferred water from the Yellow River is the main source for groundwater in the flood plain in the south of the study area, and the stable isotopic compositions in groundwater, with mean values of -8.8‰, are similar to those of transferred water (-8.9‰) increasing from the southern boundary to the inland of the flood plain. The groundwater evolves from Ca-HCO3, Na-HCO3, to Na-SO4. The conceptual model, integrating Stiff diagram, is used to describe the spatial variation of recharge sources, evolution, and groundwater flow path in the alluvial fan aquifer system.

Keywords: groundwater recharge, evolution, hydrochemistry, stable isotope, Oxygen-18, deuterium, alluvial fan system

Study of the water recharge problematic in a semi-arid zone (climatic and anthropic impacts): The case of the Essouira aquifers system (Mogador, Morocco)

[1] M. BAHIR*, [2] P.CARREIRA, [3] M.O. SILVA, [2] P.FERNANDES

[1]. Laboratoire d'Hydrogéologie, Faculté des Sciences Semlalia, BP 2390, Marrakech, Morocco.
[2]. Departemento de Geologia, Faculdade de Ciências da Universidade de Lisboa, Lisbon, Portugal
[3]. Instituto Technologico e Nuclear, Sacavém, Portugal

* Corresponding author: Tél: 212 24 43 46 49; Fax: 212 24 43 74 11
E-mail address: bahir@ucam.ac.ma

ABSTRACT

A piezometric map of the Essaouira synclinal basin (Morocco) was realized. Different water samples have been collected from drillings, sources and wells belonging to the plioquaternary and turonian aquifers of the studied region. Their electric conductivity as well as $_{18}O$, $_{2}H$ and $_{3}H$ concentrations were measured. A meteoric local line was determined and compared to the world meteoric line. The radiocarbon ages of the studied aquifers were evaluated. The recharge of the main aquifers of the studied region was investigated. It has been shown by this study that the recharge rate of the deep turonian aquifer is too low.

This may cause a lack of water for supplying the Essaouira city and its region. Nevertheless, if we return to the drought context of the past years as prevented by the present world tendency, Moroccan authorities must envisage the building of small dams on the Ksob river for better management of flooding waters which are presently lost in the Atlantic ocean.

***Keywords**:* Plioquaternary and turonian aquifers, $_{18}O$, $_{2}H$, $_{3}H$ and $_{14}C$ isotopes, aquifer recharge.

Sulfate content, $\delta^{34}S(SO_4^{2-})$ and arylsuphatase activity in fresh soil and experimental soil cores - preliminary results

[1, 2]Anna Szynkiewicz, [1, 3]Magdalena Modelska, [1]Adriana Trojanowska

[1]Wrocław University, Laboratory of Isotope Geology and Geoecology, Cybulskiego 30,Wrocław, Poland
[2]Indiana University, 1001 E 10th St, Bloomington, Indiana 47405, USA
[3]Sonora University, Department of Geology, Hermosillo, So., Mexico

ABSTRACT

Between 2003 and 2005, the analysis of sulfate content and $\delta^{34}S$-$\delta^{18}O$ of dissolved sulfate has been carried out in the surface waters and groundwater of 14 km^2 large crystalline massif located in the Sudety Mountains (SW Poland). The important increase of sulfate content in waters under study during wet seasons (abundant in precipitation) compared to the lower content during dry seasons led to the conclusion that sulfate produced *in situ* has been probably intensively washed out from the soil by the infiltrating water from precipitation. The altitude dependence on $\delta^{34}S(SO_4^{2-})$ value (average -0.18 ‰/100 m) has evidenced that the sulfur isotope composition of sulfate under study has been mainly controlled by *in situ* processes regarding to the biological transformation and/or production of that sulfate in the zone of weathered rocks.

The role of biological transformation for sulfate input into waters under study is complex and difficult for tracing directly in the field, compared to anthropogenic or geogenic sources. Therefore, we incubated two soil cores 1 meter long to estimate the liberation, migration and loss of sulfate from the soil taken from the crystalline massif under study. The analysis of sulfate content, arylsulphatase activity and $\delta^{34}S(SO_4^{2-})$ value was done three times in 4 week intervals by washing out the soil profiles with double-distilled water.

The sulfate content varied from 1.04 to 2.51 mg dm^{-3} with one exception at the beginning of the experiment, when sulfate content reached values up to 4.90 mg dm^{-3}. The theoretical rate of sulfate release, was calculated and based on the activity of the arylsulphatase, varied between 1.44 and 1.92 $\mu g\ g^{-1}$ dw h^{-1} in the upper part of the soil core and between 1.92 and 2.52 in the lower part. The arylsulphatase plays an important role in the sulfur cycle in soil during organic matter mineralization and the activity of that enzyme derives the organic sulfates to surface soils. The observed increase of arylsulphatase activity at the beginning of the experiment suggests a general decrease of sulfate content in the incubated soil. The secretion of extracellular enzymes such as arylsulphatase may be evidence for the limitation of microorganisms in biologically available forms of nutrients, in this case SO_4^{-2}. The washing out of soil cores with double-distilled water caused a gradual migration of sulfate ions to the deeper parts of the cores and finally caused a loss of sulfate in the soil. Therefore, the increase of arylsulphatase activity was observed in both cores. Incubated soil contains about 11 % of organic matter being transformed by arylsulphatase to liberate sulfate ions. The highest enzymatic activity occurred in lower (deeper) parts of the soil in both cores, which might also have resulted from the washing effect causing the movement of that enzyme down the soil core.

$\delta^{34}S(SO_4^{2-})$ value showed distinctively lower values, from -0.56 to -068 ‰ compared to that observed in natural condition, from 4.09 to 5.28 ‰. This implies that other sources of sulfate, such as sulfur-bearing minerals in surrounding rocks, canopy throughfall and anthropogenic pollution significantly influence the observed amount and isotopic characteristic of sulfate in the catchment under study.

During the conference we will also present additional data from further experiments regarding the simulation of acid rain impact on incubated soil cores.

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TOPIC 15

GIS and remote sensing analysis for groundwater regional management

Assessing the Risk of Significant Damage at Groundwater Dependent Terrestrial Ecosystems in England and Wales

[1]Paul HULME, [1]Felicity MILLER, [1]Sarah EVERS, [1]Natalie PHILLIPS, [2]Andrew BROOKS, [3]Mark WHITEMAN, [2]Anna COHEN

[1]Environment Agency, Olton Court, 10 Warwick Road, Olton, Solihull B92 7HX, UK, e-mail: paul.hulme@environment-agency.gov.uk, felicity.miller@environment-agency.gov.uk, sarah.evers@environment-agency.gov.uk, natalie.phillips@environment-agency.gov.uk
[2]Entec, Canon Court North, Abbey Lawn, Abbey Foregate, Shrewsbury, SY2 5DE, UK, e-mail: BROOA@ENTECUK.CO.UK , COHEA@ENTECUK.CO.UK
[3]Environment Agency, Rivers House, 21, Park Square South, Leeds, LS1 2QG, e-mail: mark.whiteman@environment-agency.gov.uk

ABSTRACT

This paper describes the approach for assessing the risk of significant damage at groundwater dependent terrestrial ecosystems (GWDTE) in England and Wales.

The key elements of the approach are that it considers the risk of transmission of groundwater pressures, either quantitative or chemical, via the groundwater pathway to the wetland receptor and its potential subsequent impact on the ecology of the wetland.

In England and Wales the nature conservation bodies, Natural England and the Countryside Council for Wales, have selected over 1,300 sites that they suggest are dependent on groundwater. All of these sites are designated as Sites of Special Scientific Interest. Each site is scored for the likelihood that it is significantly damaged by considering ecology and hydrology, groundwater quantity and quality. The following nationally available data were gathered in a GIS system:

- Abstraction pressures
- Phosphate pollution pressures
- Hydraulic connection between the aquifer and wetland
- Dependency of the wetland plant communities on groundwater

From the GIS a ranked list of sites was produced based on the scores for likelihood of significant damage. Subsequently, these scores were modified at ten workshops across the country where hydrogeological and ecological experts presented local evidence and the initial scores were modified accordingly. At these workshops other pressures were considered including:

- Non-abstraction pressures, e.g. drainage of the groundwater body
- Non-phosphate pollution, e.g. nitrates, pesticides

This paper illustrates the approach with reference to a variety of individual sites across England and Wales.

Keywords: Groundwater, wetlands, ecology

Gis-based groundwater management: a case of Marche-Abruzzo regions (Italy)

[1]Gabriella RUGGIERI, [2]Clemente Folchi Vici D'ARCEVIA & [3]Torquato NANNI

[1] Groundwater management -LARA, University of Ferrara, Italy,
e-mail: rgggrl@unife.it; sistemambiente@tiscali.it;
[2] University of Ferrara, Italy, e-mail: tnn@unife.it

ABSTRACT

With the advent of new technology, techniques have changed our approach to managing natural resources in general and water resources in particular. The GIS is one of these techniques because it is a powerful tool for collecting, sorting, retrieving, transforming and displaying real-world spatial data. The advantage of representing data with GIS is firstly, the ability to display and analyze information within a geospatial context and secondly restoring all spatial data into one environment. The topic of the present paper is to describe a case of regional groundwater management using GIS system. The purpose of the project has been to gain representative information about aquifers in the regions in order to do water planning. The case of study is located in central part of Italy, more precisely Marche and Abruzzo regions. The area is more then 26000 km^2 and the data a result of more then six years of research. The aim is to collect all Hydrogeological data from other researchers, many workers at different scale and to insert into one informatic environment. In this way a Personal Geodatabase represents a logical and coherent structure that can manage a huge amount of data. The methodology applied is composed of five steps: data collections, data storing, building a Database, space analysis, processing and reprocessing data and output data trough thematic map. The basic data are organized and processed in single integrated environment into Personal Geodatabase. The "feature oriented object" and relational structure are a fundamental requisite for organizing Hydrogeological data and, enabling querying and applying functions on sets of data features which are logically connected through relationships (Maidment, 2002). The database is organized in 4 different features dataset: Geology, Hydrogeology, Hydrology, and Human Activities. For example, the hydrogeology dataset includes *complex* polygon features, *hydrostructure* polygon features, *spring* points and *increment* lines. C*omplex* and *hydrostructure* are fundamental for describing groundwater systems. Hydrostructure features are related to springs and increments through the relationship, which associates the camp "*number*" of springs or increments with the camp "*legend"* of an *hydrostructure* feature. So the hydrostructure feature resulted in an instrument of synthesis for a regional groundwater system. A surface characterization of the study area, is developed from the data that allows the analysis of anthropogenic effects and surface water hydrology. A subsurface characterization, is performed using a geologic and tectonics framework that allows us to identify important hydrogeological parameters and aquifer condition. The Hydrogeological characterization is performed to obtain hydrologic features such as recharge, vulnerability, permeability and chemical parameters. In particular data point as springs and wells give some information about local conditions and time-dependent parameters (hydraulic conductivity and hydraulic head). Moreover the database and GIS application

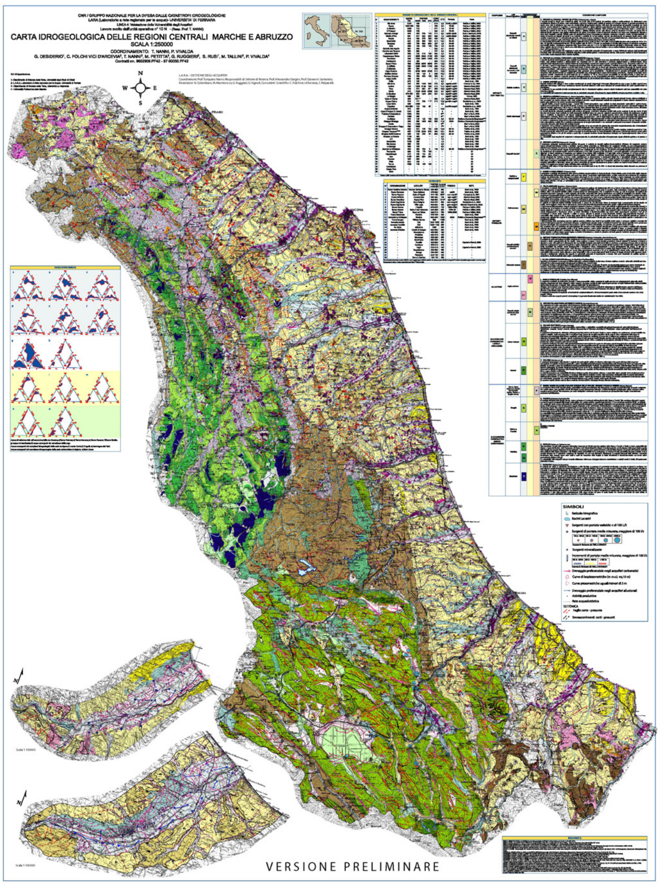

Fig.1: Hydrogeological map of Marche e Abruzzo regions (Italy)

were used to produce a hydrogeological map (Fig. 1) at the regional scale (1:250000). Through raster analyses we have identified an area with a high concentration of information and we have chosen it for the blow up. Furthermore the GIS allowed us to produce a report about the chemical analysis, and statistical diagram of the Hydrogeological parameters of springs and increments.

Keywords: Hydrogeology, GIS, Database.

Inventory of hydrogeological maps and models available in twelve European Geological Surveys. A contribution from project eWater to facilitate cooperation and exchange of hydrogeoscientific data.

[1]Juana LÓPEZ, [1]Margarita GÓMEZ, [1]Amalia DE MERA, [1]Fernando PÉREZ, [1]Román HERNÁNDEZ, [1]Alfredo IGLESIAS, [1]Javier RODRÍGUEZ

[1]Geological Survey of Spain, Spain, e-mail: j.lopez@igme.es

ABSTRACT

European countries are facing a challenge in defining Water (River Basin) Management Plans where groundwater is an important component. Groundwater is the only available source for water supply in many areas of the world, particularly in periods of severe drought, and this includes the southern European countries. Groundwater largely conditions economic development and is extensively used in agriculture. As something more recently valued, it does condition the health of the environment by providing the base flow of many rivers and wetland areas, and it plays a key role in maintaining these areas and the associated ecosystems during dry periods. European countries are also facing significant pollution of soil and groundwater resources caused by human activities in the past. Owing to the slow flow of groundwater compared to that of surface water, remediation is in many instances a long-term problem and its solution needs to be optimised in order not to deem cleaning extremely expensive and unaffordable.

The Water Framework Directive (WFD or Directive 2000/60/EC) establishes a framework for Community action in the field of water policy, and aims to protect and improve the status of the aquatic environment and promote sustainable water use, with an explicit mention of groundwater. The WFD is being implemented by involving a large number of working groups, experts and stakeholders who need to share some common basis of information. The importance of incorporating not only users of water resources in the decision-making process, also highlights how essential it is to make wide use of the knowledge available on groundwater from the experts.

The national Geological Surveys have been responsible for preparing hydrogeological cartography for decades, and now have an important role to play in managing the information on the geographical definition of the groundwater bodies, their hydrodynamic properties and their flow models. In many instances, the national Geological Surveys are responsible for the associated monitoring programmes.

Hydrogeological maps are synoptic representations of the rock-water system which provide information on groundwater and the hosting rock bodies in relation to the earth's surface. They form the base for legal and administrative issues because they define the spatial and temporal use of water resources. Hydrogeological maps have a long history and have evolved from geology-oriented paper maps to digital maps with modern display features. They have been produced from the information in projects and plans with different purposes and funding frameworks, and the result has been a variety of maps produced on different scales.

In recent years, the Geological Surveys of European Union member countries have had to take into account and adapt to INSPIRE (Infrastructure for Spatial Information in the Community). This initiative aims to harmonise the cartography existing in the EU to make it possible to analyse the metadata, and provide display and download map services. All member countries must meet the "interoperability" conditions required by INSPIRE in the medium term. The trend envisaged for the near future is to advance towards cross-border information systems.

The main objective of the project eWater is to increase the cross-border availability, accessibility and re-usability of spatial data on quality, location and use of subsurface waters. Geodata market research has shown that groundwater (hydrogeological) data is of great market demand, in second place in the rating list, immediately after the data on rock composition (lithology).

These data are currently stored in national databases and are available exclusively for the national user in the local language. Therefore, the hydrogeological data across the national borders form separated, uncorrelated, uninteroperable datasets. As a result, much of the hydrogeological spatial information is difficult to exploit in both the international and national water management contexts.

In order to achieve the main objective, the project will develop an internet system that will provide cross-border multilingual access to groundwater spatial datasets stored in the participating countries' national databases. The eWater Web portal will serve as a common gateway and meeting point for all those who have stakes in cross-border management issues, including the EC. It will undoubtedly help to meet the WFD requirements and promote a culture of participation. Sharing the information that eWater may manage will

facilitate the definition of the water bodies and their environmental impacts, the application of remediation technologies, and the incorporation of proper monitoring techniques into the system.

The eWater consortium consists of 12 European Geological Surveys (Austria, Denmark, Emilia Romana (Italy), France, Hungary, the Netherlands, the Czech Republic, Lithuania, Slovakia, Slovenia, Spain, and Sweden). These are data holders, providers and very often users, since they provide the governments with hydrogeological expertise for decision-making. The project also includes 3 commercial added-value data service companies. Their involvement will ensure that the eWater system will focus on external commercial end-users.

In order to provide a picture of all the hydrogeological maps that all the partners currently have, or may have in the near future (in the next two years during the eWater project) an inventory of hydrogeological maps has been built. The starting point was a rather complex and large amount of information that we were trying to structure and synthesise with the help of a Questionnaire designed for this purpose.

The results of the Survey conducted have provided a first glimpse of the hydrogeological maps available in the twelve project-partner countries, about half of the countries in the European Union. This information has been structured in a Database, from which any user may easily find important information describing the main initiatives done in this respect by the main organisations responsible for hydrogeological mapping in these countries. They will also obtain an idea of the efforts that are proposed in order to enhance interoperability at national and European level for this geographical information in the future.

This Database of hydrogeological maps provides information on their main characteristics regarding format (paper, digital: raster or vector), scale, coverage, legend (hydrogeological objects represented), projection system, metadata, and availability.

Major international efforts (WHYMAP - guide and standard legend for hydrogeological maps) have been shown to be valuable when small-scale views (e.g.: European) are pursued. This Standard Legend has also been successfully applied at large scales in many parts of the world. However, harmonisation requirements stemming from some larger scale cross-border projects with specific objectives and aimed at specific users need to be further refined. In most instances specific bilateral or multilateral projects need to be designed for this purpose. It must be stressed that such harmonisation initiatives are playing an important role as a mediating tool between hydrogeology specialists and the target audience, as several recent UNESCO initiatives on the Internationally Shared Aquifer Resources Management reveal. Project eWater, funded by the European Commission in the framework of the programme eContent plus, is aimed at contributing in this direction in the European Union.

Keywords: Hydrogeological maps, GIS, interoperability, hydrogeoscientific data, cross-border

Reasoning about geodatabase and advanced visualisation key role in calibration of complex 3D transient numerical models A case study after ESRI geodatabase, Tecplot and Feflow 5.3

[1]Ezio CRESTAZ, [1]Felice TATANGELO

[1] Snamprogetti SpA (ENI), Via Toniolo 1, 61032 Fano (PU), Italy,
e-mail: ezio.crestaz@snamprogetti.eni.it, felice.tatangelo@snamprogetti.eni.it

ABSTRACT

The current paper aims at discussing the major benefits of geodatabase and advanced visualization for the calibration and effective analysis/presentation of complex 3D transient flow and transport numerical models.
Geodatabase frameworks (i.e. Spatial Oracle, ESRI geodatabase architecture), support efficient management, querying and retrieval of both geographical and alphanumeric attribute data, while addressing traditional and further spatial data integrity failure risks. Most groundwater modelling environments support data linking to external geodatabase, in order to ensure consistency in model building process.

Advanced visualisation plays a major role too in supporting groundwater modelling building, calibration and investigation process, any further analysis in the framework of ESDA (Exploratory Spatial Data Analysis) principles and effective presentation at a more mature application deployment stage.
This paper addresses the above issues at calibration stage in a FEFLOW 5.3, ArcGIS and Tecplot environment, focusing on large 3D time-dependent data set, involving complex spatial and temporal querying, automation of observed vs. computed data at both steady and transient states, and computation exporting to Tecplot visualisation environment.

The above approach is briefly reviewed in the framework of an application case study focused on groundwater remediation in density dependent conditions.

Keywords: hydrogeology, groundwater modelling, geodatabase, visualisation, FEFLOW

Remote sensing upscaling of sap flow measurements for transpiration mapping in the Botswana Kalahari

[1]Diana CHAVARRO, [2] Jean ROY, [3] Maciek LUBCZYNSKI

[1]P.O. Box 6, 7500 AA Enschede, The Netherlands, e-mail: chavarro@itc.nl
[2] Formerly ITC, jeanroy_igp@videotron.ca
[3] P.O. Box 6, 7500 AA Enschede, The Netherlands, e-mail: lubczynski@itc.nl

ABSTRACT

Tree transpiration is an important component of water cycle. In arid and semi-arid environments, it can be critical. Groundwater balances often are the most unknown component. It was proved by tracer experiments in the Kalahari, groundwater can be discharged in the form of transpiration by tree rooting systems from more than 70 m depth through a process known as hydraulic lift. Hydraulic descend and reverse root sap flow also takes place after short periods of soil moisture availability when shallow roots direct the water to the deeper layer to keep it far from neighbouring vegetation. Sap flow measurements in tree stems collected in such ecosystems are susceptible to misinterpretations due to the complex soil-water-tree interactions that are the result of adaptation mechanisms.

For the identification of transpiration patterns in the Botswana savannah vegetation, ten species were measured with regard to sap velocities using Thermal Dissipation Probes (TDP). Detailed investigation of the existence of natural thermal gradients (NTG) was carried out for four of the studied species. Non-powered measurements with TDP showed that such gradients can be as large as five degrees during the night, misleading the estimated sap flow up to 100% during the most critical periods. To correct TDP measurements for NTG effects a methodology based on an intermittently powered mode was implemented. The short intervals were extrapolated to infinite time to retrieve steady stage conditions after which the standard calibration to obtain sap flow could be used. The method was validated by a novel verification experiment that includes high resolution measurements of the water consumption. Results confirmed that TDP measurements corrected for NTG are more realistic and therefore can be used in reliable assessment of transpiration mapping. Simultaneous sap velocity and volumetric measurements of transpired water contributed to the identification of non-standard transpiration related features as night-time sap flow, tree water storage and possible reverse sap flow.

Corrected sap flow measurements per species were correlated with biometric characteristics of the trees for the development of upscaling functions. Such correlations were applied to a classified high resolution satellite images from which a transpiration map was obtained. Due to the heterogeneity of the Kalahari savannah vegetation, advanced GIS and RS techniques had to be used for the identification of individual species. The resulting transpiration map of the region was implemented in the local water balances for the quantification of long term water availability.

Keywords: Tree transpiration, TDP, NTG, upscaling, GIS.

