N° 35 May 2013

European Geologist

Journal of the European Federation of Geologists

Groundwater - the critical resource

Contents

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We would like to express a particular thanks to all those who participated in the peer reviewing of this issue and thus contribute to the improvement of the standards of the European Geologist magazine. The content of this issue has been reviewed by David Banks, Ognjen Bonacci, Antoine Bouvier, José Martins Carvalho, Kevin Cullen, Alecos Demetriades, Antonio Gennarini, Ewa Krogulec, Peter Malik, Michael Sinreich, Peter Szucs, Ladislav Tometz and Fermin Villarroya.

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Cover photo:
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ISSN: 1028 - 267X

EUROPEAN GEOLOGIST

is published by the
European Federation of Geologists
C/O Service Géologique de Belgique
Rue Jenner 13
B-1000 Bruxelles, Belgium
Tel: +32 2 7887636
info.efg@eurogeologists.eu
www.eurogeologists.eu

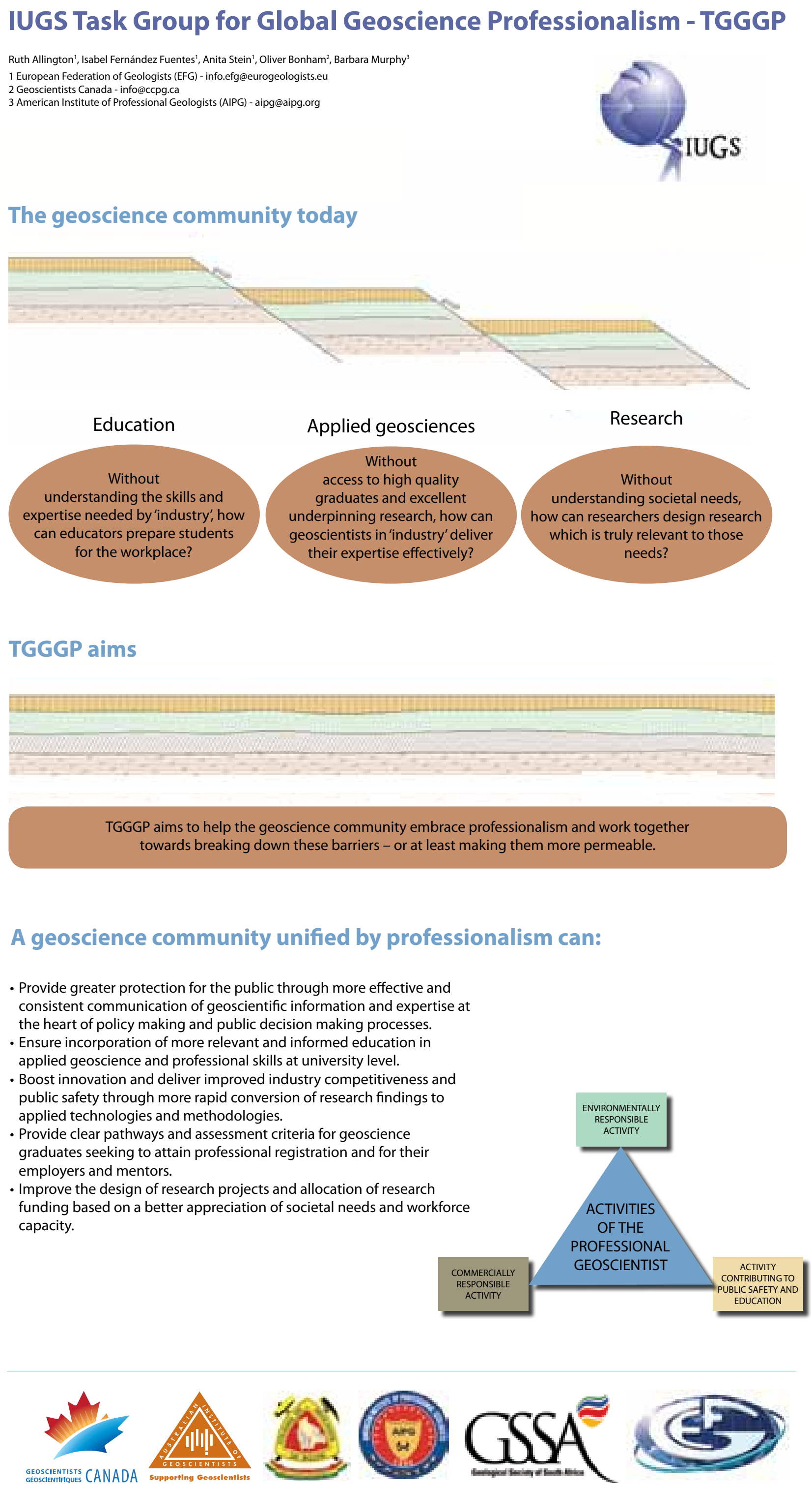

Figure 1: TGGGP Poster presented at the European Geosciences Union General Assembly in Vienna.

Foreword

EurGeol. Ruth Allington, President

This issue of European Geologist Magazine includes a themed set of papers on hydrogeology. Marco Petitta, who is the co-ordinator of EFG's Panel of Experts on Hydrogeology, has provided an excellent introduction to the topic, which highlights the vital contribution of hydrogeologists to water governance systems that:

- meet the challenges of economic development;
- help to ensure societal resilience to climate change; and
- address the pressures of population growth.

He describes the way that the roles and responsibilities of hydrogeologists have extended over the years beyond the pure study of the behaviour of water in the ground, both through the acquisition of technical and scientific skills beyond their traditional core competencies and through working more and more in interdisciplinary environments.