Subsidence faults as input of groundwater contaminants in Irapuato Mexico

[1] Ramiro RODRIGUEZ, [1] Isaias RODRIGUEZ and [2] Hector HERNANDEZ

[1] Geophysics Institute, Universidad Nacional Autónoma de México. Mexico. acuifero@gmail.com
[2] Technical Council of Water, COTAS. Mexico. hectorhhh@gmail.com

ABSTRACT

Subsidence can be provoked by groundwater abstraction. Intense extraction regimes in semi arid zones affecting aquifer systems composed of aquitards induce land subsidence. These differential movements cause fractures and faults.

In Irapuato City, central Mexico, 15 fault systems, 25 Km length, have been reported. More than 200 houses show damage. The accumulated land displacement is 2.2 m in about 8 years. The Irapuato water supply depends on groundwater.

A groundwater monitoring was carried out. Arsenic, fluorine, ethylbenzene and toluene were detected. The arsenic is from natural origin. The highest As concentration is 0.33 mg/L. Wells with high temperature, 40 to 50^{o}C, contains F concentrations over the Mexican standards for drinking water, 1,5 mg/L.

An aquifer vulnerability mapping has been done using the SINTACS method. A 50m network was defined. Faults influence area was considered. The vulnerability assessment was incorporated to a GIS. Faults and fractures increase aquifer vulnerability.

The fault subsidence in urban areas can act as input for surface contaminants. Along faults there is a fast infiltration of rainwater and leakages from pipelines and sewage. Toluene is correlated with faults and gas stations.

The GIS facilitates groundwater management alternatives to avoid and reduce subsidence velocities. Some GIS-based alternatives are analyzed. In the urban area there are more than 100 agriculture wells. Their contribution in the subsidence processes must be greater than the urban abstraction. The municipal authorities are considering their closure.

Keywords: subsidence, aquifer vulnerability, SINTACS, Irapuato

Surface Parameter Mapping Derived from Earth Observation Sensors for the Study of Groundwater Recharge

[1]Stéphane CHALIFOUX, [2]Richard FERNANDES, [1]François CHARBONNEAU, [2]Rasim LATIFOVIC, [3]Eric GRUNSKY, [1]Sylvain LEBLANC

[1]6767 Route de l'Aéroport, St-Hubert, Québec, Canada, J3Y 8Y9, e-mail: Stephane.Chalifoux@NRCan.gc.ca, Francois.Charbonneau@NRCan.gc.ca, Sylvain.Leblanc@NRCan.gc.ca
[2]588 Booth Street, Ontario, Canada, K1A 0Y7, e-mail: Richard.Fernandes@NRCan.gc.ca, Rasim.Latifovic@NRCan.gc.ca
[3]615 Booth Street, Ontario, Canada, K1A 0E9, e-mail: Eric.Grunsky@NRCan.gc.ca

ABSTRACT

The Groundwater Mapping Program is a Natural Resources Canada (NRCan) response to an emerging issue, in particular increasing government needs for science advice in the management of Canada's water resources. The Groundwater Mapping Program is advancing the National Groundwater Inventory (NGWI), to the point where decision-makers will have access to sound science advice in the form of a robust information base.

Groundwater recharge to the regional aquifers (Fig. 1), a key element of the NGWI, generally takes into account daily climate data, soil physical properties, vegetative growth and density as well as surface drainage properties. Land use and land cover (LULC) mapping, leaf area index (LAI) product and soil properties characterization are indispensable information for the estimation of water-balance parameters used in recharge modeling. The use of Earth Observation (EO) data to extract information is a practical approach because of their extensive coverage and relatively low purchase and processing costs.

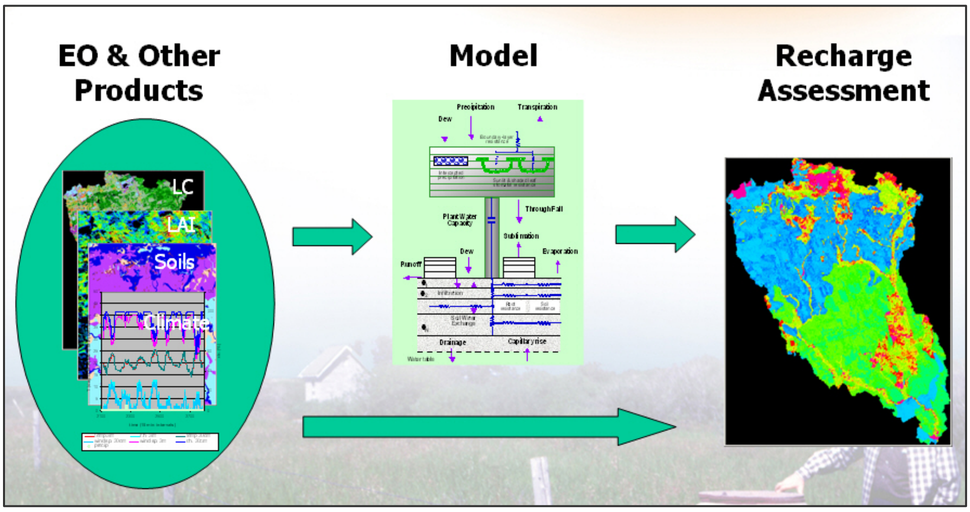

Fig. 1. Recharge assessment: Technical Aspect.

Remote sensing experts are focusing on extracting LULC information and LAI, and on mapping soil conditions using EO technologies. NRCan developed standard survey approaches that produce a relatively consistent level of information regarding confidence in map products. These approaches produce, from operational mapping methods using optical satellite images, validated regional map of land cover and leaf area index. NRCan is also developing new surface parameter products through modern earth observation sensors. This research activity aims at developing methods and prototype products for mapping specific land surface (orchard) and soil conditions (moisture pattern and permeability) using RADAR sensors in order to improve or support recharge modeling.

Keywords: Remote sensing, surface parameter mapping, recharge modeling

Vulnerability assessment and application of remote sensing - Groundwater resource analysis of National park "Tara"

[1] Igor JEMCOV, [1] Vladimir ŽIVANOVIĆ, [3] Saša ČOLIĆ, [1] Saša MILANOVIĆ, [3] Branislav TRIVIĆ,

[1] Department of Hydrogeology, Faculty of Mining and Geology, Djušina 7, Belgrade, Serbia, e-mail: jemcov@gmail.com, v.zivanovic@rgf.bg.ac.yu, sale@rgf.bg.ac.yu, milanovicsasa@sezampro.yu
[3]Department of Geology, Faculty of Mining and Geology, Djušina 7, Belgrade, Serbia, e-mail: sale@rgf.bg.ac.yu

ABSTRACT

National Parks are often faced with a problem - how to maintain the balance between tourist growth and their protection. For that reason assessment of the vulnerability of karst groundwater is important for establishing a basic document for planning, protection and proper defining of the National Park boundary.

National Park Tara represents a typical karstic groundwater system of Dinarc karst in Western Serbia, developed in Mesozoic (mostly Triassic Cretaceous) limestones, surrounded by Palaeozoic impervious rocks. Although the National Park is under protection of the state, there are many violations of the natural balance.

This paper describes a typical resource vulnerability assessment in karst areas and for this the EPIK method was applied (Fig.1). Faced with lack of data, characterising some EPIK parameters was improved by using Remote Sensing of Satellite imagery, by applying different procedures of processing of images and comparing them with field measurement data. This was done to characterise most of the parameters of EPIK method, especially geological, vegetation and soil properties. Furthermore, in order to evaluate the influence of each parameter on the vulnerability assessment, parameter sensitivity analysis was obtained.

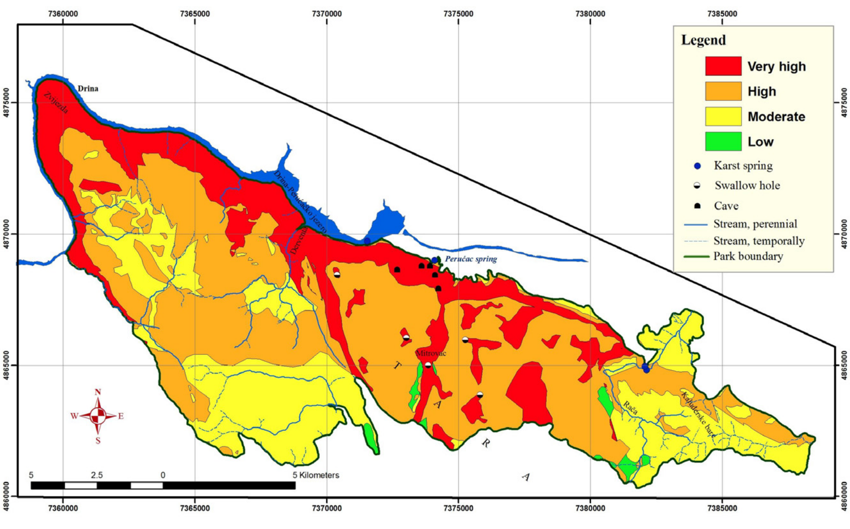

Fig. 1. Vulnerability map of the National Park „Tara“.

Keywords: National Park, karst aquifer, vulnerability assessment, remote sensing.

TOPIC 15

GIS and remote sensing analysis for groundwater regional management

Aquifer vulnerability assessment in a volcanic environment. Yuriria, Mexico

[1] Raul MORALES and [2] Ramiro RODRIGUEZ

[1] Earth Sciences Posgraduate Prog., Universidad Nacional Autonoma de Mexico, Mexico.
raulmoralesescalante@yahoo.com.mx
[2] Geophysics Institute, Universidad Nacional Autónoma de México, Mexico. acuifero@gmail.com

ABSTRACT

The pollution of groundwater is a problem that affects numerous regions in the world. In Mexico this situation is related to the by-products of various activities such as the agriculture, different industries and urban activities among others, particularly when these residues come into contact with materials with very high permeability. The results of these studies are becoming strategic tools for the development and location of productive activities in the studied area.

Volcanic rocks environments represent very vulnerable regions due to their partial constitution by fractured rocks where the pollutants can move easily and quickly. It is in these cases that the capacity of self-purification of the subsurface is almost non-existent.

This type of media is frequently found in Mexico, particularly in its central region where an intense human activity is developed. The Yuriria Lake and its hydrological basin is located within this lake, and this is a clear example of an area that contains aquifers whose water is vulnerable to contamination because it contains bodies of superficial water intensely contaminated, extensive zones of agricultural irrigation, urban zones, textile industries, different infrastructure such as gas stations, and landfills, among other potential sources of contamination.

In Yuriria the SINTACS method was used. A vulnerable zoning was obtained permitting the identification of the zones that should be protected in order to avoid or reduce the contamination of groundwater. Results were incorporated to a GIS. The GIS permits the analysis of different development scenarios for the area.

Keywords: aquifer vulnerability, SINTACS, GIS, Yuriria

Assessment of groundwater contaminant susceptibility at Porto urban area (NW Portugal): a multidisciplinary approach

[1,2] Maria José AFONSO, [1,2] Helder I CHAMINÉ, [3] Laura GUIMARÃES, [3,4] Lúcia GUILHERMINO, [5] José M MARQUES, [6] Paula M CARREIRA, [7] Paulo E FONSECA, [1,2] José MARTINS CARVALHO, [2] Ana PIRES, [2] Fernando T ROCHA

[1] Dep. Engª Geotécnica, Instituto Superior de Engenharia do Porto, Portugal, mja@isep.ipp.pt
[2] Centro de Minerais Industriais e Argilas, Universidade de Aveiro, Portugal, frocha@geo.ua.pt
[3] CIIMAR/CIMAR-LA, Laboratório de Ecotoxicologia, Porto, Portugal, lguimaraes@cimar.org
[4] ICBAS, Dep. Estudos de Populações, Lab. de Ecotoxicologia, Univ. Porto, Portugal, lguilher@icbas.up.pt
[5] Instituto Superior Técnico, Universidade Técnica de Lisboa, Portugal, jmmarques@mail.ist.utl.pt
[6] Instituto Tecnológico e Nuclear, Sacavém, Portugal, carreira@itn.pt
[7] Dep. Geologia, Universidade de Lisboa, Portugal, gpetfons@fc.ul.pt

ABSTRACT

Groundwater is an important mechanism that transports contaminants from release points to locations of human and ecological exposure. Therefore, the potential sustainability of a given urban region is greatly reduced even if the surface waters and groundwaters are not used as a human resource. Sources of contamination can include human activities performed primarily on the surface that release toxic substances into the environment. Urban aquifers are therefore vitally important but very fragile, easily damaged, and could take a long time to repair and restore. Biological and chemical quality damage is generally considered a characteristic of groundwaters abstracted from aquifers in/or around urban areas. The increasing worldwide pressure on water resources under conditions of global anthropogenic and climatic changes often requires an integrated multidisciplinary approach to address the scientific issues involving water resources.

This paper presents an environmental approach applied to the surrounding area of Paranhos spring galleries catchworks (Jardim de Arca d'Água – Largo de Alberto Pimentel sector, *ca.* 3km long and at -25 m depth b.g.l), located in Porto City (Fig. 1).

Fig. 1. Paranhos spring galleries catchworks. Porto urban area (NW Portugal).

These waters constituted for more than five centuries one of the main water supplies to Porto city. Therefore, the following steps were performed:

i) For the characterisation of the underground area, subsurface geological and hydrogeological mapping (scale 1/1.000) was applied. The crystalline bedrock of the study area consists mainly of granitic rocks, representing the so-called Porto granite *facies*: two-micas, medium- to coarse-grained, deformed, greyish in colour, changing to yellowish when weathered. In addition, fieldwork surveys permitted the identification of major tectonic accidents responsible for groundwater circulation paths and to assess lithological and structural heterogeneities;

ii) Hydrogeochemical, isotopic and ecotoxicological techniques were used for the description of groundwater quality (16 sampling sites have been selected: April to June 2005). The hydrogeological fieldwork campaigns included *in situ* determinations of temperature (ºC), pH and electrical conductivity (μS/cm). With regard to hydrogeochemistry, most of the sampled groundwaters presented near-neutral pH values (median = 6.78, the lowest rate being 5.35 and the highest 7.9). Regarding the electrical conductivity, most of the samples presented medium electrical conductivities (median = 434 μS/cm), with a minimum value of 405 μS/cm and a maximum of 530 μS/cm. Reaching chemical signatures, most of the studied groundwaters are "mixed" SO_4^{2-}/Cl^- - Ca^{2+}/Na^+ waters. The majority of these waters exceed the maximum admissible value (50 mg/L) for nitrate and the SAR (sodium adsorption ratio) plot of groundwater signatures showed that these waters have a medium salinity and low sodium concentrations. Concerning isotopic methods, the techniques employed were δ^2H and $\delta^{18}O$ in water, in combination with major and trace hydrogeochemical indicators. Two main water groups could be identified along the Paranhos spring galleries catchworks. The first one presents an average isotopic composition of $-5.33^{o}/_{oo}$ and $-33.5^{o}/_{oo}$ in ^{18}O and ^2H, respectively; the second group is composed by more depleted groundwater samples (by about $1^{o}/_{oo}$ in oxygen-18 and around $7.5^{o}/_{oo}$ in deuterium). The first group represents groundwaters collected along gutter sampling points in the Paranhos spring galleries catchworks (see Fig. 1). The second group corresponds to groundwater samples colleted from the granitic fractures along the galleries. The ecotoxicological evaluation was performed with standard acute bioassays with *Daphnia magna*. Mortality recorded in control solutions was less than 5%. No mortality was recorded at the lowest concentrations of groundwater in any of the tests, whereas occasional lethality, always around or below 10%, was recorded at concentrations greater than 25% effluent;

iii) An inventory of surface potential sources of contamination occurring in the surrounding areas of the galleries catchworks was performed, in order to evaluate groundwater degradation conditions, recurring to geographical information system tools. Most of the contamination sources were mapped as being point sources; nevertheless some of them were considered to be diffuse and line sources. The greatest potential problems are the leaking underground storage tanks, spills of hazardous materials, garages, ventilation shafts, and latrines. Moreover, several abandoned domestic wells are assumed to exist within areas now served by municipal water systems.

This methodology proved to be valuable in expanding our understanding of the susceptibility of Porto City groundwater systems. In addition, it can provide guidelines for the planning and management of water resources exploitation in an equitable, sustainable and ethical manner. In particular, geoenvironmental and ecotoxicological studies are required to assess potential variations in water composition and toxicity associated with seasonal changes in climate and human activities. Multidisciplinary approaches probably offer the best starting point for reliable groundwater and surface water studies and for assessment of geospatial parameter's variability, such as, lithological heterogeneity, structural geology features, hydrogeology and hydrobiology of a specific site.

Keywords: Groundwater, hydrogeological mapping, urban areas, GIS, NW Portugal

Change of transmissivity of shallow hard-rock aquifers induced by climate change – GIS approach

[1]Zdeněk VILHELM, [2]Zbyněk HRKAL, [3]Emílie NEDVĚDOVÁ

[1]Charles University in Prague, Department of Hydrogeology, Albertov 6, Praha 2, Czech Republic, e-mail: Zdena_@centrum.cz
[2]Water Research Institute, Podbabská 30, Praha 6, Czech Republic, e-mail: zbynek_hrkal@vuv.cz
[3]Charles University in Prague, Department of Hydrogeology, Albertov 6, Praha 2, Czech Republic, e-mail: Emia@seznam.cz

ABSTRACT

Impact of global climate change on water resources has not been regarded as a serious problem in the Czech Republic until recently. However, catastrophic floods in 2002 that struck almost one third of the whole territory of the Czech Republic and a subsequent three-year period of relatively intense drought have drawn attention to this topic. More than 60% of the territory of the Czech Republic is built of crystalline complex, especially metamorphic and plutonic rocks, which form the terrain of upland regions.

From the point of view of management of the drinking water supplies, the above-mentioned area is characteristic of a fairly uniform aquifer structure. Accumulation and circulation of groundwater occurs in a relatively shallow aquifer zone formed by delluvial Quaternary sediments horizon and underlying zone of weathered and fractured crystalline rocks. The aquifer zone extends for a variable depth below surface up to several tens of metres – the mean thickness is from 20 to 30 m below surface. Under common climatic conditions, higher total precipitation and high hydraulic gradients caused by the rough morphology of the aquifer result in extensive and dynamic groundwater circulation. The range of groundwater discharge in mountainous areas often varies between 8 and 15 $l/s/km^2$. However, this environment has a low accumulation capacity and is therefore more sensitive to prolonged periods of reduced atmospheric precipitation than aquifers with deeper basin circulation. Therefore, any delay in precipitation results in a rapid decline in yields of groundwater exploitable from the shallow aquifer. For this reason, this research was led to assess this phenomena caused predominantly by increasingly uneven distribution of precipitation, massively induced by climate change.

Two mountainous catchments in Šumava and Krušné Hory were instrumented with monitoring wells, and water levels and temperatures were measured hourly as well as meteorological data and stream flows. Major differences between infiltration and drainage areas were observed in water level decline as the effect of prolonged periods of drought. The data served for designing and calibration of hydraulic models of individual catchments. Applied coupled climatic models of atmosphere and ocean circulation models (AOGCM) in combination with local climatic models were applied to obtain climatic predictions for the Central Europe region. Based on these predictions, the transmissivities modified by the effect of predicted climatic changes were assessed. The major effect of prolonged periods of drought was observed as the water levels in infiltration areas dropped almost by 10 meters, which is in agreement with field observations.

Finally, the results of the hydraulic models were upscaled and adjusted to morphological, landuse and geological characteristics of neighbouring catchments. Using the GIS software, the data were processed and regional maps of transmissivity of shallow aquifer for the predicted scenarios of climate change were obtained. Resulting maps show that climate change, which may result in reduced precipitation and infiltration may pose serious water management problems in the environment of hard-rocks build regions. Shallow near-surface aquifer confined to morphological elevations in the area of infiltration is considered to be extremely vulnerable and sensitive to the effects of climate change.

Keywords: Climate change, transmissivity, GIS

Connection and compartmenting of the Serra Geral and Guarani aquifer systems in central Paraná State (Paraná Basin, Brazil)

[1]Francisco José Fonseca FERREIRA, [2]Alessandra de Barros e SILVA

[1]UFPR, Departamento de Geologia/LPGA, Centro Poltécnico, Jardim das Américas, Caixa Postal 19045, CEP 81531-980, Curitiba-PR, Brasil, e-mail: francisco.ferreira@ufpr.br
[2]UFPR, Departamento de Geologia/LPGA, Centro Poltécnico, Jardim das Américas, Caixa Postal 19045, CEP 81531-980, Curitiba-PR, Brasil, e-mail: ale_barros@yahoo.com

ABSTRACT

Recent research projects on the Guarani Aquifer System (GAS-granular), Paraná Basin, Brazil, have evaluated the tectonic control of its hydrogeological potential, flow patterns, chemical properties, and environmental protection aspects. One such project is the present one, that has investigated a structured area in central Paraná State, delimited by coordinates 24º00'S, 25º00'S, 51º00'W and 53 º00'W (Fig. 1). The study involves GIS integration of aerogeophysical, geological, structural lineament (DEM and Landsat imagery), hydrogeological and hydrochemical data. Basalts flows and diabase dykes (NW-SE) of the Serra Geral Formation (Lower Cretaceous) predominate in the area studied. These rocks correspond to the overlying Serra Geral Aquifer System (SGAS-fractured). The purpose of the study is to investigate the structural control of both flow and chemistry of SGAS groundwater and also to identify fractures that might represent hydraulic connection zones to the underlying granular GAS.

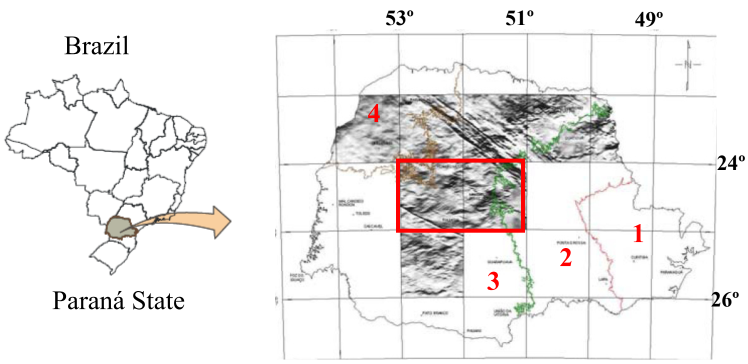

Fig. 1 – Localization of the study area (red) in the partial aeromagnetic map of the Paraná State, Brazil
1 – Precambrian basement, 2 – Paleozoic sedimentary rocks, 3 – Serra Geral Formation (Lower Cretaceous basalts and dykes - SGAS), 4 – Caiuá Group (Upper Cretaceous sandstones – Caiuá Aquifer System -CAS)

The processing and interpretation of aeromagnetic data using various techniques, useful for shallow sources, and the integration with others remote sensing and geological data permitted to outline the regional structural framework (Fig. 2). A mosaic of tectonic blocks delimited by NW-SE (diabase dykes) and NE-SW (Paraná Basin basement) structures was characterized. This new magnetic-structural framework was compared with the spatial distribution of hydrogeological (potentiometry, outflow and specific capacity) and hydrochemical parameters ($Na^{+} + K^{+}$, Ca^{++}, Mg^{++}; Cl^{-}, $HCO_3^{-} + CO_3^{--}$, SO_4^{--}; total dissolved solids – TDS and pH). An integrated interpretation allowed the recognition of the structural control on hydrogeology, hydrochemistry and hydraulic connection zones of the SGAS and GAS as indicated by their differential water mixture rates. TDS and pH were complementary indicators of water provenance of the Serra Geral Aquifer System. In general, the SGAS typically shows average pH of 7.4 and TDS between 80-120 mg/L, average 100 mg/L. Values of pH and TDS respectively above 7.5 and 150 mg/L were interpreted as contamination by GAS water. Anions, cations, TDS and pH data, associated with the structural framework, have indicated places that are of typical SGAS waters and also places of SGAS/GAS connection waters. The former ones are bicarbonated calcic and bicarbonated calcic magnesian. The second ones are bicarbonated sodic and bicarbonated sodic calcic. The results, presented in a georeferenced map, show the principal connection zones of the SASG and SAG (Fig. 2).