Also needed is effective communication and collaboration between the three main parts of the geoscience community (researchers, educators and applied practitioners). This concept was a driver for the formation of the IUGS Task Group on Global Geoscience Professionalism (TGGGP), which was conceived by EFG and other professional geoscience organisations at the International Professional Geology Conference in Vancouver in January 2012 (4IPGC) and approved by the IUGS Executive Committee at 34IGC in Brisbane in August 2012. The poster reproduced on the left (***Fig.1***) was produced by the TGGGP for display in April 2013 at the European Geosciences Union General Assembly in Vienna, and expresses why this is so important. The TGGGP is now working hard on a website to act as a portal for its work and this is expected to be launched in the summer or autumn of 2013.

This is my last foreword as President of EFG, as I stand down at the Council meeting in Stockholm on 1st and 2nd June 2013. I therefore sign off by thanking all those who contribute to this excellent magazine – those who submit papers, those who advertise, proofreaders, peer reviewers and the Editorial Board. Particular thanks are due to Eva Hartai (EU Delegate on the EFG Board), who chairs the Editorial Board, and Anita Stein (Brussels Office Assistant). Eva's vision, leadership and hard work since taking on this role and Anita's skills in layout and graphic design have led to significant improvements in the content and appearance of the magazine – the results are clear to see in this issue.

Introduction by the EFG Panel of Experts on Hydrogeology

New challenges for hydrogeologists

Marco Petitta[*]

With the publication of the Blueprint document by EU, a new perspective on water issues has been adopted by the EU, identifying obstacles to the optimal governance of water resources and consequent actions to be developed to remove them. Hydrogeology has a crucial role in this process, because groundwater must be evaluated, monitored and protected in order to ensure human needs and also to meet environmental requirements. Hydrogeologists must be involved in this process, offering their irreplaceable ability in several topics of high importance, such as identification of ecological flow, the reduction of over-abstraction, the calculation of water accounts and the effect of climate changes. The hydrogeological community has the background and the opportunity to offer convincing answers to all these problems.