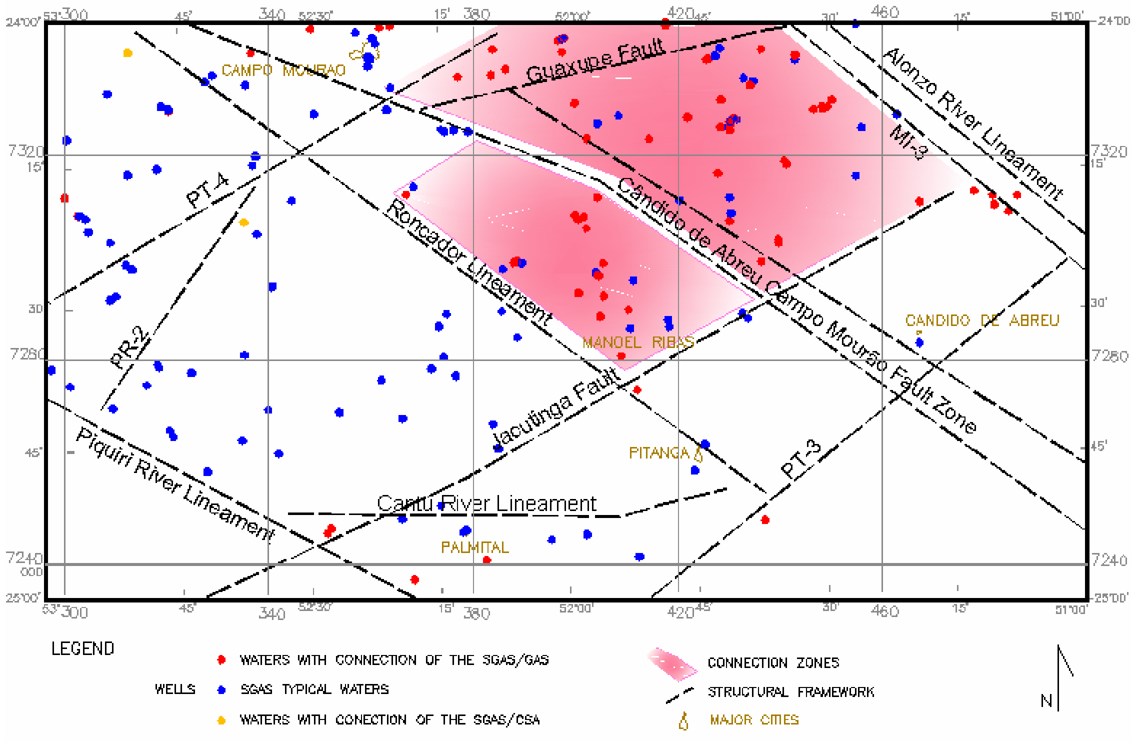

Fig. 2 – Localization map of the principal connection zones (red) of the Serra Geral and Guarani aquifers

Keywords: Guarani Aquifer System, Serra Geral Aquifer System, Paraná Basin, hydraulic connection, aeromagnetometry

Contribution of Geographical Information System (GIS) to approach Hydrodynamic groundwater. Case of the Liassic aquifer of the Saïs plain (Morocco)

[1]F. AMRAOUI, [2]M. RAZACK, [3]L. BOUCHAOU, [1]F. El KAMEL and [4]S. RHAOUTI

[1]Géosciences Laboratory, Hydrosciences team, Faculty of Science Ain Chock, Hassan II university, BP 5366 Maarif, Casablanca, Morocco. E.mail: amraoui_f@hotmail.com
[2]Hydrogeology Department UMR 6532, University of Poitiers, 40 avenue du Recteur Pineau, 86022 Poitiers Cedex, France. E.mail: moumtaz.razack@hydrasa.univ-poitiers.fr
[3]Applied Geology and Geo-environment Laboratory, Faculty of Science, Ibn Zohr university, BP 8106, 80000 Agadir, Morocco. E.mail: lbouchaou@yahoo.fr
[4]Agence du Bassin Hydraulique du Sebou – Fès, Maroc. E-mail : srhaouti@yahoo.ca

ABSTRACT

In the Mediterranean basin the karstic aquifers constitute an essential water resource for domestic drinking supplies and/or irrigation. The object of this study is to approach the very complex hydrodynamic of the carbonate aquifer of Liass in order to better understand the global functioning of the system. This knowledge is of essential importance for the quantitative and qualitative management of water resources. This becomes urgent in the context of prolonged drought and the arid climate.

The hydrodynamics of the Liassic aquifer is analysed using the hydrogeological database, in particular the data of several deep boreholes drilled in the studied area. A geographical information system (GIS) was carried out for this aquifer with a geographical extension of 2100 km^2. It plays an important role in the drinking water supply of the two big cities of Mèknes and Fès (two million inhabitants).

The GIS seems the ideal tool to provide information on the geometry and structure of the aquifer. All the data allows the establishment of multiple hydrodynamic maps that can considerably improve knowledge on the functioning of this aquifer system and can help the decision makers better manage the water resources of this area.

Keywords: Saïs Plain, liassic aquifer, major boreholes, SIG, hydrodynamic of groundwater, management.

Contribution of remote sensing methods and techniques in the detection of coastal and submarine springs in karst environments (Korinthia area, Greece)

[1] Evaggelos ROKOS, [2] Kostas MARKANTONIS, , [3] Ioannis KOUMANTAKIS

[1] National Technical University of Athens, Greece, e-mail : vag@metal.ntua.gr
[2] National Technical University of Athens, Greece, e-mail : mmgski@central.ntua.gr
[3] National Technical University of Athens, Greece, e-mail : markantonis@metal.ntua.gr

ABSTRACT

The purpose of this poster presentation is investigate the contribution of remote sensing methods and techniques in the detection of submarine/coastal springs in the Korinthia area, in Peloponnesus, Greece.

Remote sensing combined with knowledge of geological and hyrogeological conditions of the area, can provide useful information in locating thermal anomalies that could be indications of fresh water, discharges into the sea water and therefore existence of submarine springs.

A Landsat 7 image was selected for this study. Landsat 7 is the latest satellite of the Landsat program and it was launched on April 15, 1999. The primary goal of Landsat 7 is to refresh the global archive of satellite photos, providing up-to-date and cloud free images. The date of the image used in this study is April 5th 2002.

Various image processing techniques were applied, including thermal band processes, selected RGB composites, band ratios and principal components analysis. The results of this study are presented in this paper.

Keywords: submarine springs, hydrogeology, remote sensing

Development of a GIS-based screening model for regional groundwater management

[1]Janmaizatulriah JANI, [1] David N LERNER, [2] Steve WISE

[1]Catchment Science Centre, University of Sheffield, Sheffield S3 7HQ, UK,
email: cip06jj@sheffield.ac.uk, d.n.lerner@sheffield.ac.uk
[2] Department of Geography, University of Sheffield, Sheffield S10 2TN, UK, email: s.wise@sheffield.ac.uk

ABSTRACT

Geographical Information Systems (GIS) are an important tool for monitoring and modelling the flow of water and pollutants at the surface at the regional scale. Besides providing a range of tools for modelling surface flow, GIS has the ability to combine this with other environmental and socio-economic data. However groundwater modelling is typically done only at the aquifer scale, because of the complexity of the processes involved, and does not make use of GIS, due to lack of tools for 3D modelling in GIS. Given the need for regional modelling of all aspects of the movement of water and pollutants, and the clear benefits of using GIS, this study will seek to explore the possibility of extending GIS-based modelling to include groundwater, on a regional scale. The initial approach will be to adopt a simple approach in which topography is the main control on flow. This will be modified to include the effect of other factors such as aquifer properties, and the nature of individual pollutants, in order to provide a better understanding of groundwater flow and to achieve better model results. This GIS based model will also result in tracking of pollutant pathways and travel times in groundwater flow system.

***Keywords**:* GIS, groundwater, regional scale, pollutant

GIS and remote sensing for improvement of groundwater management in Northern Algeria

[1]Vladimir BELICEVIC, [2] Radmila PAVLOVIC, [3]Branislav TRIVIC, [4]Mileta BOJOVIC, [5]Goran LJUMOVIC

[1] Energoprojekt, Mihajla Pupina 12, Beograd, Srbija, e-mail: vladimir_belicevic@yahoo.com
[2] Faculty of Mining ang Geology, Djusina 7, Belgrade, Sebia, e-mail: prada@rgf.bg.ac.yu
[2] Faculty of Mining ang Geology, Djusina 7, Belgrade, Sebia, e-mail: btrivic@rgf.bg.ac.yu
[3] Energoprojekt, Mihajla Pupina 12, Beograd, Srbija, e-mail: mileta_bojovic@yahoo.com
[4] Energoprojekt, Mihajla Pupina 12, Beograd, Srbija, e-mail: gljumovic@sbb.co.yu

ABSTRACT

The area which is the subject of the project described in this paper is around 300,000 km^2 in North Africa i.e. Northern Algeria. This area stretches between the Mediterranean in the north, state borders with Tunisia and Morocco in the east and west, respectively, and a natural tectonic boundary – South Atlassic Fault in the south.

The project objective is to quantify groundwater resources for selected hydrogeological units for the purpose of successful groundwater management planning by using GIS technology. Particular importance is given to this objective by current imbalance between available quantity and demand, i.e. real exploitation.

An interactive map of resources was prepared, based on geological, hydrogeological, topographic and hydrometeorological maps. The level of details contained in the map of resources corresponds to 1:200000 scale. For this project, existing documents and information were collected and analyzed. The collected input was validated and updated by applying remote sensing method. For that purpose 26 Landsat 7 ETM satellite images were used.

In the first stage, a homogenous compiled geological map of the investigation area was prepared, based on available maps with the scale of 1/50000 up to 1/500000 and geological interpretation of satellite images. In this way, the problem of non-homogeneity and non-existence of geological maps was resolved. The next step involved preparation of a hydrogeological map and accompanying special-purpose maps required for hydrological and hydrogeological calculations. Database was enhanced by adding elements for the third dimension of the aquifer, i.e. data obtained by drilling and geophysical investigations.

The project was implemented in ESRI GIS environment. A data model was designed, the created database containing spatial data was transferred to RDBMS SQL server 2000 and communication with ARC GIS is implemented through SDE (Spatial Database Engine).

Keywords: Groundwater resources, remote sensing, GIS, data model

GIS utilization to estimate the quantity and distribution of nitrate and chloride in a porous aquifer

[1]Giuseppe SAPPA, [1]Maria Teresa COVIELLO

[1]Dept. Hydraulics Transportation and Roads – University of Rome "La Sapienza", Italy,
e-mail: giuseppe.sappa@uniroma1.it, mariateresa.coviello@uniroma1.it

ABSTRACT

Data obtained from water samples collected by ARPA (Regional Agency of Environmental Protection) from 2003 to 2006 have been used to estimate the total mass of nitrate-nitrogen and chloride stored in a shallow porous aquifer and to analyze the spatial distributions of these anions and their correlation with hydrogeological factors and known land classes. The hydrogeological factors examined include aquifer position within the stratigraphic report, the presence or absence of confining layers and the aquifer thickness. For this, a 3D model of the stratigraphy of the test site has been built on the base of 1097 drillings (Fig. 1).

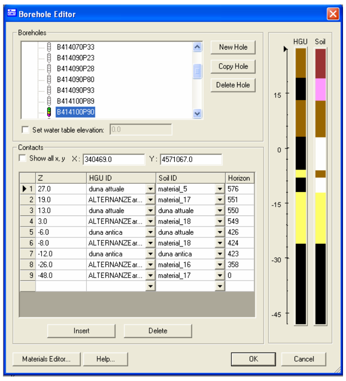

Fig. 1. Example of a table referring to a drilling

Spatial analysis indicated a positive relationship between the density of croplands of the area and nitrate levels in groundwater. The concentration of nitrate and chloride correlate with the vertical position of an aquifer within the stratigraphic unit, observing that a lower concentration where a confining unit is present, like profiles extracted from a tin interpolated from nitrate concentration values show a general decline in nitrate concentration with the increase in lithology thickness.

The background nitrate contamination of the aquifer is about 10-15 mg/l but values as great as about 100-250 mg/l occurred in many wells (Fig. 2).

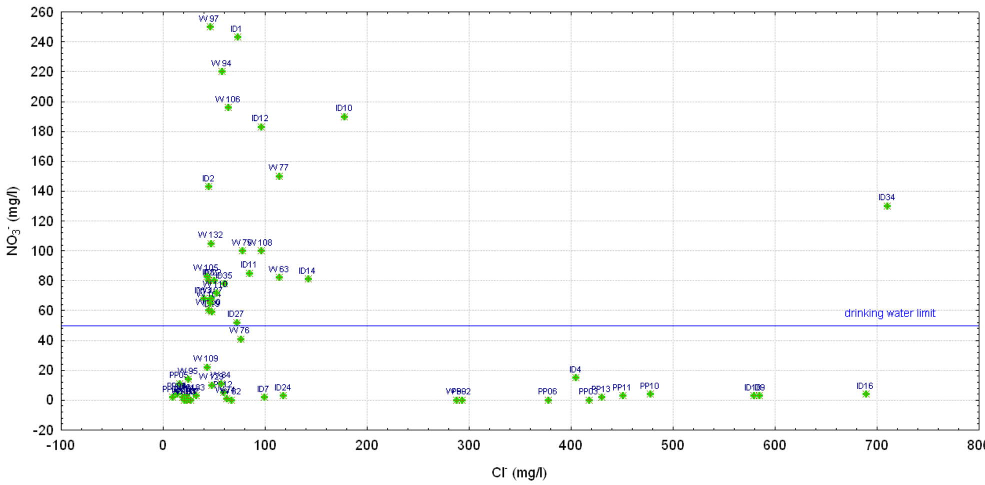

Fig. 2. Nitrate contents in wells (mg/l)

This surface groundwater is locally exploited for irrigation use, on land located in the southern area of the Latium region, where the main anthropic activity is represented by intensive agriculture with the massive use of fertilizer. Moreover the composition of these strata which makes up the aquifer is really variable, and consequently, the different hydraulic conductivity that the aquifer is a multistrata one.

This work gives a spatial distribution of nitrate contamination and shows that irrigation and the movement of contaminants in areas of different hydraulics gradients are responsible for localized peaks of nitrate concentration.

Keywords: spatial analysis, nitrate-chloride, stratigraphy, agriculture

Global Monitoring of Groundwater Resources

Neno KUKURIC

IGRAC, Princentonlaan 6, 3508 TA Utrecht, The Netherlands

ABSTRACT

Assessment of the global groundwater resources is the core mission of International Groundwater Resources Assessment Centre (IGRAC). The change of groundwater in time makes the groundwater assessment a dynamic process and the groundwater monitoring a necessary precondition for the assessment. Groundwater is monitored in many parts of the world, mainly by measuring groundwater levels, groundwater abstraction, spring discharge and water quality. The results of these point measurements are sometimes interpolated and combined with other information to produce various groundwater (related) maps covering aquifers, regions or even countries. There is, however, no systematic monitoring and assessment of groundwater change on global scale.

IGRAC intends to establish a sustainable global groundwater monitoring system and to use monitored data for a periodic assessment of the global groundwater resources. The term 'system', rather than 'network' is used to avoid an impression of an apart, global network of monitoring wells. Further on, this "new" network does not imply any (re)design of existing groundwater monitoring networks world-wide. The global monitoring system network will use *aggregated information* on groundwater in order to assess a *global change* of groundwater resources.

Aggregation of the point groundwater measurements need to be carried out by local experts, involving their knowledge of hydrogeological conditions, measurement practice, historical records, socio-economical setup, and other factors relevant for derivation of reliable figures. In its turn, IGRAC is developing a web-based tool to encourage and enhance the aggregation procedure and the process of global monitoring in general.

A Global Groundwater Management tool will enable the local expert (an IGRAC representative) to regularly produce on-line maps showing the change of groundwater variables in time. Representative point measurements (from monitoring wells or springs) and proxy information (such as precipitation and demography) can be uploaded in the application to assist the aggregation procedure. Moreover, the uploaded point measurements can be automatically interpolated, making the basis for a fine aggregation by hand. Once the aggregation is completed, the information is stored in IGRAC database and combined with information from other monitoring regions. In this way the info on a global state of groundwater resources can be further processed and visualised.

As complementary to the above described terrestrial measurements, IGRAC is exploring the possibility of using remote sensing (GRACE) observations for monitoring the change of global groundwater resources.

Keywords: global monitoring, GIS, remote sensing

How can remote sensing data contribute to groundwater vulnerability and risk intensity? - Three case studies.

[1] Heike WERZ, [1] Heinz HÖTZL

[1]Department of Applied Geology, Universität Karlsruhe (TH) – Research University,
Kaiserstraße 12, 76128 Karlsruhe, Germany
werz@agk.uka.de, hoetzl@agk.uka.de

ABSTRACT

In the past three decades remote sensing data have been applied successfully to various topics in geosciences, also focusing on hydro(geo)logy. However, since most satellite sensors have no ground penetrating capabilities normally the hydrogeological information derived from remote sensing data is obtained indirectly by qualitative methods or semi-quantitative approaches. Thus, the correlation between the remote sensing data and ground truth measurements is essential.

This paper outlines three case studies how remote sensing data can contribute to conventional groundwater vulnerability and risk intensity mapping (which include the preliminary assessment of groundwater vulnerability and hazards) and where there are possible limitations. For all three studies a method combining remote sensing data, aerial photography, GIS modelling and field validation for semi-arid regions is / was applied. Although, several parameters that are important for risk intensity mapping are based on information beneath the Earth's surface, the spatial cover and ease of up-to-date data acquisition in remote areas with data scarcity make remote sensing data a valuable tool for these studies.

The first case study included the mapping of groundwater vulnerability, hazard, and groundwater risk intensity (scale 1:50.000) in order to provide a basis for groundwater protection in Jordan. Due to the semi-arid to arid climatic conditions, Jordan has limited groundwater resources. Especially, in the karst areas, as a result of agricultural activities and untreated wastewater, the groundwater is mainly contaminated microbiologically. The mapping included the use of optical remote sensing data to enhance conventional data acquisition. LANDSAT ETM+ data, colour and panchromatic aerial photographs on different scales were incorporated using visual image interpretation and digital image processing. For the assessment of groundwater vulnerability, remote sensing data was mainly used to allocate or supplement missing topographic map or land cover information and to assess relevant surface features (karstification) to get information about the infiltration conditions. For the hazard mapping remote sensing data proved to be very useful to indicate the location, size and extension of many hazards like agricultural areas, excavation sites, street network, urban areas, waste water treatment plants, animal barns and detached houses.

The second study demonstrated that the use of digital aerial orthophotos in conjunction with state of the art remote sensing techniques for digital image processing certainly yields potential for classifying karst features in Mediterranean carbonate mountain ranges. Based on orthophotos a GIS-based karst feature map (scale: 1.50.000) of two carbonatic mountain ranges in southern Spain was produced with the aim to serve as karstmorphological data layer input for groundwater vulnerability. Available input data included digital colour and black and white orthophotos, topographic and geologic digital maps, as well as GPS mapped true ground points as reference for accuracy assessment. The analyses focused on the direct comparison of visual and automatic classification procedures on the basis of a karst features interpretation key. A hierarchical layer approach was modelled for a subset part of the investigation area.

The third case study currently takes place in Jordan, Israel and the Westbank within the multilateral project "Sustainable Management of Available Water Resources with Innovative Technologies" (funded by the Federal Ministry for Science and Education, Germany; BMBF). The objective is to map the vulnerability,-hazards and groundwater risk intensity for the Lower Jordan Valley in an overview map with a basis scale of 1:250.000 and focus at hot spots of groundwater contamination with larger scaled maps. The maps will be included as a basis for a regional groundwater management and a decision support system. Hereby, infiltration conditions, soil cover, land use and karstification will be derived from remote sensing information. Shuttle radar topographic mission (SRTM) data is used for digital terrain model generation. The detection of hazard types by remote sensing is possible for all hazards that exhibit distinct characteristics that can be recognised on the images by their spectral characteristics, tone, texture, pattern, shape and size or other associated characteristics and will be useful particularly for large agriculture, urban and industrial hazards.

Summarised, remote sensing data cannot be used as a stand-alone technique able to completely replace conventional data acquisition (such as field or laboratory work and measurements) for groundwater vulnerability and risk intensity mapping, but the combination of remotely sensed data with ancillary data integrated in a GIS

system has shown high potential to provide reasonably accurate up-to-date information and to enhance and supplement needed thematic information.

Keywords: groundwater protection, groundwater management, hazard mapping, remote sensing, Middle East.

Hydrogeological subsystem (SUBSYSTEM HYD) geologically documented objects database (GDO)

[1] Pavel TVRDY, [1] Jan MAULE

[1] Czech Geological Survey – Geofond, Kostelní 26, Praha 7, Czech Republic, e-mail: geofond@geofond.cz

ABSTRACT

SUBSYSTEM HYD is part of the GDO database and it contains detailed information on water wells, observation stations, geothermals, mines and geological boreholes, including the observation wells of the Czech Hydrometeorological Institute, where hydrodynamic, chemical and other tests are carried out.

SUBSYSTEM HYD was established between 1991 and 1993 by transferring to the automated digital format the traditional files which have been in existence since 1966, together with older historical records (the earliest from 1620 in Jáchymov). By 31.3.2007 it included information on more than 71.600 objects.

The GDO database also contains SUBSYSTEM GEO - geological information on objects and their geodetic fixing and SUBSYSTEM KAR - logging. These subsystems of the GDO database enable a complex data service for any separate borehole.

SUBSYSTEM HYD has been managed by the user applications in an Oracle relational database since 1998.

There are HTM and MDB (ACCESS) formatted outputs of SUBSYSTEM HYD offered by the Hydrogeological department of CGS – GEOFOND (Czech Republic, Kostelní 26, Praha 7 – 170 21, tel.: +420 233371190, fax: +420 233373806, e-mail: geofond@geofond.cz, website: www.geofond.cz). The following selection criteria can be used (Table 1):

Table 1

Selection criteria	Specification
„KLIC_GDO“ identificator	number of the object in the GDO database - 143698, etc.
hydrogeological number „C_HDB“	number of the object on the map - M33077BD0046, etc.
numer of report	P052145, P085148, atd.
basic/topographical map	1:25 000, 1:50 000, 1:100 000, 1: 200 000
municipality	district (rural district)
locality	name of the land register, urban area
hydrogeological area	number and name – 111 kvartérní sedimenty Orlice
river basin	1-13-05-018
author	surname, first name
firm	name, IČO
completion	year
utilisation	exploration borehole, observation object, water withdrawal for water supply
type of object	borehole, water well, spring
co-ordinates, contours of the area	X, Y co-ordinates (JTSK): 1189000 550000 1190500 550500 1192000 547000 1190500 546000 1189000 550000
spa source area protection, number	Mariánské Lázně – 4601

Keywords: hydrogeology, object, database, information system

Land use and groundwater management conflicts - Is a SDSS sufficient tool for decision makers?

[1]Barbara ČENČUR CURK, [2]Barbara MAGAGNA, [3]Stephan KOLLARITS

[1]IRGO – Institute for Mining, Geotechnology & Environment, Ljubljana, Slovenia (barbara.cencur@irgo.si)
[2]Institute of Landscape Development, Recreation and Conservation Planning, University of Natural Resources and Applied Life Sciences; Vienna, Austria (magagna@boku.ac.at)
[3] PRISMA solutions; Mödling – Austria (stefan.kollarits@prisma-solutions.at)

ABSTRACT

Governmental authorities within the European Union are forced by law to take decisions within the framework of European, national and regional directives in the fields of spatial planning, groundwater and environmental protection. Integrated water ressource management has to balance groundwater protection requirements with a variety of demands for land-use activities in the sence of sustainability. This is difficult to achieve in practice. It requires an exceptional knowledge of natural resources and skill and knowledge of physical planners who have to optimize effects of human activities. This complex issue can be supported by Spatial Decision Support Systems (SDSS), in which legal frameworks and socio-economic aspects with emphasis on land-use activities will also be implemented. A decision-support system (DSS) is comprised of specialised databases (including GIS), knowledge base and interactive modelling. Basic work for such a SDSS has been done within the transnational and interdisciplinary project KATERII (Karst waTER research project), supported by the EU INTERREGIIIB CADSES programme, involving co-operation between institutions from Austria, Croatia, Italy and Slovenia. The major studied land-uses in four pilot areas were summer and winter tourism, settlements, transport, forestry, agriculture and pasture management. In the paper methodological aspects for SDSS will be presented, mainly focused on knowledge base development. Knowledge base is a system of rules describing the concrete forms of impact of land-use activities (derived from an activity impact-effect model) on the natural environment, as described in vulnerability models. The system of rules – the formalised knowledge base - is the core of the decision support system and it was made in existing ontology DOLCE.

Keywords: SDSS, groundwater management, groundwater protection, planning tasks, land use, ontology, knowledge management

Numerical model for recharge evaluation at the outcrop zone of the Guarani Aquifer System

[1]Edson WENDLAND, [2]Jorge Luis RABELO

[1] University of São Paulo, Department of Hydraulics and Sanitary Engineering, PO Box 359, São Carlos-SP, 13560-970, Brazil, e-mail: ew@sc.usp.br
[2] Universidade Federal do Recôncavo da Bahia, Centro de Ciências Exatas e Tecnológicas, PO Box 0082, Cruz das Almas-BA, 13560-970, Brazil, e-mail: rabelo@ufba.br

ABSTRACT

This work assesses the recharge of the Guarani Aquifer System with the aid of a numeric model, applied to an area of 7,500 km^2 delimited by the hydrographic basins of the rivers Jacaré-Guaçú and Jacaré-Pepira (sub-basin of the Tietê River, in the central region of São Paulo State, Brazil). GIS based tools were used in the storage, processing and analysis of data from intense bibliographical revision as well as generated maps with the dimensional and hydrogeologic characteristics. Main hydrologic phenomena were selected, leading to a groundwater conceptual model for evaluation of recharge and groundwater flow, taking into account the significant outcrop region in the study area (showed in Fig. 1).

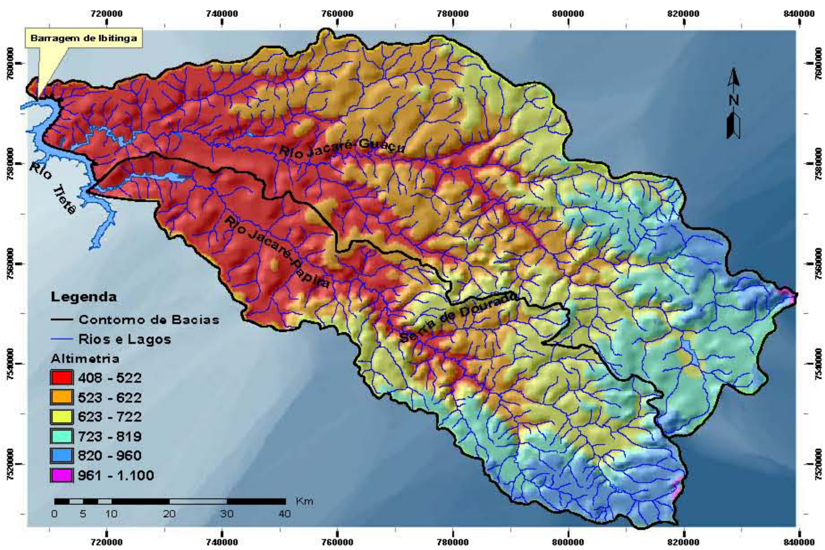

Fig. 1. Digital elevation model of the study area.

The geologic formations and structures were attributed to six corresponding zones of recharge that compose the semi-confined and free aquifer. The model was calibrated against base flow derived from daily hydrograms observed in the main rivers and against static level observed in wells. A sensitivity analysis including the calibrated parameters was carried out. The results show that there is strong interaction between both basins and that the aquifer mainly drains its recharge into the rivers. Lateral groundwater exchange (flow between basins), deep recharge to the regional system and the groundwater exploitation from wells represent small exits in comparison to the total discharge through surface water bodies. However, operation of concentrated wells in the biggest urban centers of the study area induces local trends indicating areas of intense drawdown. The determination of base flows along the main rivers identified the stretches, along which the aquifer is drained and recharged. Although the aquifer essentially supplies the rivers, the stretches in which the river is recharged are significant and important since the aquifer is potentially more vulnerable. For the management of the whole Guarani Aquifer System, the results indicate that the global recharge estimates should be carefully reevaluated.

Keywords: Guarani Aquifer, recharge, flow model, numerical modeling, GIS

Quantification of groundwater recharge using publicly available GIS data

[1]Maria-Theresia SCHAFMEISTER, [2]Andreas MUSOLFF, [1]Tammo MEYER

[1]University of Greifswald, Institute for Geography and Geology, F.-L.-Jahn-Str. 17a, D-17487 Greifswald
[2]Helmholtz Centre for Environm. Research – UFZ, Dept of Hydrogeology, Permoserstr. 15, D-04318 Leipzig

ABSTRACT

Groundwater recharge is one of the fundamental parameters needed for any study meant to further the understanding of hydrodynamic processes in an area of interest. It is used in different spatial and time scales depending on the study's goal e.g. as as input variable for the estimation of sustainable water resources, as a boundary condition for numeric groundwater models and for the quantification of the vulnerability to groundwater contamination. Groundwater recharge represents the water quantity which links hydrodynamic processes of surface water, water in the vadose zone, and groundwater. Thus different estimation techniques were developed which approach this quantity using data from either of these hydrodynamic processes, i.e. (i) surface-water runoff measurements, (ii) soil water balance or lysimeter data from the unsaturated zone or (iii) pump and tracer test results from the saturated zone. Which of the aforementioned techniques is selected depends on the considered spatial and time scale of the study, on the geological, on the climatic, geological and socioeconomic conditions of the area, on the availability of reliable data, and on the affordable time and financial resources.

Techniques based on processes and data in the unsaturated zone are most efficient when the aim of the study is the mean annual groundwater recharge. An advantage of this kind of estimation is that it takes into account spatial differentiation. Because groundwater recharge is strongly influenced by vegetation type and soil properties, which often vary significantly in the working area, spatial differentiation is an important issue. Especially in local or regional groundwater modeling studies taking into account the spatial variability of groundwater recharge has a major impact on any groundwater management measure which follows the modeling results. The disadvantage of these techniques, based on the consideration of soil water balance, lies in their necessity of an extensive and detailed database: spatially differentiated data on climate, soil and vegetation must be gathered and digitized before they can be processed within the GIS based computation of groundwater recharge.

Today GIS is a standard tool in hydrogeology and an astonishing amount of free GIS data on soil, land use and climate are available in the World Wide Web. The main goal of this study is to compare the results from groundwater recharge estimation based on free GIS data with those obtained by using data from a well studied area.

The study area is located in northern Germany and covers 11 km^2 thus representing a typical local-scale problem. The land use is characterized by a patchy mixture of cropland, grassland and forest. Soil substrate is dominated by loam and silty sand. The mean annual precipitation is 536 mm, potential evapotranspiration is 464 mm. Land use and soil data where mapped in the field; climate data where derived from meteorological data from the closest weather stations. In this study the mean annual groundwater recharge is estimated using the method of Renger & Wessolek which was developed for unconsolidated sediments of northern Germany. This well approved method is based on multiple regression analysis and derives groundwater recharge from mean annual precipitation, potential evapotranspiration, land use and available soil water content (available field capacity within the root zone derived from soil data). Surface runoff is not considered. Mean annual groundwater recharge rate using the method of Renger & Wessolek is 84 mm, i.e. 16 percent of the precipitation rate.

The same method is applied to data from publicly available GIS sources. Land cover was retrieved from Corine Land Cover (Coordination of Information on the Environment) of the European Union. The available soil water content was derived from a German chart based on soil type (AG Boden). Soil type was taken from the World Soil Map of the FAO (Food and Agriculture Organization of the United Nations). As the study area only has an extent of 3 to 4 km, land cover and soil data are not differentiated within it, showing cropland on orthic luvisol. Estimated mean groundwater recharge rate is 67 mm, i.e. 12.5 percent of the precipitation rate.

The results show a good agreement between estimated recharge rate based on a comprehensive highly differentiated database and a less differentiated but publicly available database. Given the specific conditions of northern Germany, i.e. moderate climate and unconsolidated soils, the free GIS data appear to be a reasonable base for estimating groundwater recharge on a local to medium scale. Further research is needed on the use of publicly available world wide climate data (as from United Nations Environmental Programme) and the application of this method to larger scales.

Keywords: groundwater recharge, GIS, spatial differentiation, sustainable water reserves, groundwater modeling

Support to decision making integrating groundwater monitoring data into a numerical model within a GIS. The case of Tadla plain (Morocco)

[1]Elisabetta PREZIOSI, [1]Emanuele ROMANO, [2]Ali HAMMANI

[1] Water Research Institute, C.N.R., via Reno 1, 00198 Rome (Italy). Email: preziosi@irsa.cnr.it
[2] Institute d'Agronomie et Veterinarie, Rabat (Morocco)

ABSTRACT

In the framework of the EC FP6 Integrated Project "AquaStress" (www.aquastress.net), eight test sites in Europe and in the Mediterranean region have been chosen, in which causes of water stress as well as technical and non technical mitigation options are analysed. Among others, Tadla irrigated perimeter in Morocco has been selected as being representative of water stress in the agricultural sector in the Mediterranean climate.

Tadla irrigated perimeter, one of the most ancient in Morocco, is located in the Oum Er Rbia river basin, 200 km northeast of Marrakech. In the late forties an important irrigation system with dams and canals was developed in order to exploit the surface waters to sustain the economic growth of the region. However, irrigation has had a strong impact on Tadla aquifer dynamics, which have been largely modified by the surface water availability and the irrigation activity performed in the perimeter using a traditional gravity method called "robta". This method consists in periodically flooding each parcel of land with an amount of water which largely exceeds the plant needs. Hence irrigation losses to ground waters are huge and the phreatic aquifer suffered from an excessive uprise of the water table before 1980. A qualitative degradation of water and soil due to salts is a further consequence.

Eventually Morocco experienced a strong drought between 1981 and 1984. As an answer to the restriction on the usage of surface waters, Tadla farmers started to exploit ground waters in a diffuse way by means of individual wells. Groundwater exploitation, which has allowed a high crop intensification in Tadla, constitutes a chance for the perimeter to mitigate water stress. It has been estimated that the contribution of groundwater to the annual volume of irrigation supply can often exceed 50% through private pumping at around 10.000 wells in the whole of the irrigated perimeter (Hammani *et al.*, 2004)). However, in spite of the fact that only 50% of the farmers can really exploit the aquifer, groundwater pumping can be excessive and overexploitation has occurred during dry years. As a result, a necessity for a collective management is required also for ground waters; furthermore the Moroccan Law on water (Law 10/95) stipulates that all ground waters are public and any abstraction requires previous authorisation by the River Basin Authority.

In order to control these undesired fluctuations, namely the excessive uprise and drawdown of the phreatic aquifer observed in the southern side of the plain called Beni Moussa, a monitoring network has been implemented by ORMVAT (Office Régional de Mise en valeur Agricole du Tadla) with the objective of tracking the evolution of groundwater levels, in order to prevent it to lower too much or conversely to rise up to the topographic surface. A second monitoring network is run by ABHOER (Agence de Bassin Hydraulique de l'Oum Er Rbia), taking into account water quality and quantity in the oueds, in the reservoirs and in the aquifer system.

ORMVAT has also implemented a data base with all the hydrological information gathered over time (piezometric levels and electrical conductivity, which provide essential information on quantitative and qualitative status of the water table aquifer). Tadla aquifer system has largely been studied by hydrogeologists (Hsissou *et al*., 1996; Hammani, 2004) and numerical models of groundwater flow have been implemented both in steady state and transient conditions (Barthelemy, 2003; Akram *et al*., 2003).
However, these activities have not led to a change in the aquifer management especially at the farmers' behaviour. The existing procedure of data collection and analysis should be reconstructed and carefully examined together with the stakeholders in order to individuate the bottlenecks. This is a problem that frequently arises when monitoring activities are implemented and a huge quantity of data is collected but a change in the management strategy does not follow.

The research described in this paper aims to realise a decision support system which would be able to give advise on how to control excessive water table fluctuations when they exceed defined thresholds. The proposed tool, to be run in a GIS environment, should integrate the results of the monitoring activities concerning the piezometric head evolution, into a groundwater numerical model. It is intended to be used by ORMVAT in order to link the monitoring data on the aquifer head evolution and the Tadla aquifer development choices. This tool contemplates the effective possibility that ORMVAT is able to control the water table by starting/stopping pumping water at selected locations.

The general architecture of the tool is described. Firstly the operator has to analyse the data gathered in the monitoring activities and uploaded in the GIS (mainly quantity data). A water table is produced by interpolation of point data by means of a predefined geostatistical method (e.g. kriging). Hence the operator should be able to identify local or generalised critical situations using early warning indicators. In case a critical situation is foreseen, the operator could run numerical simulations starting from the current situation with the aim of analysing possible future scenarios (e.g. at 3, 6, 12 months). Simulations can be performed assigning as an input:

- the piezometric field resulted from monitoring data at a certain date,
- the recharge foreseen for the simulation period (rainfall infiltration, irrigation return)
- the abstraction rates

Conversely, the hydrodynamics features of the aquifer, as geometry, porosity, conductivity and boundary conditions are assigned as default.

If numerical results confirm the critical trend, the aquifer manager could decide to adapt measures on the aquifer in order to hinder the foreseen evolution by means of:

- start/increase pumping in the areas and periods of excessive uprise of the water table,
- stop/decrease the pumping rates where and when the water table is decreasing excessively.

In this case other numerical simulations would be run in which the operator is given the possibility of modifying the pumping rates at selected localities, in order to identify a good cost-effectiveness management program.

A detailed architecture for linking the monitoring network with the numerical model is currently being developed.

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Keywords: decision making, ground water modelling, GIS, monitoring networks

The Vulnerability of the Warmwatersberg Hot Spring in the Klein Karoo, South Africa: A Geological, Geophysical, Hydrogeochemical and GIS and Remote Sensing Investigation.

[1]Ashton MAHERRY, [1] Louise SOLTAU

[1] Natural Resources and the Environment, CSIR, South Africa,
e-mail: amaherry@csir.co.za, lsoltau@csir.co.za

ABSTRACT

The Warmwaterberg hot springs are situated on the Warmwaterberg in the Klein Karoo, South Africa. The main eye has an average flow rate of 17 000 ℓ/h and an average temperature of 43.5 °C. An investigation into the structural control of the main spring was undertaken in order to build a conceptual model and identify borehole drilling areas with a high risk of intercepting the hot spring water as a means of ensuring sustainability. The investigation comprised: hydrocensus of local boreholes; a resistivity survey to identify the major fracture zone; geological mapping of the anticlinal fold and major joint orientation; and a GIS and remote sensing survey to identify joint and fractures as well as the fault zone orientation in aerial and satellite imagery.

The major fault zone was identified from the resistivity profiles as NE-SW orientated with a dip between 75-90° to the North. The geological mapping identified an anticlinal fold hinge with a mean plunge direction of 120° ESE with a dip of 10-20° from the horizontal. The major joints identified from the geological mapping and remote sensing survey were E-W and SE-NW orientated.

The hydrocensus identified a chemical signature for the hot spring water which was seen in the chemistry of the eye, the regional boreholes and surface springs. These water sources appear to be located on the anticlinal hinge of the fold zone orientated in an ESE direction. Thus it would appear from the hydrocensus data that, although the hot spring is located on the intersection of the major fault zone and the anticlinal fold hinge, the main structural control on the regional groundwater regime is the anticlinal hinge. This was confirmed by the reduction in the main geothermal spring flow observed with the drilling of a borehole located on the fold hinge. The chemical signature of the hot spring was identified in the hydrocensus, allowing chemistry as well as temperature to be an indicator for the hot spring water. Should a borehole be drilled in the future, the chemical signature of the groundwater can be used as an indicator to show whether interception with the hot spring flow path has occurred. Temperature can also be used as an indicator for deep geothermal groundwater. However it does not necessarily imply interception of the hot spring flow path.

The Warmwaterberg hot spring is located on the intersection of the major fault zone identified in the resistivity survey and the anticlinal hinge identified in the geological field mapping. The Warmwaterberg hot springs illustrates the complexity of the natural system and the possible danger involved with GIS and remote sensing surveys as a non-integrated desktop survey. The major fault zone was identified using aerial photography and satellite imagery. However, the chemical signature of the local groundwater suggests that the major controlling structure is the anticlinal fold, which was not identified using satellite imagery. Thus GIS and remote sensing must be used in an integrated approach with a sound hydrogeochemical investigation.

Keywords: resistivity, GIS and remote sensing, hot spring

Use of GIS to prevent groundwater pollution

[1]Benito AGUIRRE, [1]Guadalupe ESTRADA, [1]]Leonel MELCHOR, [1]Jose SANTOS, [1]Lourdes VILLALBA, [2]Lourdes BALLINAS.

[1] Facultad de Ingeniería, Universidad Autónoma de Chihuahua, Circuito No. 1 Nuevo Campus Universitario, C.P. 31125 Chihuahua, Chih. México. e-mail: baguirre@uach.mx
[2] Facultad de Ciencia Químicas, Universidad Autónoma de Chihuahua. Ciudad Deportiva S/N. Chihuahua, Chih. México. e-mail: mballinas@uach.mx

ABSTRACT

In every city, it is necessary to have drainage systems to move wastewater; therefore cities need to focus on wastewater treatment, both in residential and industrial areas

Due to the development and growth of Chihuahua City more water is needed to satisfy the people's water needs, and as a natural consequence the volume of liquid in the drainage system has increased and flows into the city's rivers. The water that flows into the rivers is polluted by contamination elements found in wastewater and is sometimes used for agricultural use.

Chihuahua City is working on pollution prevention and built a plant for water treatment. The plant treats water for the northern part of the city, from Americas-Agustín Melgar streets. The flow is of about 30 240 M^3 per day which is the equivalent of 28 821 domestic water meter readers. All the water treated in this North plant is from residential and industrial sources like Complejo Industrial Chihuahua, Supra e Impulso. Another water treatment plant in the south of the city is planned to be built at the end of this year.

Because of the little control of wastewater flowing in the different sections of the city, it becomes important to know the characteristics of wastewater and that way the process of wastewater treatment is made effective.

With the use of systemized monitoring, we can detect illegal water discharge that contains high levels of contaminating elements and toxic agents most of the time.

The main objective is to zone wastewater, drainage wastes and the natural flow of the Sacramento and Chuviscar rivers water flow, considering the County's Ecology terms. All this information will generate city planning that will include water characteristic in shape filing having used GIS.

To achieve this wastewater zone planning, information from public and private sources will be needed for the desired control and better process, preventive actions and alternatives in the water treatment plants. Another thing that can be filed is the city's wastewater history of Chihuahua City with its geographical source so that future waste water controls are made in the same place and therefore contains more reliable information.

With GIS aid, we have the opportunity to avoid the process of pollution of groundwater, therefore we encourage the water departments to the general use of this tool.

Keywords: Contamination, Geographic Information System, Wastewater.

TOPIC 16

Valuing groundwater quality and its importance for the sustainable development of dependant ecosystems and populations - economic concepts and approaches

A new strategy for agri-environmental measures to reduce N-surpluses more cost-effectively

Thomas G. SCHMIDT, Bernhard OSTERBURG and Tania RUNGE

Federal Agricultural Research Centre (FAL), Institute of Rural Studies,
Bundesallee 50, D-38116 Braunschweig, Germany,
e-mail: th.schmidt@fal.de, bernhard.osterburg@fal.de, tania.runge@fal.de

ABSTRACT

This paper presents an analysis of farm accountancy data with regard to N-use and N-efficiency in order to detect reasons the N-surplus in agricultural management and to develop a result-oriented approach. Within the EU-LIFE-Project ´WAgriCo´ (Water Resources Management in Cooperation with Agriculture) farm N-balances are calculated for Lower Saxony in the North-West of Germany with the aim to support the monitoring and to provide essential information to implement the EU-Water Framework Directive (WFD). A new strategy of voluntary agri-environmental measures is investigated to support the WFD-management plans.

The first part of this study is based on monetary and physical accounting data from 7,000 farms in Lower Saxony (approx. 10 % of total farms). These data are used to detect the efficiency of organic N in order to estimate the mineral fertilizer input depending on farm type, plant uptake and organic inputs. Fig. 1 shows a large range of dairy farm N-balances that indicates a big potential of management options to reduce nitrogen pollution.