Avec la publication d'un document de Projet européen, une orientation nouvelle pour les problèmes liés à l'eau a été adoptée par l'Europe, en identifiant les obstacles pour atteindre une gestion optimale des ressources en eau ainsi que les actions associées à mettre en œuvre pour éliminer ces obstacles. L'hydrogéologie a un rôle crucial dans ce processus parce que l'eau souterraine doit faire l'objet d'une évaluation, d'un suivi et d'une protection pour garantir les besoins humains et pour répondre aussi aux exigences environnementales. Les hydrogéologues doivent être impliqués dans cette démarche en offrant leur compétence irremplaçable dans plusieurs secteurs prioritaires tels que l'identification du flux écologique, la réduction de la surexploitation, le calcul des ressources en eau et les changements climatiques. La communauté des hydrogéologues a les compétences et l'opportunité d'apporter des réponses convaincantes à l'ensemble de ces problèmes.

Con la publicación del Anteproyecto por parte de la UE, ésta ha adoptado una nueva perspectiva que identifica los obstáculos que se plantean a la gestión óptima de los recursos de agua y las acciones a desarrollar para eliminarlos. La hidrogeología tiene un papel crucial en este proceso, porque el agua subterránea debe ser evaluada, controlada y protegida con objeto de garantizar las necesidades humanas y cumplir con los requisitos ambientales. Los hidrogeólogos deben estar implicados en este proceso, ofreciendo su experiencia irreemplazable en varios temas de suma importancia, como la identificación del caudal ecológico, la reducción de la sobreexplotación, el cálculo de la contabilidad del agua y el efecto del cambio climático. La comunidad hidrogeológica tiene los fundamentos y la oportunidad de ofrecer respuestas convincentes a todos estos problemas.

Water is central in the activities of European Commission, as demonstrated by the water policy of EU, based on the Water Framework Directive (2000/60/EC) (European Commission, 2000) and on the following Groundwater Directive (2006/118/EC) (European Commission, 2006). Beside these documents, other directives are directly connected with the water issue, such as the nitrate, the sustainable use of pesticides and the urban waste water treatment directives (European Commission 1991a, 1991b, 2008, 2009).

In the last decade, the River Basin Management Plans (RBMP) (European Commission, 2012a) have represented the basic instrument for managing and evaluating water resources availability and renewal, but first of all the quantitative and qualitative status of EU waters. This effort, coupled with the analysis of water scarcity and droughts, has led to the attainment of a comprehensive framework of water problems at the EU level, where single member states are characterised by different level of knowledge, critical issues, water availability, need and consumption. At the end of the first phase of RBMPs, the state-of-the art and mainly the future challenges for EU on water safeguard have been illustrated in the Blueprint document (European Commission, 2012b). In this important document, which summarises all information obtained by previous studies and by extensive public consultations, some key themes include improving land use, addressing water pollution, increasing water efficiency and resilience, and improving governance of subjects involved in managing water resources. Consequently, the Blueprint represents the guideline for all those involved in the water issue for the following years at the EU level.

The Blueprint identifies obstacles and consequent actions aimed to remove those which at this moment are hindering the goal of achieving the sustainability of all activities impacting waters, thus ensuring the availability of good-quality water for sustainable and equitable water used. Land use and especially changes in water bodies due to human activities are affecting the ecological status of water bodies. In fact, it is predicted that in 2015 only half of the water bodies across EU will be able to achieve a good ecological status, requiring additional efforts to improve this situation in the following years (European Commission, 2012b). Consequently, the adoption of natural water retention measures, the identification of ecological flow (e-flow), the restoration of green infrastructures and the reduction of over-abstraction of water represent challenges for the next years. At the same time, the chemical status and pollution have to be better evaluated by introducing and enforcing monitoring obligations, including emerging contaminants such as pharmaceuticals. Beside these "basin-scale" actions, a particular emphasis in the Blueprint is devoted to water efficiency measures (irrigation efficiency, leakage of distribution networks, metering, etc.), to contrast the widespread water scarcity and stress, also by developing water accounts of the river basins, including groundwater bodies. In terms of vulnerability, climate change has enhanced the river flow droughts and floods across Europe (European Commission, 2012b). To integrate the actions related to the water issue, crosscutting solutions have also been identified, improving both the knowledge base and the governance. Finally, a global perspective is required, looking at other countries where access to safe drinking waters and basic sanitation services is not guaranteed.