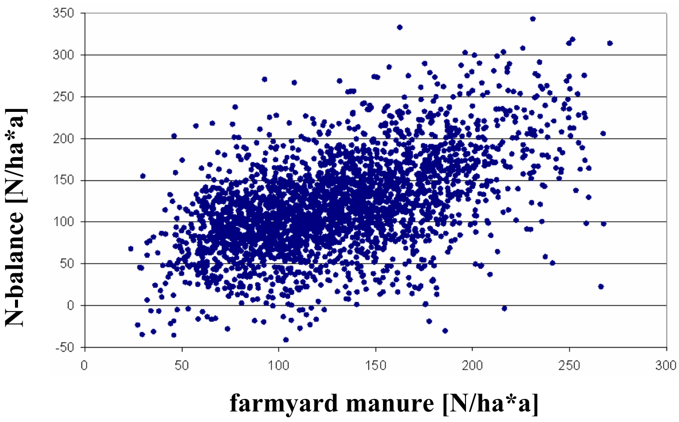

Fig. 1. Nitrogen balances of dairy farms depending on farmyard manure

The observed high variance of N efficiency within farm groups with similar conditions indicates that prediction of the N balance is difficult for individual cases, but also that there is still scope for increasing N efficiency. Especially for farms with animals it is crucial to improve the efficiency in organic fertiliser use and, in this way, to reduce the input of mineral fertiliser. Therefore an innovative result-oriented approach rewarding the improvement of nutrient management at farm level is put into practice. All farmers participating in the WAgriCo-Project have the facility to take part in the result-oriented scheme. They have a free hand in their adjustments to improve N efficiency, and are thus actively involved as entrepreneurs. This approach has the potential to increase positive environmental impacts and cost-effectiveness. Each farmer can choose adequate adaptations out of a catalogue of measures to reduce diffuse nitrogen pollution with regard to their proper weak points. The calculation of improvements to be rewarded is based on a farm gate balance, with additional information about on-farm use of fodder and organic fertiliser. Coefficients for N-efficiency are calculated separately for mineral and organic N to allow for a documentation of efficiency improvements independent of structural changes. Thus, increases or decreases in livestock numbers or land area is not remunerated, thus avoiding unjustified windfall profits. Only farm land in production is chosen as reference area, excluding "dilution effects" of fallow land.

Keywords: agriculture, farm accountancy data, nitrogen balance, fertilizer efficiency, diffuse pollution

Characterization of Ibero-American coastal aquifers: state of knowledge and management

[1]Emilia BOCANEGRA, [2]Gerson CARDOSO DA SILVA, [3]Emilio CUSTODIO, [4]Marisol MANZANO, [5]Suzana MONTENEGRO, [6]Jenny REYNOLDS-VARGAS

[1]Nacional University of Mar del Plata, Argentina, ebocaneg@mdp.edu.ar
[2]Federal University of Rio de Janeiro, Brazil, gerson@acd.ufrj.br
[3]Technical University of Catalonia, Spain, emilio.custodio@upc.edu
[4]Technical University of Cartagena, Spain, marisol.manzano@upct.es
[5]Federal University of Pernambuco, Brazil, suzanam@ufpe.br
[6]Nacional University, Costa Rica, jennyrv@yahoo.com

ABSTRACT

Coastal areas are transition spaces between the marine and continental domains where natural or anthropogenic processes of consumption, production and exchange of mass and energy occur at high intensity rates. Such processes exercise an intense pressure on natural resources. One of the main resources in coastal areas is groundwater which plays a very important role as the main - and in many occasions, unique - source of fresh water for human populations, ecosystems and the industrial and agricultural sectors. Consequently, sustainable use of groundwater resources is imperative in these locations. Creation of effective public policies towards sustainability is necessarily based on the technical knowledge of the aquifers and on the evaluation of their current potential, hydrogeological characteristics and vulnerability.

A comparative analysis was conducted on 33 coastal aquifers draining to the Mediterranean and Caribbean seas and to the Atlantic and Pacific oceans, in Argentina, Brazil, Colombia, Costa Rica, Cuba, Chile, Mexico, Nicaragua, Peru, Portugal, Spain and Uruguay. Taking into account the most common situations in Ibero-American coastal areas, aquifers were divided in five categories: carbonated aquifers, thick detrital aquifers, small aquifers of local interest, urban and periurban aquifers and aquifers in small islands. In the majority of the studied cases, intensive groundwater abstraction used to satisfy local population's needs or tourist-focused developments has produced marine intrusion and significant depression of piezometric levels. Additional problems include salinization caused by irrigation return flows and groundwater contamination due to lack of sewage systems and leaching of urban waste disposal areas. In some cases, the decrease of groundwater flow to streams, lagoons and wetland areas is already notorious.

The aquifers that have proved to have fewer management actions are usually those in which there is a low level of knowledge regarding their geometry, dynamics and hydrogeology. Conversely, aquifers that are well known, regularly monitored and to which modern and more sophisticated techniques have been applied (such as hydrogeochemical and isotopic techniques, flow and transport modeling, evaluation of marine intrusion and contamination risk assessment), usually present various management strategies. Common actions include remediation by artificial recharge, decrease and relocation of extractions, and even procedures to modify the dynamics of saltwater-freshwater relationships by means of freshwater injection and extraction of saltwater. In some cases, legal and regulatory activities to protect groundwater resources are scarce or nonexistent, whereas in other cases they constitute the support of an effective management plan. It was confirmed that, in general, an effective intervention of institutions that congregate and successfully represent the users and the civil society is a necessary step for proposing and implementing adequate management strategies. Nonetheless, this approach also requires important efforts on building technical knowledge and credibility.

The greatest challenge in coastal areas is the lack of awareness of the majority of decision makers and users regarding the negative impact of aquifer over-exploitation and contamination. Another important deficiency is the lack of financial resources for scientific investigation. Research is necessary in order to generate and implement alternatives for the sustainable management of coastal aquifers. International cooperation could help improve the current situation of coastal areas in the Iberian American region and thus promote sustainable management of endangered coastal ecosystems. Efficient water-management policies would dramatically help reduce the vulnerability of groundwater systems and consequently, the present risk situation for biodiversity, human population and economic development in coastal areas of twelve different countries.

The present work has been carried out under the project UNESCO IGCP 519: Integrated management of coastal aquifers in Iberian America.

Keywords: Coastal aquifers, Iberian America, marine intrusion, hydrogeology

Drought and discarge effects on groundwater availability of a wide semiarid region: the case of Apulian region (Southern italy)

[1] Maurizio POLEMIO, [1] Vittoria DRAGONE, [1] Pier Paolo LIMONI

[1]CNR-IRPI, via Amendola, 122/I, Bari, Italy

ABSTRACT

The Apulian region is characterized by very low availability of surface water resources due to the its widespread karstic nature. Considerable groundwater resources are located in large carbonate coastal aquifers. Groundwater is often the only available resource for diffuse water-demanding human activities in the area. Groundwater for domestic, irrigation and industrial use has been withdrawn in large and increasing quantities over the years, due to the development of the local population. Groundwater is affected by two types of degradation risks: quality and quantity degradation. There is salt contamination of the Apulian groundwater, due to the effects of seawater intrusion. Nowadays, a strong connection between the increase in salt contamination and the lowering of piezometric levels, which can be ascribed to groundwater overdraft and/or a natural decrease in groundwater recharge, has been recognised in coastal aquifers. For this reason a decreasing piezometric trend highlights not only a decrease of groundwater availability, but also a risk of quality degradation. Starting with the analysis of a long hydrological time series, the dramatic decreasing trend of groundwater availability is characterised, and the negative effect in terms of groundwater quality is highlighted.

This study is based upon the analysis of monthly time series, mainly piezometric data, including rainfall and temperature measurements.

Keywords: groundwater degradation, semiarid climate, hydrological time series, Italy

TOPIC 16

Valuing groundwater quality and its importance for the sustainable development of dependant ecosystems and populations - economic concepts and approaches

Economic analysis to support the River Basin Plan: an example in the Tevere River Basin (Eastern Monti Cimini- Central Italy)

[1]Antonio MASSARUTTO, [2]Alfredo DI DOMENICANTONIO, [3]Paolo TRAVERSA, [3]Valeria VERGA

[1]Università di Udine, Dipartimento di Scienze Economiche, 30/A via Tomadini, 33100 Udine,
e-mail: antonio.massarutto@uniud.it
[2]Autorità di Bacino del Fiume Tevere, 12 via V. Bachelet, 00185 Roma, Italy,
e-mail: didom@abtevere.it, paolo.traversa@abtevere.it
[3] WWF Ricerche e Progetti, 12 via Basento, 00198 Roma, Italy,
e-mail: valeriaverga@gmail.com

ABSTRACT

Mining areas in mountain regions have led to the infiltration of highly contaminated waters, which transport the The economic analysis of the River Basin Plan is to be understood as a support for the definition of water policies through a series of actions, such as:

- defining profitable use from a social point of view, in order to protect them;
- defining a mix of interventions for the achievement of the policy objectives, minimizing the costs and distributing them fairly over the different areas of the community;
- defining financial mechanisms to cover all the costs associated with the supply of water resources.
- Comprehensively, the economic analysis allows one to analyze and quantify the effects of water resource allocation on different users in the river basin.
- The economic analysis of the planned measures has a double objective.
- to minimize the social cost of the water uses, individualizing the overall less expensive measures required for reaching the objectives;
- to know how the costs are distributed and which social actors are involved (farmers, water service users, energy producers, …), as well as the eventual differences between territorial areas.

The methodological process provides the first general analysis of all the basin, making it possible to characterize different uses of the water resource. The second step is to determine, on the basis of the previous analysis, the basin areas characterized by a critical state of the water resource (scarcity) and different concurrent uses, in order to proceed with an in-depth analysis. An analysis of different scenarios of water resource use (with reference to the possible measures needed to be implemented: decision-making norms, infrastructural interventions, etc.) is carried out in this area. In the context of each scenario a thorough assessment of the value of water in regard to conflicting uses is conducted through methodologies that allow the assessment of the different values involved.

The following main consumptive uses have been identified:

- household
- agriculture
- industry
- hydropower

Recreational uses and other environmental functions related to landscape and ecological quality are also being investigated.

The paper will present the results of the characterization and economic evaluation of water uses in the hydrogeological basin of the eastern side of the Monti Cimini in the Tevere River Basin, as well as some considerations of the economic analysis methodologies, such as tools to support river basin water management. In particular, scenarios from general databases (land use, inventories, etc.) will be compared with scenarios from hydrogeological balance data with distributed parameters.

The study area is a part of the Monti Cimini volcanic hydrogeological system, north of the city of Rome. The structure is related to the Quaternary volcanic activity which took place in Central Italy. This area is defined as a Water Body in accordance with the Water Framework Directive 2000/60.

A general imbalance of the water circulation emerged from studies on the assessment of the hydrogeological balance carried out in this area. Excessive groundwater withdrawals cause a lowering of the water levels in the aquifer. Consequently water resources are subtracted to the surface water circulation. For this reason tools were set up in order to identify areas characterized by higher withdrawal rates.

The objective of this work is to recreate economic assessment scenarios that are closer to the actual distribution of water uses over the territory.

Keywords: Economic analysis, water management, river basin planning

The importance of groundwater flow systems functioning in environmental hydrological services payment programme in Mexico

[1]Liliana A PEÑUELA-ARÉVALO, [2]J Joel CARRILLO-RIVERA

[1]Earth Sciences Postgraduate Programme, Geophysical Institute, UNAM, México
e-mail: lilianapenuela@gmail.com
[2]Institute of Geography, UNAM, México, e-mail: joeljcr@igg.unam.mx

ABSTRACT

In the last decade, the boom of climate change awareness has created an awareness in different communities of the world because of its expected negative effects on natural resources, such as water and forest. Governments are now interested in formulating new strategies towards sustainable development, to protect and preserve nature and to find equilibrium between human activities and the environment.

One of the recent strategies created is the environmental services payment programme (ESPP), which makes a payment to the owners of territories of environmental interest. The owners are obligated to preserve specific characteristics of their land to guarantee the offer of environmental services. There are four principal ESPP in the world: hydrological, carbon capture, biodiversity and scenic beauty.

Mexico began in 2003 the first Environmental Hydrological Services Payment Programme (EHSPP), based on the Costa Rica experience from 2000 to 2003. The programme is operated by the *Comisión Nacional Forestal* (National Forestry Commission, CONAFOR by its Spanish acronym). Its aim is to stimulate the communities of the mountains to preserve their forest areas and more specifically to keep their groundwater recharge potential. The hypothesis of the program is that the existence of a forest cover contributes to regulate the hydrologic cycle besides the provision of other environmental services. CONAFOR makes an annual payment to the communities (owners of land with forest) who demonstrate the conservation of the forest area during the payment period.

This study is focused on the environmental hydrological services payment (EHSP) to the south of the Mexico Basin. It includes twenty *ejidos* (communal properties) that are grouped in two zones (Fig. 1).

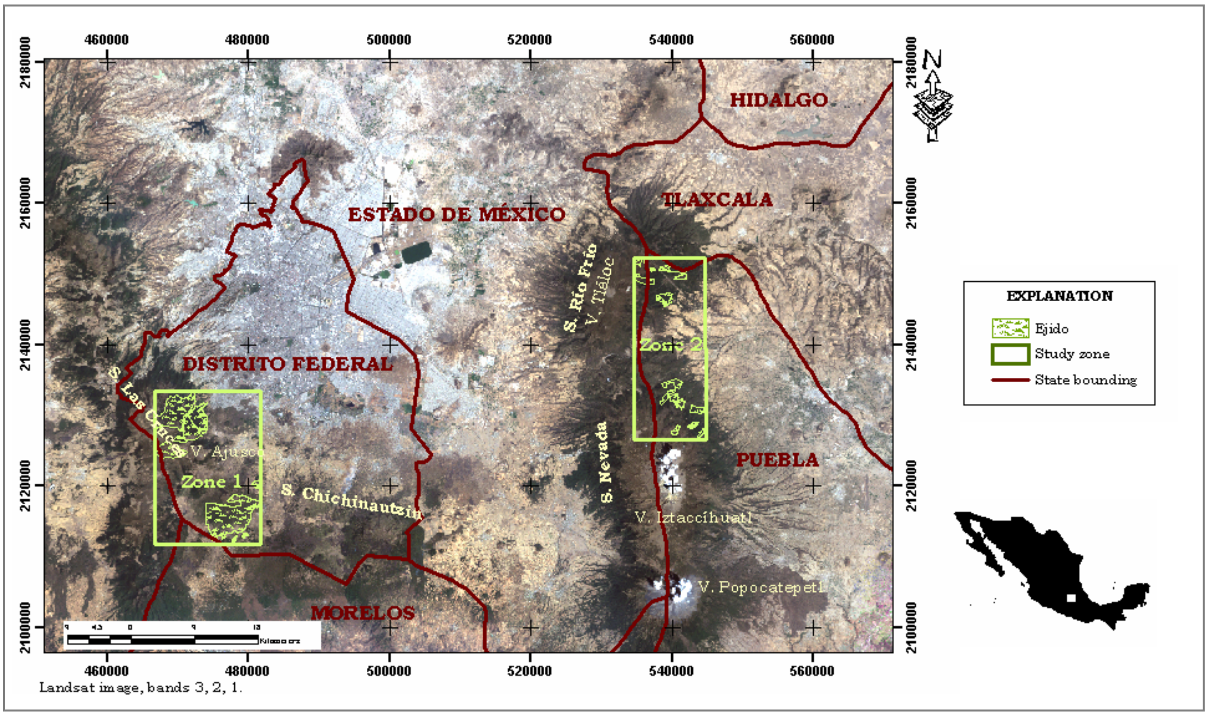

Fig. 1. Location of the study reference territory and hydrological services evaluation zones.

A preliminary study of the physical effects of the application of EHSP in the two study zones was conducted for the *Instituto Nacional de Ecología* (National Ecology Institute, INE by its Spanish acronym) in 2003, which reported a lack of control on springs and wells (yield, water quality, lack of compliance to sanitary and technical norms) as well as forest cover. Fieldtrips revealed forest was cut and the quantity of trees sometimes fails to match with eligibility criteria.

The number of *ejidos* and other communities involved in the EHSP in Mexico is increasing but there is a lag in groundwater knowledge and its interaction with different elements of the landscape. It is clear that the application of this programme was not supported with studies of the physical media (specifically hydrological and hydrogeological) that would have identified groundwater recharge areas (aim of EHSP) and possible impacts to water or to other elements of the environment.

This study identifies and evaluates processes related to impacts to water through the knowledge of the functioning of the groundwater flow system and the response of other components of the environment. The first part of the study was the integration of data bases of accessible information from the study zones (climatology, geomorphology, hydrology, lithology, hydrogeology, edaphology, vegetation) and the collection of groundwater samples for physical, chemical and isotopic analyses.

The geological units outcropping in the reference territory have a regional extension and a continuous distribution; they are more than 2,000 m thick and are composed mainly of fractured volcanic rocks of Tertiary and Quaternary age that correspond to the Trans-Mexican Volcanic Belt. These units cross central Mexico from west to east over a distance of more than 1,000 km that are about 400 km wide. In the reference territory the volcanic units overlay a sequence of more than 1,000 m of fractured and karstic limestone strata. From the groundwater flow systems perspective, there is an underground hydraulic continuity of surface watersheds which, is enhanced by the thickness (depth to basement) of more than 3,000 m.

Results from the study zones indicate the prevalence of springs representing local and intermediate groundwater flow systems (Tóth, 2000) with temperatures of 8 to 25 ºC and electrical conductivities of 67 to 854 μmhos/cm, respectively. The aim of the EHSP is to pay for the conservation of recharge areas; an aim which is not fully acknowledged because several *ejidos* that receive payment are located in discharge areas. This contradiction is a result of a lack of previous studies to determine the location of recharge areas. However, this study recommends the PEHS to include discharge areas for payment in order to control the chemistry and water discharge yield for subsequent studies to understand the functioning of prevailing groundwater flow systems.

This study is an initial contribution to the knowledge of groundwater dynamics in the south of the Mexico Basin and creates a consciousness of the importance of understanding the groundwater flow systems functioning before any application of subsequent EHSP or any other environmental programme. This kind of analysis may assist to obtain improved results that provide data on the location of recharge areas from where their importance in the contribution to specific springs might be defined and the benefit to the environment could be evaluated.

Keywords: Environmental hydrological services, groundwater, flow systems, recharge and discharge areas

The problems and father of groundwater of colliery in east China

[1] Li JUNHU， [2] Dong YONGGUAN， [3] Qiu YONGQUAN

[1] e-mail: njljuhu@163.com
[2] e-mail : njdyongguan@cgs.gov.cn
[3] e-mail: njqyongquan@cgs.gov.cn

ABSTRACT

By investigating the geological environment of mines in six provinces in east China, we analyse how the ecological system has been destroyed and groundwater influenced by coalfield mining, discuss the geological calamity type, as well as its causes, and the required countermeasures. There are three sections in this paper:

1. The geological calamity type, the cause of its formation by groundwater change as a result of coalfield mining and the effect of ground subsidence, the bursting of mining water and the distribution of groundwater ecology.
2. The influence of this geological calamity on the ecological system because of groundwater change.
3. The governance technology, economic policy and steps to measure the geological calamity as a result of groundwater change to be taken by the government of China.

***Keywords**:* coalfield mining; groundwater; ecological system; east China

TOPIC 17

Other major groundwater issues

A proposal to protect Aquifer Dependent Ecosystems in South Africa: recommendations for sustainable governance of a critical resource

[1]Christine COLVIN and [1]Irene SAAYMAN

[1]Natural Resources and the Environment, CSIR, Stellenbosch, South Africa.
email: ccolvin@csir.co.za,
email: isaayman@csir.co.za

ABSTRACT

This paper summarises a proposed policy to the South African Department of Water Affairs for the sustainable protection of aquifer dependent ecosystems (ADEs). The 1998 South African National Water Act changes the focus of groundwater management from the classic borehole and well-field safe yield objective, to one of more integrative management and the pro-active protection of water resources and dependent ecosystems. One of the objectives of the Act is "protecting aquatic and associated ecosystems and their biological diversity". There are a variety of ecosystems which are linked to aquifers in South Africa and dependent on groundwater: springs, rivers, wetlands, estuaries, riparian zones and terrestrial forests and veld. This variety and dependency on a hidden, sub-surface source, means that they are difficult to recognise, manage and protect as an entity because they encompass a range of habitats and environments. An overarching policy is considered necessary because: a range of spheres and tiers of government are mandated to protect ecosystems and their water requirements, including ADEs. These organs of state are currently under-capacitated and implementation is incomplete and uncoordinated; groundwater abstraction is controlled at municipal, mine, farm, village and household levels, currently with little understanding of the potential impacts on the surface environment. Given that the principals of sustainability underwrite the current legislation and the legal mandate already exists for the protection of ADEs, the overarching goal of this policy is*: To define operational objectives to enable the protection of groundwater requirements for protected aquifer dependent ecosystems*.

A gap analysis is outlined in this paper which indicates that operationalising sustainable groundwater management and the protection of ADEs will require a campaign style programme to provide an enabling mechanism for coordination and focus for sustainable groundwater management. The core duties will be to: direct the generation of data/ information and knowledge on the occurrence and extent of ADEs and dependency on groundwater; facilitate a process of (conservation) prioritisation of ADEs and contribute to understanding ecosystem trade-offs when classifying groundwater resources; inform the diverse range of groundwater users on best practice for sustainable use. It is proposed that the campaign will form an Aquifer Health Programme, to reside within the already functional River Health Programme. The programme should begin with pilot testing of the research, monitoring, governance and public information requirements for successful implementation in an area where ADEs are at risk. Mechanisms to link job-creation to the Aquifer Health programme should be explored, as has been successfully achieved in the Working for Water Programme.

Drawdown hazard of springs and wells in tunneling: predictive model and verification

[1]Riccardo TORRI, [1]Antonio DEMATTEIS, [1]Massimo SPANO, [1]Luca DELLE PIANE and [1]Benjamin SERRANO

[1]SEA Consulting S.r.l. Via Cernaia 27 – 10121 Turin, Italy, e-mail: torri@seaconsult.it

ABSTRACT

Considerable progress in the management of the hydrogeological impacts of underground works on springs and wells has been made during the last fifteen years, due to increasing attention paid to environmental aspects related to water resources, has been made. At present, the management of the impact that deep tunnel have on groundwater is an essential part of the tunnels design. A new approach that aims to define a general methodology for evaluating tunnelling impacts on groundwater-flow has been proposed previously (Dematteis *et al*. 2001): this method is a probabilistic analysis called Drawdown Hazard Index (DHI) based on the application on hydrogeological problems of the system approach developed by Hudson in rock engineering (Hudson 1992). Since 2001, DHI method has been applied to several underground construction design. This paper presents a recent application of this method to an 8 km tunnel in the Eastern Pyrenees: DHI forecast had been provided during the design phase. Back-analysis has been provided during the excavation and allowed the sensitivity analysis of the fundamental parameters in relation with the hydrogeological context. Great care has been taken in fault and shear zones and fractured rocks that have an important role in hydrodynamics behaviour of the groundwater systems intercepted by the tunnel. The DHI analysis was carried out on over 100 springs and wells fed by different groundwater systems. As a matter of facts, in the studied area different types of water outflow occur: type-1 springs are connected to local and shallow circuits whereas type-2 thermal and mineral springs are linked to deep and regional groundwater systems and associated to gas emission (mainly CO_2) along the fault zones. The case study presented here is based on geological and hydrogeological analysis, geochemical and isotopic data and is completed with a monitoring campaign of the water points began before excavation and measurements of the water outflow from the tunnel during the boring phase.

The aim of this method is to provide a tool of analysis that is useful during the tunnel design phase, also during the conception of a water management project and that enhances the application of environmental laws concerning water resources.

Keywords: groundwater protection, risk analysis, groundwater monitoring, tunnelling

Management of groundwater in Gaza strip

[1]Prof. Magdy H. MOWAFY, [2]Eng. A.moein Mohamed SHAHWAN

[1] Professor of water structures, Head of Water Eng. & Water Structures Eng. Dept. Zagazig University, Faculty of Engineering.(E-Mail, Magdy_Mowafy@hotmail.com).
[2] Ph. D. Student in Water Structures Eng. Dept. Zagazig University, Faculty of Engineering.
(E-Mail- alyamen_shah@yahoo.com)

ABSTRACT

Gaza Strip area is about 365 km^2; the length from the north (Bait hanoun) to south (Rafah) is 45 km. The width ranges from 5-7 km in the northern area for a maximum of 12 km in the south. it is bounded on the west by Mediterranean Sea, on the east by the green line of Israel, in the South also by Israel and on the west by Egypt. Groundwater is the only natural resource in Gaza Strip, even though the quality is very poor in some areas. There is very limited water supply for domestic use that is potable and more than 70% of the aquifer is brackish or saline water and less than 30% is fresh water. About 65% of the total pumped water is used for agricultural purposes. If uncontrolled pumping is allowed to continue the aquifer, which is the primary source for the Gaza Strip, will become unusable as a source of fresh municipal water and most agricultural extraction will be too saline for irrigation. Drinking water in Gaza Strip is made available for people by digging wells. These water wells are distributed along the Gaza Strip from north to south along the coast. Heavy-duty vertical multistage centrifugal pumps are usually used to pump water from the groundwater reservoir. Rainfall is the main recharge source for groundwater with an average (300 mm/year). The groundwater in Gaza Strip is over-pumped. It is estimate over between 120 – 140 million cubic meters (MCM) is pumped from the coastal aquifer per year, although the sustainable yield of the Gaza sub-aquifer is between 50 – 60 MCM/yr. The amount of water that can be extracted from the aquifer annually will interpret the sustainable yield, while still maintaining ground water levels and water quality.

This research will determine:

1. The actual situation of water wells in Gaza Strip to propose the required fast action to be taken towards improving the water supply management system.
2. Formulate a water resources development plan to achieve both of the optimum usage of the resources and conserving it for sustainable development.
3. Using a suitable computerized system to managing and planning water supply in Gaza Strip.
4. Develop a new systematic plan; for integrated management and operation of the available water resources.
5. Recommending the operational groundwater plan for Gaza Strip.

Methodological approach for a quantitative evaluation of hydrogeological impact produced by tunnel construction in fractured rocks

[1]Juan R. RAPOSO, [1]Jorge MOLINERO, [1]Juan M. GALÍNDEZ

[1] Universidade de Santiago de Compostela. Escola Politécnica Superior. 27002 Lugo, Spain, e-mail: jraposo@lugo.usc.es, molinero@lugo.usc.es, johannes@lugo.usc.es

ABSTRACT

Tunnels below the water table constitute a preferential flow path through which water stored into rock massifs may drain. Drawdown of water table induced by the excavation may cause geotechnical, hydrological and environmental impacts, which in turn may affect private wells and springs close to the tunnel axis. Furthermore, this impact on particular wells for water supply presents a relevant problem in densely populated rural areas.
In this work, a procedure for environmental monitoring of a tunnel excavation is presented, along with a new methodology for quantitative evaluation of the hydrogeological impact produced, by means of the development and calibration of Water Budget Models over the affected hydrological basins.

The methodology applied herein makes use of lumped models in order to characterize the aquifer under unaltered conditions, i.e., before the excavation of the tunnel. To that aim, the code Visual Balan (Samper et al., 1999a) was employed. Visual Balan is a hydrological modelling code which allows for the use of daily hydrometeorological data into water budget calculations. Hydrological lumped models enjoy several advantages such as the availability of required data, easy use, reduced cost and applicability to any type of groundwater recharge. These models, appropriately calibrated, are capable of reproducing the evolution of the water table and the discharge rate of the aquifer as a function of meteorological data and the physical parameters of the medium, as can be seen in Fig. 1.

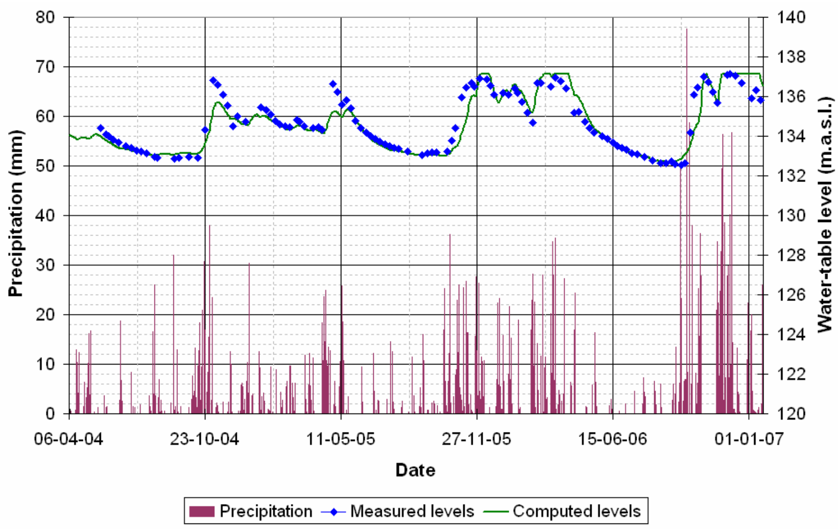

Fig. 1. Water table evolution measured (dotted line) and computed (solid line) in one of the basins under study.

Physical variables such as water-table level and discharge rates from the aquifer undergo natural oscillations. This suggests the need to distinguish those variations with respect to those induced by the tunnel excavation. This methodology has been applied successfully to a case study of tunnel construction in a fractured granitic bedrock near the city of Ferrol (Northwest of Spain). Fig. 2 shows the quantitative evaluation of the hydrogeological impact exclusively due to the construction of a tunnel in one of the observation points available in the site.

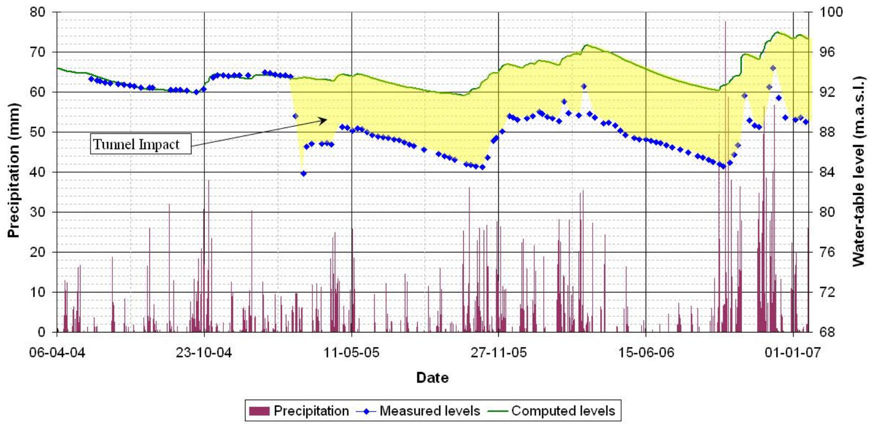

Fig. 2. Quantitative evaluation of the hydrogeological impact in one of the observed points in an affected basin.

It allowed the identification and quantification of an increase of the recharge rate after the construction of the tunnel impacted on the area.

The increase of the hydraulic gradient in the unsaturated zone favours the infiltration of rainwater into the aquifer. According to the analyzed data, after the excavation of the tunnel, the recharge rate of the aquifer rises up to 2.5 times with respect to the recharge rate under unaltered conditions, as can be seen in Fig. 3.

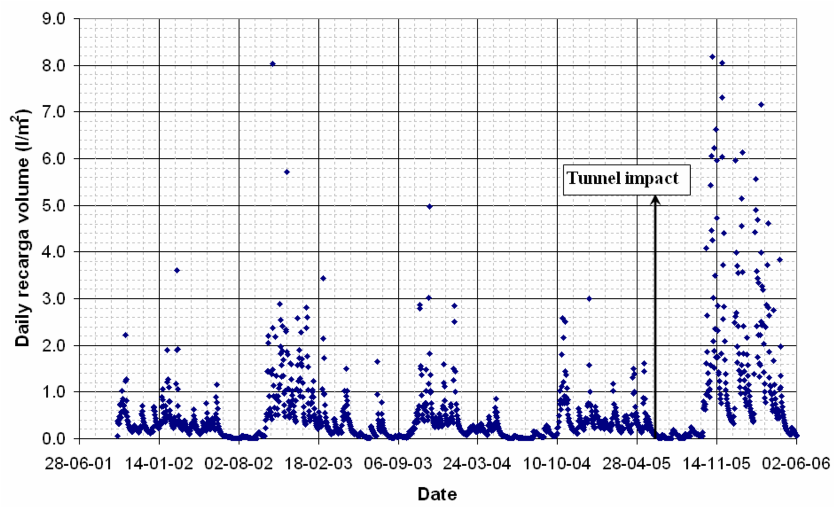

Fig. 3. Computed recharge function in one of the basins under study. Water volume infiltrated into the aquifer in $L*m^{-2}*day^{-1}$.

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Keywords: Hydrogeology Impact, Tunnel, Water budged, Modelling

Multi-tracer tests to assess the impact of the new railway tunnels in Northern Tuscany, Italy, on ground and surface waters

[1]Valentina VINCENZI, [1]Alessandro GARGINI, [2]Nico GOLDSCHEIDER, [3] Leonardo ERMINI

[1] Earth Sciences Department, Univ. Ferrara, via Saragat 1, Ferrara, Italy, e-mail: vncvnt@unife.it, gga@unife.it
[2] Centre of Hydrogeology, Univ. Neuchâtel, Switzerland, e-mail: nico.goldscheider@unine.ch
[3] Florence County Government, via Ginori, 10, Firenze, Italy, e-mail: l.ermini@provincia.fi.it

ABSTRACT

Between 1996 and 2005, 73 km of high-speed railway tunnels were drilled between Bologna (Emilia-Romagna region) and Florence (Tuscany region), across the Northern Apennine chain (Italy). The 7 main tunnels are 3.5 to 18 km long and the maximum rock coverages range between 518 and 556 m. Four of the tunnels cross siliciclastic or calcareous turbidites, generically described as Northern Apenninic Flysch, consist of an alternation of sandstones and claystones. Despite the intense and clearly visible fracturing of the sandstones, these formations were previously considered as non-aquifers. However, during the drilling process, large quantities of water arrived in the tunnels, often as sudden inrushes at places where the tunnel intersects fracture and fault zones. Since then, the flow rates have only slightly decreased: tunnels are still draining the aquifer.

An environmental monitoring programme, performed since 1995 by the drilling consortium CAVET, collected a database of springs and streams. The monitoring revealed dramatic changes: 31 main springs, previously used for public water supply, dried up totally or seasonally; 11 creeks, 10 of which had a permanent flow previously, are now mostly dry during the summer season. The loss of spring and stream flow corresponds approximately to the flow rate of the tunnel drainage.

Before the tunnels were constructed, stream baseflow during the dry season was supplied by the aquifer, either diffusely from the bordering slopes or localised from extensional faults and fractures intersecting the streambed. This baseflow was about three times higher than the spring discharge, suggesting that the streams represented the major natural drainage network of the hydrogeological system (Canuti et al. 2005, Gargini et al. 2006). Although piezometer data are relatively scarce, it can therefore be supposed that the groundwater level in the aquifer was generally above the streams and often followed the topography, i.e. drainage divides coincided approximately with topographic boundaries.

As a consequence of the tunnel drainage, gaining streams have transformed into losing streams, suggesting that the regional groundwater surface has been lowered below the level of the streams. The drying up of the streams and springs deteriorated the freshwater ecosystems and also induced negative effects on human activities, such as agriculture, cattle breeding and fishery, but also drinking water supply. Various liability and environmental issues arose, addressing the project responsible and regulatory agency. With the goal to mitigate the environmental impact, the Florence County Government has started a feasibility study focusing on the best remedial works that are currently available for stream baseflow and associated surface ecosystem preservation.

In order to verify and quantify the hypothesis of regional aquifer drainage towards the tunnels, and to localise the main hydraulic stream-tunnel connections, a comprehensive investigation program was conducted on 4 watersheds, including 4 multi-tracer tests with a total of 9 injections into losing streams and monitoring in 3 tunnels. These were the first tracer tests conducted in turbiditic formations at a regional scale, except for a first pilot test with uranine performed in 2002 on one of these watersheds (Canuti et al. 2005).

Uranine was used as a tracer for all experiments; lithium, sulforhodamine G and tinopal CBS-X were additionally used for some experiments. The monitoring program for the tracers included a combination of continuous measurements (flow-through field fluorimeters), discrete sampling (manually and with auto-samplers), and qualitative / accumulative sampling by means of charcoal bags. The flow rates were measured using the salt-dilution methods. Uranine always produced positive results, while the other tracers failed, showing once more that uranine is the most reliable artificial tracer. The last tracer test was done in order to compare uranine and sulfo G signals, and the low reliability of the second one has been confirmed.

The results proved connection between the streams and numerous water inlets in the tunnels, with maximum linear distances of 1,3 km and velocities of 90 m/d, mainly along faults. In some cases the underground flowpaths cross the topographic borders (valley and mountain ridges), suggesting that the tunnel has completely modified the natural regional flow system. The tracer tests also confirm the hypothesis that the regional groundwater level is now below the level of the streams (Fig. 1). So, the main process of water loss is the regional lowering of the groundwater table and the progressive aquifer depletion. In a natural state, the streams were fed by groundwater. Now, the streams have lost most of their natural baseflow during the dry season and are only fed by insignificant shallow water reservoirs, such as perched aquifers, or simply by

ephemeral interflow along the slopes. This remaining quantity of stream water often sinks into the fractured underground.

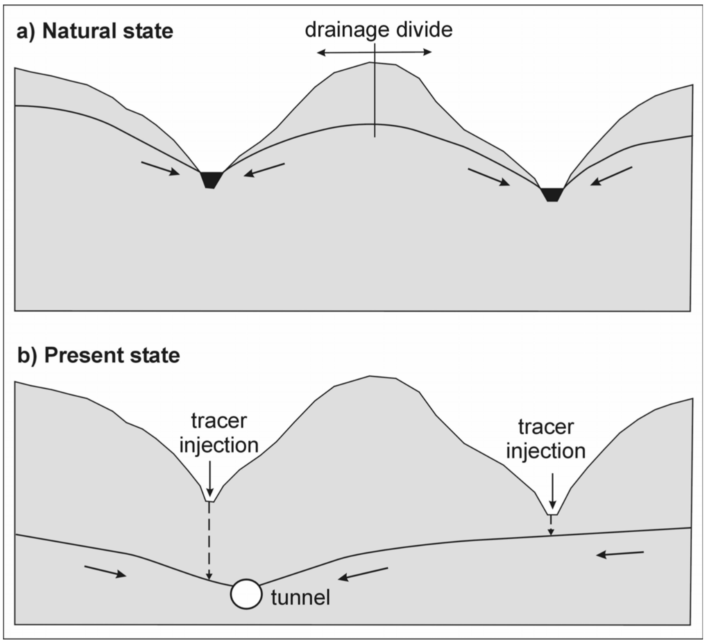

Fig. 1: Conceptual model of the regional surface and groundwater flow in a natural state (a) and after the tunnels were drilled (b). The model was set up on the basis of hydrological observation and confirmed by the tracer tests.

Although aquifer restoration is impossible, some kind of stream baseflow preservation is necessary for the surface water ecosystems defence. Two main approaches were evaluated by the Florence County Government: (1) the sealing of the streambeds in the most fractured reaches by means of invasive techniques, such as concrete injection or massive use of bentonite, and (2) the installation of water pipes in order to by-pass the reaches where the highest water losses occur. The preliminary results of the tracer tests suggest that the network of mountain streams, often cut into fractured sandstones, is so complex that the sealing of streambeds appears unfeasible. For this reason, a first pilot-experiment was realised on a creek: a by-pass tube, with a diameter of 120 mm and a length of 1400 m, has been posed in the median reach of this creek. The preliminary results are quite satisfactory and suggest the setting up of a set of fully impermeable pools connected by a network of by-pass tubes as a long-term solution to the “stream to tunnel drainage”. This solution, although causing the complete drying up of some reaches of the creeks during low flow season, allow the maintenance of an effective ecosystem and, at the same time, represents a reversible solution if better techniques should be available in the future.

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Keywords: Tracer test, tunnel, fractured aquifer, turbidites, stream baseflow

Spatial Distribution of Tunnel Inflows in the Central Aar and Gotthard Massifs (Switzerland)

[1]Olivier MASSET, [2] Simon LOEW

[1]Engineering Geology, Swiss Federal Institute of Technology ETH, Zürich, Switzerland,
e-mail: olivier.masset@erdw.ethz.ch
[2] Engineering Geology, Swiss Federal Institute of Technology ETH, Zürich, Switzerland,
e-mail: simon.loew@erdw.ethz.ch

ABSTRACT

Deriving the large scale hydrogeological properties of crystalline rocks is of relevance for the sitting of deep geological repositories, for geothermal and hydrocarbon reservoir exploitation, for groundwater resource management, for tunnelling and other geotechnical applications. During the last 15 years, several researchers attempted to obtain these properties in different locations and with different methods. Most of them used the spatial distribution of faults and/or joints to derive large scale hydrogeological properties of such rocks. The originality of the present study is to deal with the distribution of inflow to tunnels and galleries directly instead of estimating groundwater flow distribution from the distribution of discontinuities (faults and/or joints). The goal of this study is to compare the obtained inflow distributions with discontinuity distributions in the same area.

The studied area is located in the Central Swiss Alps and includes the Aar massif and the Gotthard massif. Each of these units has its own multiphase geologic and tectonic history resulting in spatial variations of the distribution and type of fractures and faults. For example in the studied area, ductile shear zones dominate in the Aar massif and most of the brittle faulting occurs in the Gotthard massif.

Inflow data used for this study come from the following four tunnels and galleries:

1. The Goeschenen pressure gallery: located in the Aar massif, oriented parallel to the main tectonic contacts (E-W), 8300 m long, maximum overburden of 400 m,
2. The Realp leg of Furka base tunnel: located in the Gotthard massif, oriented parallel to the main tectonic contacts , 3800 m long, maximum overburden of 1515 m,
3. The Gotthard railway SBB tunnel: located in the Aar and Gotthard massifs, oriented perpendicular to the main tectonic contacts, 15000 m long, maximum overburden of 1700 m,
4. The Gotthard A2 security gallery: located in the Aar and Gotthard massifs, oriented perpendicular to the main tectonic contacts, 16000 m long, maximum overburden of 1500 m.

During construction, the geological and hydrogeological survey of these galleries also included the location of each inflow and its rate (or class of rate). In the case of Gotthard SBB tunnel, inflows have been reported in three classes: light dripping zone, heavy dripping zone and continuous inflow. In Fig. 1, the inflow spacing of these three different classes is plotted against their cumulative frequency on a double logarithmic plot.

Continuous inflow spacing (crosses) tends to plot on a straight line (dashed line), which is a characteristic of power-law distributions. Its mean spacing is 167 m. Light dripping zone spacing (stars) plots on an exponential curve (continuous line), which is characteristic of random distributions. Its mean spacing is 79 m. Finally, the heavy dripping zone spacing (dots) lies in-between but its trend is closer to the exponential curve. Its mean spacing is 74 m. Other tunnels of the region show the same relations. Therefore inflow distribution type seems to be a function of inflow rate.

It is well known from former studies that most of the continuous inflow result from the intersection of a gallery with a fault or a fault zone and that most of the dripping zones can be attributed to joints. However, joint spacing distribution of the Gotthard A2 security gallery is power-law whereas light dripping zone spacing distribution in Gotthard railway SBB tunnel and in Goeschenen pressure gallery is negative exponential. Similarly, fault, fault zone and shear zone spacing distribution in Gotthard A2 security gallery is close to negative exponential whereas continuous inflow spacing distribution of the same gallery is power-law. Thus, there is no simple correspondence between the type of discontinuity spacing and inflow spacing. The distribution of continuous inflow spacing in a tunnel is a function of the brittle fault zone spacing, the distribution of conductive fractures within the fault damage zones, and the distribution of flow within the considered discontinuities.

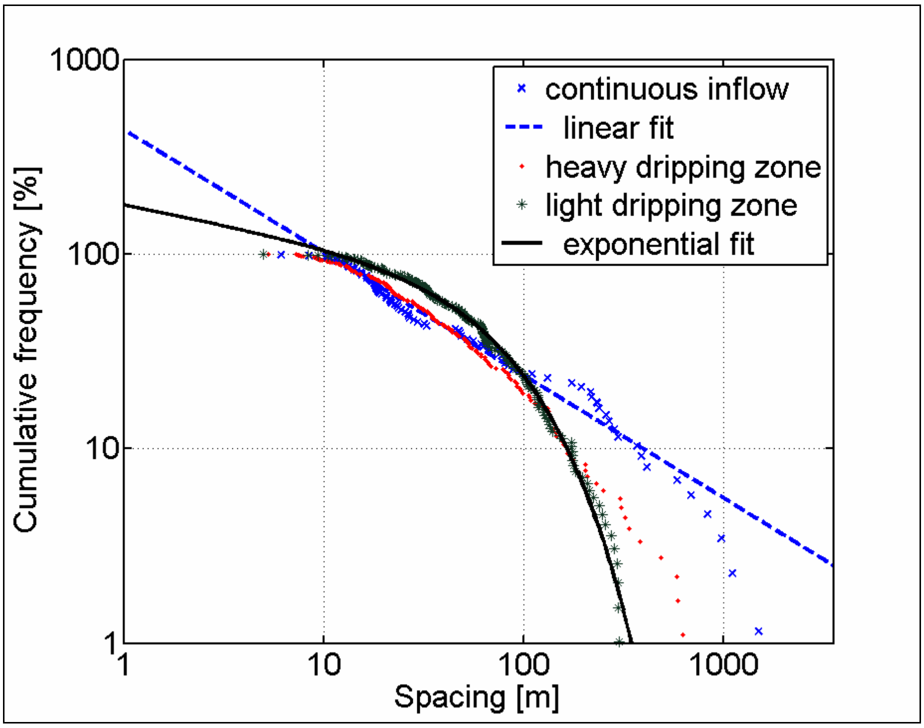

Fig. 1. Continuous inflow and dripping zone spacing in Gotthard SBB tunnel log-log plot.