All these themes require the contribution of hydrogeologists, who are the main cat-

[*] Dipartimento di Scienze della Terra, Università di Roma "La Sapienza", Italy; Chairman of IAH Italian Chapter; Coordinator of EFG PE on Hydrogeology, marco.petitta@uniroma1.it

egory of specialists having the background to investigate and evaluate the groundwater bodies. The Blueprint identified several problems and related actions where the hydrogeological contribution is crucial, such as ecological flow, monitoring, water scarcity and accounts, pollution and remediation. New challenges for scientists, technicians, and professional people operating in the water sector are established by the Blueprint and the hydrogeological community must be ready to offer convincing answers to all these questions.

Traditionally, hydrogeology was related to water resource evaluation and withdrawals, identifying aquifers and their water availability and renewal rate (Freeze and Cherry, 1979). Groundwater corresponds to the more precious resource compared with surface waters, because of its high-quality standard and longer time-residence. Step by step, hydrogeology became an interdisciplinary topic, including hydrochemistry as an important tool for studying the quality and the flowpaths of groundwater. When pollution problems started interest grew in groundwater bodies, and gradually the main focus of hydrogeology shifted to include low-permeability layers (aquitards and aquicludes) as limits for groundwater flow but also as sites where geochemical and biological reactions can modify groundwater quality (Cherry *et al.*, 2006). Withdrawals and management plans require increasing monitoring activities, both for quality and quantity, which have become the principal activity in the hydrogeological field (Wu *et al.*, 2005). At the same time, mathematical tools for groundwater modelling add enormous possibilities to forecast the effects of groundwater governance (Anderson & Woessner, 1989). Finally, in the last years the growing importance of the ecological status of surface waters requires additional attention to surface/groundwater interactions, both in quantitative and qualitative ways (Bonell, 2002). The gradual transformation of hydrogeology into an interdisciplinary topic is now complete and the modern hydrogeologist is not only looking for groundwater exploitation, but has to take care of water vulnerability, pollution and remediation, not only for human needs but also for environmental protection. This means a great responsibility and a wider background to be continuously implemented.

In this scenario, the contribution of the hydrogeological community is absolutely necessary, but it has to be based on solid knowledge and background. A list of possible actions and topics related to the Blueprint vision can be highlighted and developed exclusively with the collaboration of hydrogeologists.

First of all, during the first stage of River Basin Management Plans particular emphasis has been reserved for surface waters, as is obvious. The characterisation of groundwater bodies is more difficult, but they are strictly interconnected with surface waters, guaranteeing the baseflow during the dry season. In addition, quality data are mainly related to surface water, while information on the chemical status of groundwater bodies is limited. Storage and renewal rates of groundwater bodies are not completely known at the EU scale: a particular effort is required for evaluating the recharge of the aquifers, because it represents the input information for water account at the basin scale. The problems of water scarcity and of climate change are unsolvable without evaluating the groundwater resources and strategic reserves. This is a basic requirement, but the novelty is represented by the link with the e-flows: in other words, water accounts must calculate not only human requirements, imbalances and overexploitation, but the ecological requirements have to be taken into account too. This challenge requires the study of the interaction between surface waters and groundwater, not only at basin scale (flow exchanges), but also at the riverbed scale, where ecological functions can be influenced by natural or man-induced modifications. Consequently, the "classical" hydrogeological water budget has to be modified, including the e-flow evaluation, which represents a priority to be guaranteed. Taking into account the growing influence of climate change effects, an up-to-date analysis of the groundwater availability is necessary at different scales (member states and basins, at least).