Keywords: Groundwater, crystalline rocks, tunnel inflow, fracture flow, channelling

Water Resources Management in Tunneling: insights in the decision-making process to improve tunnels environmental sustainability

[1]Antonio DEMATTEIS, [1]Riccardo TORRI, [1]Michel LOOSER

[1] SEA Consulting, 27, Via Cernaia, 10121 Torino, Italy, e-mail: dematteis@seaconsult.it, torri@seaconsult.it

ABSTRACT

An integrated decision-making process for water-resources management in tunneling has been developed by the authors during the design and construction phases of several large tunnel projects in Europe. All those projects concerns deep tunnels under construction or under design in mountain regions, and therefore this integrated decision-making process is particularly suggested for complex, fissured and heterogeneous geological settings.

During the planning stages designers' activities normally focuses on the way the groundwater influences the tunneling techniques and tunnel design. The assessment of environmental impacts on tunnel design has been introduced only in recent times. This is the consequence of some European Community Directives (00/60/CE, 91/271/CE and 98/83/CE), whose adaptation is gradually increasing in all nations of the Alpine region (Italy: D.L. 152/06, L. 36/94; France: Loi sur l'Eau 92-3/92; Switzerland: LEaux 24/01/91; and Austria: BGBI 215/59 and BGBI 74/97). These laws rightly and clearly demand the protection of groundwater.

Today those laws are applied but, as every tunnel has a very specific context, it is difficult to extrapolate the results achieved on new situations. There is a lack of consolidated methodologies for evaluating tunneling impacts on underground water-resources in a complete and integrated manner. This paper describes a decision-making process aimed at helping the water resources management in tunneling. This process should also improve the environmental sustainability of tunnels. The usage of water discharge drained into the tunnels and the exploitation of energy coming from those waters and from water and rocks heat transforms what was normally considered as a lost into a gain.

This paper tries to make a synthesis of experiences coming from the Turin-Lyon railway connection (53 km base tunnel between Italy and France in the western Alps), the underground Milan–Genoa railway (22 km long tunnel in Apennines and Alps, Italy) and the Brenner Basis railway Tunnel (54 km between Austria and Italy). The effectiveness of the approach was tested during the tunneling phases of the Pont Ventoux Hydroelectric power plant (northern Alps in Italy), the Modane exploration tunnel of the Lyon–Turin railway connection (France) and the Perthus railway tunnel (8 km long between Spain and France).

This decision-making process links six topics aimed at risk assessment analysis, to valorize the water resources and to compensate the impacts. Those topics are: (1) definition of the hydrogeological reference model (based on the geological data); this includes the geometric and hydrodynamic parameters characterization that allows to find the most critical areas and to give a qualitative and probabilistic forecast for the expected hydrogeologic conditions during tunneling and operation phases (Venturini *et al*., 2001); (2) quantification of the uncertainty in terms of geological forecasting reliability (e.g. Perello *et al*., 2005); (3) prediction of tunnel discharge rates with analytical solutions for steady-state final values (e.g. the analytical approaches of Goodman *et al*. 1965, Chisyaki 1984, El Tani 2003) or transient inflows (Perrochet 2005); (4) prediction of springs and wells drawdown hazard around the tunnel (Dematteis *et al*. 2001); (5) valorization of groundwater-inflow, such as the groundwater-catchment into the tunnel and the energy recuperation from groundwater-inflow (Rybach & Pfister 1994, Unterberger *et al*. 2005) and (6) solutions that are to be adopted in order to compensate for the impact on the drained area outside the tunnel, such as the design of new groundwater-catchments.

The application of this approach should help hydrogeologists and decision makers to improve the water resources management in tunneling.

Keywords: Environmental sustainability, water-resources management, tunneling, Europe

TOPIC 17

Other major groundwater issues

Discovery of naturally high sulphate concentrations in soils and groundwater during the investigation of a salt impacted site in southern Saskatchewan, Canada.

[1]Eric FAUVEAU, [1]Laurra OLMSTED, [2]Darren STOKES

[1]Matrix-Solutions Inc., Calgary, AB, Canada, e-mail: efauveau@matrix-solutions.com, lolmsted@matrix-solutions.com
[2]Talisman Energy Inc., Calgary, AB, Canada, e-mail: dstokes@talisman-energy.com

ABSTRACT

High concentrations of sulphate were encountered in soil and groundwater (as much as 56,000 mg/L sulphate) during a routine site investigation to delineate salt impacts related to the oil industry. The purpose of the investigation was to determine the most effective remediation strategy for the site. The investigated site consists of a non-operating oil well and a remediated flare pit (waste pit). Typical oilfield-related activities have resulted in salt impacts, originating from pipeline spills between 1970 and 1990, and the migration of hydrocarbons and sodium chloride salts from the former flare pit. The surficial deposits underlying the site are composed of low-relief morainal plane sediments characterized by calcareous glacial till deposits up to 61 m thick. These deposits consist of unsorted mixtures of clay, silt, sand and calcareous gravel. The land use is agricultural with the adjacent land used for grazing of cattle. There is a feedlot supporting 80 head of cattle located approximately 400 m south of the wellhead. The landowner operates the feedlot and waters his cattle from dugouts (man-made surface/groundwater basins) which are located approximately 300 m downgradient (southwest) of the wellhead.

During the site characterization, information was obtained from historical aerial photographs. A photograph from 1959 indicated that there was a large shallow slough (natural water body) that covered most of the site and the area west of the site. In subsequent aerial photographs, the slough had dried up, leaving a white residue (salt ridge) in the area that corresponds to the margin of the slough.

An electromagnetic survey (EM31/38) was conducted to assist in delineation of the salinity impacts. Borehole drilling and the installation of monitoring wells facilitated the sampling and evaluation of soil and groundwater impacts. Groundwater was encountered approximately 2 m below ground, flowing from the area of the salt ridge towards the southwest. East of the salt ridge, the water table was found at depths of approximately 10 m. Sodium, chloride and sulphate concentrations exceed the applicable regulatory guidelines in many soil and groundwater samples. However, water samples from the dugouts do not exceed the livestock watering guidelines.

All the information acquired during the characterization of this site indicate that there are sodium chloride impacts related to the activities on the site, which were imposed on soils enriched in natural sulphate. The data collected was interpreted to indicate that sulphate-rich groundwater flows vertically upwards from a deeper strata, coming to the ground surface at the former margin of the large slough. It has been noted that groundwater samples collected in monitoring wells that are located closer to the salt ridge contain higher magnesium to calcium ratios than samples collected further away from the salt ridge. This ratio is often used as an indicator of evaporative waters. This confirms that once at the surface, the water has, over time, been subjected to highly evaporative conditions, which has played a role in the drying up of the slough to the west.

Understanding of the origin and behaviour of sulphates at the site affects the remediation strategies considered for this site. Under the current situation, the sulphate-rich groundwater plume is static. However, if the hydraulics were to change during remediation, this naturally enriched water may become mobile, putting the landowner’s dugout at risk of impact due to sulphates. Given the concentration of sulphate in the groundwater, mobilization of this plume could result in deterioration of the dugout water quality to the point where it could not be used for the intended purpose of watering livestock. Therefore, any remediation strategies for dealing with the sodium chloride impacts need to be addressed with the natural sulphate enrichment in mind.

Keywords: Hydrogeology, natural sulphate, remediation of salts

Environmental effects from extensive groundwater abstraction in the Queretaro Aquifer, Mexico

[1]Carlos VARGAS-CABRERA, [2]Jaime GARFIAS-SOLÍS, [3]Eloísa DOMÍNGUEZ-MARIANI, [4]Oscar ESCOLERO-FUENTES

[1] Postgrade Programme on Earth Sciences -UNAM, Mexico, e-mail: varcarlos@hotmail.com
[2]Interamerican Water Resources Centre -UAEM, Mexico, e-mail: jgarfias@uaem.mx
[3]Potosino Institute of Scientific and Technological Research, Mexico, e-mail: edominguez@ipicyt.edu.mx
[4]Geology Institute, Mexico, e-mail: oescolero@yahoo.com

ABSTRACT

Since the 18th century, groundwater has been the main source of water supply in Queretaro Valley. Boreholes drilled to extract groundwater have been increased in depth as the demand grows. However, the water table in the aquifer decreases with over-abstraction. As a result of this over-abstraction, the groundwater quality is also adversely affected. Springs and base flow rivers have been lost as a consequence of the water table decreases and this has caused the wetlands ecosystems in the valley around surface water bodies to disappear as well. These wetlands contrast with the prevailing semi-arid ecosystems in the region.

This paper focuses on the excessive groundwater abstraction occurring in the valley. We examine various changes in regional flow patterns, and the ever decreasing groundwater levels throughout the valley. We also examine modifications in the regional groundwater flow.

Hydraulic head data were used for hydrograph analyses; they show that the hydraulic head decreases with time. On the other hand, the historical conditions in the valley were established from the bibliographic review and oral communications with local elders and indicate the presence of surface water bodies and their associated environment.

The study area is the Queretaro Valley, along the south-western border of Queretaro State, in central Mexico (Fig. 1). The valley forms an open basin toward Guanajuato State, with the north, east and south boundaries formed by a volcanic tableland and mountains. The weather is semiarid with annual mean precipitation of 500 to 600 mm per year. This precipitation is concentrated during the summer through torrential rains.

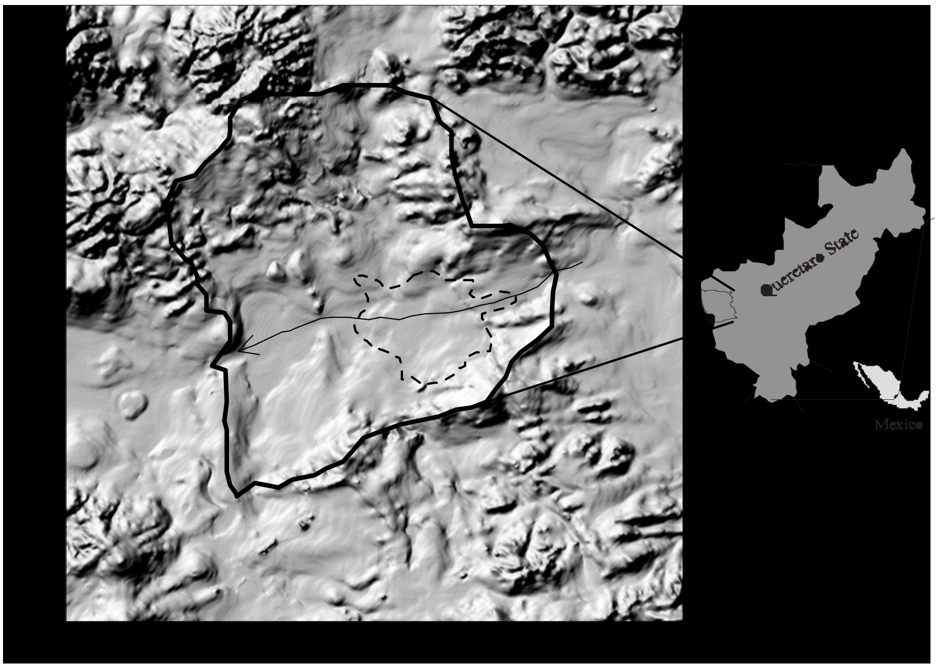

Fig. 1. Map of the study area. The figure shows the Queretaro basin's limits (continuum thick line), the urban area (dashed line) and Queretaro River (continuum thin line).

The valley´s stratigraphy consists of a Cenozoic age volcano-sedimentary sequence which underlies carbonatious, cretaceous rocks. The hydrostratigraphic units, derived from the lithologic ones, are as follow:

An aquitard consisting of the shallow, fine-grained deposits at the lowest part of the Valley; two granular aquifer units in the pyroclastic and lacustrine deposits, interbeded with two fractured volcanic aquifer units (intermediate to basic composition); and a unit of massive volcanic rocks with low fracturing which forms the underlying confining layer.

Springs and streams are indications of the groundwater manifestations on surface before the groundwater system's conditions were altered in the valley. The Cañada's spring was the main source of drinking water before the 20th century. This spring's water formed part of the Queretaro's river supply and discharged to Guanajuato State to the west. According to the initial river path, in the early 18th century, the river water was used for farming and vegetable gardens which were indigenous to the area. These agricultural products were sent to markets to the north of the spanish colony where agricultural production was scarce as a result of the arid conditions of those regions. The sale of these products resulted in economic prosperity for the local people. This increased the value of the land as well.

Others important springs, in terms of economic activities in the Valley, were the El Salto and Acequia Blanca springs to the north of Queretaro City near Juriquilla village. At the El Salto spring area a big farm known as Juriquilla in the 18th century, was established as an important agricultural production unit at that time. The rest of this water spring formed part of the Jurica River that is a water source for the abundant phreatophytic vegetation (mainly willows).

Some local names also indicate the presence of surface water bodies in the south of the valley. El Obrajuelo and El Batán are two names of places that had associated tanneries that used surface water to move the hydraulic machines used for the skin softening processes.

Springs, streams and other surface water bodies began to disappear in the beginning of the 20th century when groundwater abstraction was about 2 million cubic meters per year. Then the river flow direction began to invert. The State Water Commission (CEA) reported that in 1999 nearly 110 million cubic meters per year were abstracted from the local aquifer. This intensive abstraction has caused a decline in the hydraulic head of approximately 92 m in 32 years with a mean rate of decline of 2.9 m/year (Fig. 2). However, CEA has reported critical decreases on the order of 7 m/year in some places. Thus, the piezometric level is between 120 and 170 meters deep with a cone of depression.

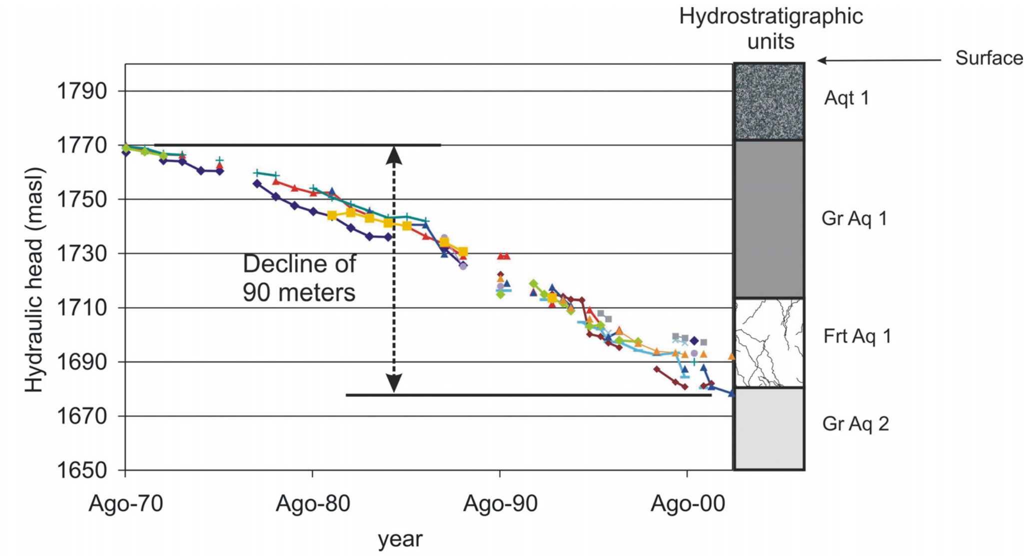

Fig. 2. Well hydrographs showing hydraulic head decline asociated with hydrostratigraphic units: Shallow aquitard (Aqt 1); Granular aquifer units (Gr Aq 1 and 2); and one Fracture aquifer unit (Fr Aq 1).

As a consequence of the water table drawdown, the springs in the valley as well as the base flows in the rivers have disappeared, with associated ecosystem impacts. The new land use, including bigger urbanized and industrial areas, tends to increase the demand for water, driving the water supply crisis of the crises of balancing ecosystems.

Keywords: springs, intensive use, ecosystems

Evaluation of the efficiency of minimization measures for the protection of groundwater from road pollution negative impacts

[1]Teresa LEITÃO, [2]Mihael BRENČIČ, [3]Manuel M. OLIVEIRA

[1] Laboratório Nacional de Engenharia Civil, Av. do Brasil, 1700-066 Lisboa, Portugal, e-mail: tleitao@lnec.pt
[2] Geologic Survey of Slovenia, Dimiceva 14, Ljubljana, mbrencic@geo-zs.si
[3] Laboratório Nacional de Engenharia Civil, Av. do Brasil, 1700-066 Lisboa, Portugal,
e-mail: moliveira@lnec.pt

ABSTRACT

In the context of the main target established by the Water Framework Directive, i.e. to have EU waters in a good state by 2015, the need for action to avoid long-term deterioration of freshwater quality to consider a programme of steps aimed at sustainable management and protection of freshwater resources is recognised.

Road pollution is among the anthropogenic activities that represent a pollution threat to the quality of EU water bodies. Its main sources include traffic and cargo, pavement and embankment materials, road equipment, maintenance and operation, and external sources. Some of the pollutants coming from road and traffic sources that deserve more attention include heavy metals (e.g. from vehicle corrosion, cargo spills and road equipment), hydrocarbons (from fuels, lubricants and bitumen), nutrients (generated from motor exhausts), particulates (from pavement and exhausts) and de-icing salt.

The importance and degree of impact of road pollution on the environment depends on the vulnerability of the receiving media, or in other words, how likely the transport of pollutants is and to which extent a pollutant can be retained in the soil. Runoff, splash/spray and seepage through the road construction and the soil are major transport routes of pollutants from the road to the environment. In order to define the areas where protection measures should be applied, several EU countries have defined areas sensitive to road pollution. In those areas, measures need to be taken in order to protect water resources from the negative impacts from roads. These measures usually include the runoff water treatment to a quality level that is acceptable for further discharge in a water body. Infiltration and retention ponds are amongst the most frequently used treatment systems (cf. Fig. 1).

Fig. 1. Infiltration pond at A2 road, Borba, Portugal

In this article, an overview of the efficiency of minimization measures implemented for the protection of groundwater from road pollution is made based on case-studies from Portugal and in Slovenia. Those results are analysed, based on a perspective of the sites sensitivity to road pollution.

Furthermore, a global assessment of existing information concerning downgradient groundwater quality is done for both countries, for areas where minimization measures were applied. Finally, aiming of better road management, a proposal of database for compiling this type of information is presented, using the example of a Portuguese database (cf. Fig. 2).

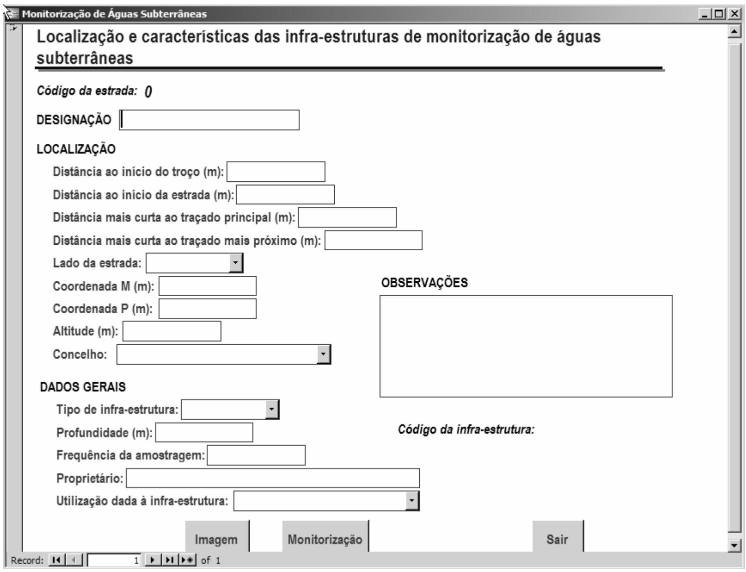

Fig. 2. Example of a menu of a Portuguese database for groundwater monitoring in road environment

The work to be presented in the article contains data gathered from several ongoing and past projects done in the National Laboratory for Civil Engineering (namely "Environmental evaluation and management of road runoff", 2001/04, to the Portuguese Water Authority; "Evaluation of the effectiveness of environmental impact minimization measures implemented in Portugal", 2005/08, to the Portuguese Road Authorities; LNEC Research Plan for 2005-2008; and "COST 351 Water Movement in Road Pavements and Embankments (WATERMOV)", 2003/07, European Union), as well as several projects carried out by the Geologic Survey of Slovenia, namely the "Water pollution from roads related to traffic load" project, and the COST action above mentioned.

Keywords: road pollution; minimization measures; groundwater protection, EU Water Framework Directive.

Groundwater Chemistry and Contamination in the Volturno River Plain, (southern Italy)

[1]Alfonso CORNIELLO, [2]Daniela DUCCI

[1] Sez. Geologia Applicata, Dip. Ing. Geotecnica, Università di Napoli Federico II, P.le Tecchio 80, 80125 Naples, Italy, e-mail: corniell@unina.it
[2] Sez. Geologia Applicata, Dip. Ing. Geotecnica, Università di Napoli Federico II, P.le Tecchio 80, 80125 Naples, Italy, e-mail: daniela@unina.it

ABSTRACT

The large plain of the Volturno River (1340 km^2) is surrounded by limestone Mesozoic mountains (N and E), by the old Roccamonfina volcano (N), by the Somma-Vesuvius volcano (S), by the Phlegrean Fields pyroclastic hills (SW) and by the Tyrrenian Sea (S and W).

The elevation of the wider part of the plain ranges between 0 and 100 m a.s.l.. The plain is made up of Quaternary alluvial-pyroclastic and pyroclastic porous deposits. Almost everywhere the "Campanian Ignimbrite" tuffs cross or underlie these sediments and overlie Plio-Pleistocene lacustrine, palustrine, and marine deposits. The sequence of the Plio-Pleistocene sediments indicated marked tectonic subsidence of the plain. In the eastern part of the town of Naples the tuffs are absent and there are a succession of volcanic-pyroclastics and alluvial sediments interbedded with peat levels and marine deposits.

The main aquifer of the Volturno River Plain is located in the alluvial, pyroclastic and marine porous sediments underlying the "Campanian Ignimbrite" tuffs. The hydrogeological setting is strongly related to the thickness and to the physical characteristics (lithification, granulometry, amount of scoria, etc.) of the Campanian Ignimbrite, which plays the role of semi-confining or confining bed. The main aquifer is recharged by rainwater infiltration and by underflow from the adjacent ranges

Although, on the basis of these characteristics, it is possible to zone areas with different hydrogeological conditions, the aquifer can be considered a single continuous body.

The piezometric surface (drawn up on the basis of a monitoring network of about 850 wells) stresses the groundwater inflows to the Piana Campana aquifer and shows a groundwater divide, which separate the flow in two parts: the first directed towards W and the second, in the eastern part of Naples, towards S. Moreover, Piezometric surface shows the same pattern of the year 1988 but a generalized lowering, due to the intensive pumping for agricultural, industrial, and domestic use.

Groundwater geochemistry has been defined on the basis of more than 300 chemical tests. These allowed to confirm the groundwater inflow from the surrounding slopes. In detail, the values of the r(Ca+Mg)/r(Na+K) ionic ratio decrease from the limestone mountains to the sea, for the enrichment in alkalines coming from pyroclastic deposits.

Volturno river plain groundwater presents different kinds of “natural contamination”such as high fluoride concentration (almost everywhere > 1.5 mg/l), related to volcanic formations, and, in some sectors, high sulphates derived from deep regional flows and heating processes (hydrothermal present and/or past conditions).

On the other hand, human activities are the cause of the widespread NO_3 contamination. Many wells showed very high nitrate concentrations (up to 150 mg/l), well over the WHO threshold of 50 mg/l, also recognised by Italian drinking water legislation (DPR 236/88, D. Lgs. 31/2001).

Nitrate contents show a drastic decrease close to the Volturno river, in spite of the massive presence upstream. The real reason for such peculiarity consists in the groundwater flow crossing of a part of aquifer with reducer conditions. Low contents in sulphate and high contents in Fe and Mn corroborate the presence of a reducing zone.

Groundwater decontamination systems are difficult, prolonged and expensive for such widespread contamination (hundreds of km^2) and therefore it is necessary to implement a pollution prevention policy, limiting the sources of nitrogen supply. The “Nitrate Contamination Risk Map” can be used to individuate different sectors and/or different sources in areas with high NO3 concentrations and to steer better decontamination actions.

Keywords: Groundwater Contamination, Fluoride, Nitrate, Volturno Plain, southern Italy

Hydrogeochemistry and Structural Control of the Area around the Ancient City of Troia, Northwestern Anatolia

Alper BABA, Doğan PERİNÇEK, Deniz ŞANLIYÜKSEL, Hande KIZIL

Çanakkale Onsekiz Mart University, Engineering and Architecture Faculty, Department of Geological Engineering, 17020 Çanakkale-Turkey, e-mail: alperbaba@comu.edu.tr

ABSTRACT

Troia is one of the oldest and most famous archaeological sites, and is located in Biga Peninsula, northwest Turkey. This site is an important point of reference for the chronology of the ancient world from the early Bronze Age through the Roman Empire.

The purpose of this study is to determine the hydrogeochemistry of waters in Troia. For this purpose a total of 55 water points around Troia (well, spring, dug and fountain) were monitored for their physical parameters. In addition, 11 water samples were collected for determination of hydrogeochemical properties (major anion, major cation and selected heavy metal concentrations). The pH of water varies from 6.8 to 7.7. The electrical conductivity values range from 161 to 2280 µS cm^{-1}. Generally water samples from aquifers of Troia showed varying properties. Based on the dominant cations and anions, four different water fasies are seen around Troia. First group, Ca-HCO_3 type, comes from springs; second group, Mg-Ca-HCO_3 and Cl type, which originates from alluvium aquifer; third enriched by Ca-Mg-HCO_3-SO_4 affected by volcanic rocks and last group water showed richness of Mg-Ca-Na-Cl and HCO_3 that comes from sedimentary rocks.

Keywords: Hydrogeology, hydrogeochemistry, Troia, tectonic

Hydrogeology in urban aquifers: a challenge in the sustainable management of the water in the cities. The case of Burgos (Spain).

[1] Luis MARCOS, [2] Silvino CASTAÑO, [2] Luis MORENO, [1] Mónica VÁZQUEZ

[1] Chemistry Department of High Polytechnical School; University of Burgos (Spain). Av. Cantabria s/n, 09001-Burgos (Spain). E-mail: qplamn@ubu.es, movaz@mixmail.com
[2] Instituto Geológico y Minero de España (IGME). C/ Ríos Rosas s/n Madrid (Spain).
E-mail: s.castano@igme.es, l.moreno@igme.es

ABSTRACT

In the time of Global Change where we live in developed societies, the sustainable management of resources becomes an ethical and technical exigency and the eyes of the managers of the water in the cities, are turning towards the underground water resources, stored in the subsoil of our large cities. Urban Hydrogeology is receiving an increasing amount of interest from the environmental people in charge and the managers of the water in our cities.

The relation between aquifers and the networks for distribution of the potable water and the residual water collectors, the tremendous modifications in the normal operating conditions of the aquifers in the urban areas resulting from the practices that are developed in the cities, and the interest to have information on and sometimes to use, the existing underground water resources in the urban subsoil, caused the development of the Urban Hydrogeology project. Also, the problems resulting from the quality of urban underground waters are receiving increased attention, due to the evident interaction of microbiological and chemical contaminants from urban activity with the groundwater of water-bearing aquifers.

The knowledge of this relation, and the study of the presence of polluting agents in these water resources, determines the possible uses of such. The city of Towns, with a population of almost 180,000, and an interest in the development of industrial scopes and infrastructures, is located mainly on the water-bearing alluvial aquifer of the Arlanzón River.

Aquifers have traditionally been ignored as part of the water management of this urban nucleus. However it has an important impact on the network of urban water distribution, in the city-planning performances on the subsoil, in the determined dynamics of pollution migration and in its potential as a complementary water resource at the time of developing an integral and sustainable water source for the city of Towns. In the present study the latter tendencies are reviewed in Urban Hydrogeology and the concrete role that the Alluvial Aquifer can play.

In this paper, we revised the relations between the surface water of the Arlanzón river and the aquifers of the town, and the chemical compositions of their waters is studied. We also established the potential and real pollution of their waters, and which of the urban human activities affects the water quality. Also, the relationship between the water supply activities and the hydrological behaviour of the aquifers have been studied.

Keywords: Groundwater, Urban Hydrogeology, Water pollution, Sustainable management of waters.

Low-Flow/Low-Volume Purging and Sampling of Ground-Water Monitoring Wells - Performance and Application Criteria

[1]David B. KAMINSKI, [2]Paulo NEGRÃO

[1] 3333 Vincent Rd, Suite 219, Pleasant Hill CA 94523, USA, e-mail: DavidKQED@aol.com
[2] rua Antonio Lapa 214, Campinas, SP 13025-240, Brasil, e-mail: p.negrao@clean.com.br

ABSTRACT

Sampling ground water has traditionally involved purging a monitoring well to remove stagnant water in the well casing prior to sampling. The traditional approach of purging three to five volumes of the well can produce large volumes of purge water and can affect sample quality and greatly increase sample turbidity that could result in "false-positive" or biased analytical results.

Low-flow/low-volume sampling is a methodology that can be used to overcome many of the limitations created by traditional well volume purging. Low-flow/low-volume sampling can control sample turbidity and minimize sample chemistry alteration by pumping at very low flow rates from the well screen zone, avoiding disturbance to the water column in the well and minimizing stress on the surrounding formation. By pumping water only from the screen zone and not significantly drawing water from the casing above the screen (if present), the volume of water purged to achieve stable water chemistry can be reduced significantly. Samples obtained in this manner will better reflect the ground-water chemistry at ambient flow conditions and the true mobile load of contaminants if present.

Keywords: Ground water sampling, monitoring, contamination monitoring.

Review on current situation of the rural water supply in Mozambique

[1]Humberto A SAEZE, [2]Messias HA MACIE

[1] Departamento de Geologia. Faculdade de Ciências. Universidade Eduardo Mondlane. Caixa Postal 257. Avenida de Moçambique.Telefax: +258 21 475280, Maputo - Moçambique, e-mail: saeze@hotmail.com
[2] Departemento de Água Rural. Direcção Nacional de Águas. Avenida Eduardo Mondlane N° 1392,4°. Telefax: +258 21 430110, Maputo-Moçambique, e-mail:jmacie@myway.com

ABSTRACT

In Mozambique, about 70% of the population lives in the rural areas and, approximately 55% of this population live below the line of absolute poverty. The rural population relies mainly on groundwater for domestic use. In these areas of the country, there is about 16,300 dispersed water points, of which about 11,800 (73%) are functional whereas, the remaining points are non-operational or obsolete. Additionally, the rural population is also supplied by small piped water supply schemes (SPWS) and an unknown number by surface water. In this context, the average coverage of services of water supply in the rural areas is about 42.1%, where 4,0% are assured by SPWS and the remaining 38,1% by dispersed water points. Table 1 shows in detail the levels of water access in each province of Mozambique. In relation to rural sanitation, it is estimated that in 2004 about 35% of the rural population benefited from some type of adequate sanitation.

Although there has been a steady increase in access to water in rural areas (from 10% in 1992 to 12% in 1997, 35% in 2000 and 42.1% in 2005), the weak coverage of these services, promote prevalence of some infection-contagious illnesses such as, diarrheas, cholera, dysentery, malarias and other derivatives of contaminated water consumption and/or deficient habits of hygiene and sanitation.

In order to improve the rural water sector situation, the Mozambican government has been approving policies and regulation, implementing numerous projects and taking several important steps. Examples are the National Water Policy approved in 1995 (currently the new version is being prepared), the Manual of Rural Water Supply Projects Implementation in 2001 and Poverty Reduction Strategy Plan (PRSP) also in 2001. Presently the water and sanitation sectors are working on the Country's Millennium Development Goals (medium term challenges).

Table 1. Level of access of water for rural population in Mozambique

Province	Rural Population	Water Points			Population Served			Coverage (%)
		Existing	*Operational*	*Non operational*	*Dug wells, boreholes, springs*	*SPWS*	*Total*	
Niassa	924,750	1,199	1,149	50	575,500	7,112	581,612	62.9
Cabo Delgado	1,441,490	1,790	1,035	755	517,500	209,939	732,439	52.2
Nampula	3,137,187	2,128	1,246	882	623,000	67,000	690,000	22.0
Zambézia	3,298,782	2,262	1,971	471	895,500	44,345	939,845	28.5
Tete	1,461,356	1,674	1,123	551	561,500	49,400	610,900	41.8
Manica	1,220,074	1,228	948	280	474,000	27,575	501,575	41.1
Sofala	1,076,300	1,568	1,313	255	656,500	52,248	708,748	65.9
Inhambane	1,292,950	2,173	1,524	649	762,000	105,297	867,597	67.1
Gaza	1,142,339	1,556	1,084	472	542,000	34,500	576,500	50.5
Maputo	565,956	731	631	100	315,500	28,500	344,000	60.8
Total	**15,561,184**	**11,844**	**4,465**	**16,309**	**5,922,000**	**625,916**	**6,547,916**	**42.1**

The National Water Policy establishes the basic principles and specifies directories for water sector. This states that, the satisfaction of the basic necessities of the communities constitutes a priority, requiring an increase of coverage of the water supply and sanitation, especially for the rural populations and population groups of low income. The aims of this policy are:
i) Participation of all the beneficiaries in the rural water supply and sanitation project cycle; ii) Recognition of the economic and social value of water; iii) Operation and maintenance be decentralized; iv) Development of an integrated board for water/health/sanitation/hygiene; v) Institutional Capacity Building and; vi) Large

involvement of the private sector in activities of the water sector.

The perspective is that, with this board, and in coordination with the cooperation partners, it may stimulate great investments in the Water Sector, either in the construction and rehabilitation of water supply infrastructures, namely, wells and dug wells equipped with manual pumps, protected springs; or expansion of SPWS for villages and areas of high population density, especially in those areas where population groups of low income live. Regarding sanitation, it is expected to stimulate investment in the systems of at least improved traditional latrine for rural communities.

As results of this new board, the governmental institutions are more organized and rural communities should show ongoing positive adherence, whereas the cooperation partners demonstrate availability to contribute to the sector. Nevertheless aspects such as technical and human resources capabilities at local level (provincial and district), knowledge of country hydrogeology, network hand pumps spare parts commercialization and additionally the level of response of the private sector, if not handled correctly, may frustrate the desired plans.

Keywords: Rural, sanitation water supply, policies

Seasonal hydrochemical changes of water from alluvium aquifers: Drean-Annaba aquifer case study (NE Algeria)

[1]L.DJABRI, [1] A.HANI, [2] J.MUDRY, [3] A.Pulido BOCH

[1] 11, Rue Asla Hocine Annaba 23000.Algerie djabri_larbi@yayoo.fr
[2] Université de Franche Comte France jacques.mudry@univ-fcomte.fr
[3] Université d'ALMERIA .Espagne, apulido@ual.es

ABSTRACT

Water quality frequently changes in the Drean-Annaba alluvium aquifer. Water – rock interaction can not be the only process that produces the observed modification. Droughts that the country experienced in the last two decades have greatly contributed to the water quality changes. During this period, irregularities in the distribution of rainfall in time and space have been observed. As a result, a periodicity in hydrochemical changes in water of wells and rivers was noticed. Statistical (APC) tools and Tickel diagrams have been used, through chemical presentation, to show these effects. The results indeed show seasonal changes of water quality for the period 1999-2000. From a cationic point of view, a competition between alkaline and alkaline earths is shown. On the other hand, from an anionic point of view, there is a transition from chlorides to sulphates and possibly to bicarbonates.

The present study was carried out in a relatively small area and this was useful to show the relationship that exists between droughts and water quality of both the aquifer system and surface water.

Sources of water salinities in the Morsott-Laouinet aquifer. Northern Area of Tébessa. (North East of Algeria).

[1] Chemseddine FEHDI, [2] Abderrahmane BOUDOUKHA, [3] Elias SALAMEH

[1] Centre Universitaire de Tébessa, Institut des Sciences de la Terre, Tébessa 12002, Algérie. <fehdi@yahoo.fr>
[2] Université de Batna, Département d'Hydraulique, Batna, Algérie<boudoukha_abderrahmane@yahoo.fr >
[3] University of Jordan, Department of Geology, Amman 11942, Jordan. < salameli@ju.edu.jo>

ABSTRACT

The increase in salinity is one of the most conspicuous phenomena that affect the water quality in Morsott-El Aouinet area (North East of Algeria). Future exploitation and management of the water resources under these conditions will require a deep understanding of the sources and mechanisms of contamination.

The studied area is located within the arid zones of Algeria, situated fifty kilometres far from Tebessa city and is characterised by a precipitation of less than 400 mm per year. It extends from El Aouinet in the north, to Morsott to the south, for about 180 km². This aquifer plays a very important role in providing drinking water for the local population. Overexploitation of this resource has caused a progressive degradation of the water quality in the irrigated area resulting in high salinity zones

In this paper groundwater hydrochemistries are studied through well sampling from the study area, showed extremely high concentrations of salts, ranging from 1154 to 23800 μScm^{-1}, decreasing from South towards North, far exceeding the acceptable limit for various purposes as given in Algerian Water Quality Guideline. Hydrochemical end products were identified and the sources of water salinization defined. It was found that the evaporites within the Triassic rocks are the main contributors to the salinization of groundwater. From the hydrochemical evaluation of the analyses results, two different water types could be identified:

- A fresh groundwater end-product: Ca-HCO_3 water type with a low salinity concentration.
- A saline water end-product: predominantly Na-Cl water type with high salinity concentrations.

The results obtained with stable isotopes (oxygen 18 and deuterium) broadened and strengthened our knowledge about conditions and recharge areas of the Plio-Quaternary aquifer.The isotopic study shows that this aquiferous receives a refill from efficient rainfall without a high evaporation.

Keywords: aquifer, salinity, Trias, isotopes, Morsott-El Aouinet.

The Corgas Aquifer, Sazes do Lorvão, Central Portugal

José M.M. AZEVEDO, Centre of Geophysics & Department of Earth Sciences,
Coimbra University – jazevedo@dct.uc.pt
Jorge F.C. SERAFINO, Geologist of Soc. Exploração da Fonte das Corgas-Buçaco
Ana I.S.S. ANDRADE, Centre of Geophysics & Department of Earth Sciences,
Coimbra University – aandrade@dct.uc.pt
Francisco SILVA, Geologist of ASS, Mealhada – franciscojcs@netcabo.pt
Fernando P.O. FIGUEIREDO, Department of Earth Sciences, Coimbra University – fpedro@dct.uc.pt

ABSTRACT

The Corgas aquifer is one of several highly productive aquifers located on the Paleozoic Syncline of Buçaco-Penacova (about 15 Km NE of Coimbra). This NNW-SSE oriented Syncline, about 38Km in length and 4,5Km in width, consists of an Ordovician to Silurian sequence which unconformably overlies Cambrian terrains (Schist-Greywacke Complex-SGC) (Fig. 1). The sequence comprises, in Lower Ordovician, a red greywacke followed by a large sequence of metamorphosed sandstones (Armorican Quartzite), overlain by a sequence dominated by dark shales and siltstones with more or less important sandstone intercalations, which alternate at the top with volcanic and carbonate rocks (middle and upper Ordovician) and ends with schist with nodules (Silurian).

This particular aquifer occurs in the west flank of the syncline within the volcanic-carbonated sub-vertical level included on the Upper Ordovician Formation (Fig. 2). The volcanic rocks are mafic metavolcanics, highly vesiculated and lowly metamorphosed. The carbonate levels are dolomitic and has been metamorphosed to a medium degree.

The main aquifer recharge is probably related to infiltration along the lower Ordovician ridges (quartzite ridges with sub-vertical stratification and densely jointed) located at NW domains. The N-S and NW-SE sub-vertical fractures occurring in this region certainly play an important role in the recharge process.

Aquifer discharge is strongly controlled by the interception of N-S and NE-SW sub-vertical faults. The Corgas spring (Fig. 1) is a natural process of aquifer discharge.

The Corgas aquifer is a fractured semi-confined aquifer, with a transmissivity (T) of around $240 m^2/d$ and a storage coefficient (S) between $3x10^{-3}$ and $4x10^{-3}$.

The aquifer water is weakly mineralized (hyposaline) and has a total mineralization of around 340 mg/l. It presents a strong association between bicarbonate and calcium-magnesium, which results in a bicarbonate calcium-magnesium hydrochemical facies and also in a hardness value of 200 mg/l $CaCO_3$. Its emergence temperature is 21ºC, which allows us to consider it as thermal water and to infer a somewhat deeper groundwater circulation. The bicarbonate calcium-magnesium facies is clearly related to the aquifer lithology.

Tacking into account the aquifer characteristics, particularly its volumetric, lithology, hydrogeological parameters and the water chemistry it is foreseeable that it could be an important groundwater resource. However this assumption must take into account that (1) the affiliated Corgas spring is an indispensable agent on the preservation of the downstream ecosystems and (2) the spring discharge is partly used for agricultural purposes by local and small-scale farmers.

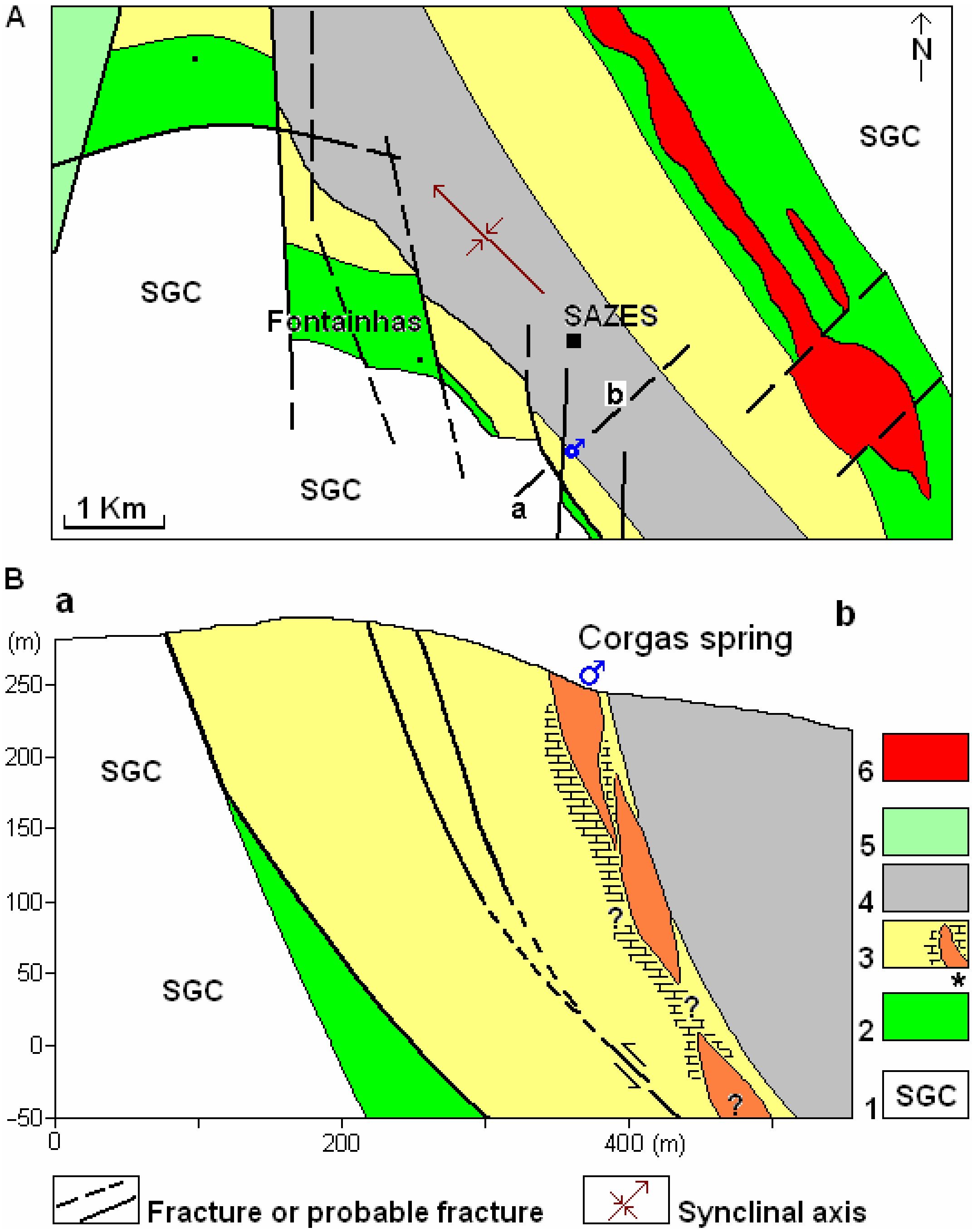

Fig. 1- Geological and structural settings for the Corgas Aquifer: A- Geological map (adapted from Silva et al., 1990; A. Cavaco report, 2001); B- Geologic section.
Legend: 1- Ante-Ordovician Schist-Greywacke Complex (SGC), 2- Lower Ordovician quartzites, 3- Middle and Upper Ordovician, mainly shale and schist, (*) volcanic-carbonated level, 4- Silurian schists, 5- Continental Carboniferous, 6- Meso-Cenozoic detritic cover.

Keywords: Aquifer, Lithology, Recharge, Discharge, Hydrochemistry

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