Simply to obtain data about water accounts, monitoring activities are crucial. Monitoring, both quantitative and qualitative, has a growing importance in this context. Monitoring the network of groundwater requires hydrogeological skills. Monitoring and sampling water from wells and monitoring wells is only apparently a simple activity. The depth of the wells and mainly the provenance of water samples have to be carefully considered. Low-flow procedures are largely diffused to avoid unrepresentative samples of groundwater, but multi-level sampling is not universally considered at the moment. In particular for polluted groundwater, concentration data can be affected by vertical distribution of contaminants, both as the nature of the compound and for different biogeochemical contexts in laterally and vertically heterogeneous aquifers and aquitards. In several cases, groundwater pollution is not correctly evaluated because of limited knowledge of the hydrogeological system and of samplings having limited representativeness. Consequently, planning the monitoring network is a sensitive activity, to be conducted by expert hydrogeologists, using modern tools and instruments, in order to avoid unreliable information.

Collected data need to be interpreted and placed in a comprehensive framework, represented by the conceptual model (***Fig. 1***). The conceptual model is the logical synthesis of the information gathered by field activities, and it has to summarise the groundwater flow and quantity, including quality data if necessary. In addition, the construction of a conceptual model is an iterative process, requiring additional data to be validated and reformulated if necessary; therefore, monitoring and elaboration of data are part of the conceptual model, too. Only if starting from a trustworthy conceptual model can management

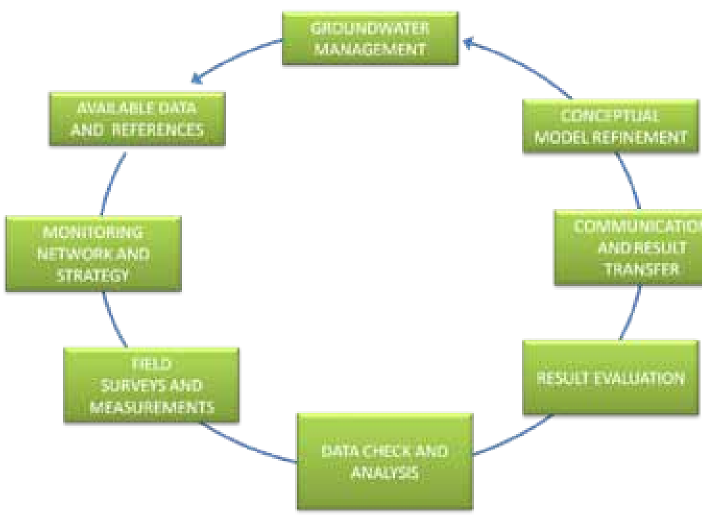

Figure 1: Conceptual model scheme.

actions have positive effects on critical issues pointed out by the Blueprint, such as ecological status, hydromorphological pressures and water efficiency.

Modern technologies and tools such as tracers, isotope analyses, with particularly numerical modeling greatly improve hydrogeological knowledge and can validate the conceptual model of groundwater flow,. These are instruments of widespread use, but frequently their role is restricted to the hydrogeological community. A challenge would be represented by the implementation of these tools as real land planning tools, to build future scenarios of water management and availability. The integration of databases and GIS data with groundwater modeling offers this possibility, but a thorough control of data representativeness and quality must be conducted by hydrogeologists, to avoid incorrect use and consequently any unreliability of the obtained results. Therefore, undiscriminating application of models must be avoided, because of the possibility of obtaining unverifiable results. Additional possibilities are offered to the hydrogeological community by the need to better focus on other water issues, including vulnerability evaluation, environmental impact assessment, water/energy relationships, drought occurrence and mitigation, and climate change's secondary effects on water availability. All of these areas require instruments similar to those discussed previously, including robust monitoring and conceptual models, to be analysed and to implement valid actions.

EU aims and guidance on water problems surely require an important contribution by hydrogeological community, but to provide significant answers, two points have to be highlighted and ensured: firstly, the unquestionable skills of the hydrogeologist based on his background, his updating and his professionalism, requiring wide competences and a modern interdisciplinary approach. On the other hand, the role of hydrogeology in this process has to be better explained and officially acknowledged by the various institutions, the European Commission, its technical bodies and by local authorities of member states too. At the same time, it is important also to modify the perception of the overall population and of the opinion makers regarding the role of hydrogeologists.

This issue of the European Geologist Magazine represents a first step in the process, offering contributions on the state-of-the-art of groundwater knowledge, investigation and tools, using the abovementioned keyword of "multidisciplinary approach", across different European countries, inside and outside the EU. New challenges are starting, and we will be ready to face them.

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Quality of hellenic bottled mineral and tap water as a proxy for groundwater geochemistry

*Alecos Demetriades**

The quality of Hellenic bottled and tap water, and indirectly of groundwater, was assessed by the collection of 61 still bottled waters, representing 41 locations, and 53 tap waters, covering almost the whole territory of the Hellenic Republic (Hellas or Greece). All water samples were analysed for 72 parameters. Since the dominating lithology in the Hellenic Republic comprises limestone, dolomitic limestone, marble, and mafic-ultramafic rocks (ophiolite), the dominant major ions in Hellenic water are Ca^{2+}, Mg^{2+}, CO_3^{2-} and HCO_3^-. The processes contributing to the concentration of major ions in groundwater depend on carbonate dissolution and precipitation, cation exchange, and in some cases to dissolution of aluminosilicate minerals. Source aquifers are apparently continuously replenished by fresh water.

La qualité de l'eau, en bouteille ou au robinet, et indirectement de l'eau souterraine, a été évaluée à partir de 61 échantillons d'eau naturelle prélevés dans 41 endroits différents, et de 53 échantillons d'eau de robinet, provenant de la quasi-totalité du territoire de la République grecque (Hellas ou Grèce). Tous les échantillons furent analysés en tenant compte de 72 paramètres. Puisque les roches dominantes en Grèce sont représentées par le calcaire, le calcaire dolomitique, le marbre et les roches mafiques et ultramafiques (ophiolites), les ions principaux présents dans l'eau grecque sont : Ca^{2+}, Mg^{2+}, CO_3^{2-} et HCO_3^-. Le processus qui contribue à la concentration des ions majeurs, dans l'eau souterraine, dépend de la dissolution et de la précipitation des carbonates, de l'échange des cations, et parfois de la dissolution des minéraux à base de silice et d'alumine. En apparence, les aquifères sont continuellement rechargés en eau douce.

Se evaluó la calidad de las aguas griegas embotelladas y del grifo, e indirectamente la de las aguas subterráneas, en base a la recolección de 61 botellas de agua correspondientes a 41 lugares y 53 aguas del grifo, que cubren casi toda la República Helénica (Grecia). De todas las muestras de analizaron 72 elementos. Dado que las litologías dominantes en Grecia son las calizas, las calizas dolomíticas, los mármoles y las rocas máficas e ultramáficas (ofiolitas), los iones dominantes en las aguas helénicas son Ca^{2+}, Mg^{2+}, CO_3^{2-} y HCO_3^-. Los procesos que han contribuido a la concentración de los principales iones en las aguas subterráneas dependen de la disolución y precipitación, el intercambio iónico y en algunos casos la disolución de minerales aluminosilicatados. Los acuíferos de procedencia son aparentemente continuamente recargados con agua dulce.

The EuroGeoSurveys Geochemistry Expert Group's mandate is to provide high quality harmonised databases on the geochemistry of earth materials to decision makers, geoscientists, researchers and the public alike. The Geochemical Atlas of Europe provided the first harmonised pan-European multi-determinand databases on residual soil (top- and sub-soil), humus, stream and floodplain sediments, and stream water (Salminen *et al.*, 2005; De Vos *et al.*, 2006). Groundwater, although very important, was missing from this database. The main reason is that to collect systematically representative groundwater samples on a European scale is not an easy task, and would be prohibitively expensive if performed at a high sample density. The EuroGeoSurveys Geochemistry Expert Group conceived the novel idea that 'groundwater' samples can be readily bought from supermarkets throughout Europe as bottled mineral water, and used as a first proxy for groundwater geochemistry and quality on a European scale. In addition, in Hellas most domestic tap water comes from groundwater, thus additional samples were collected for better coverage. The results of this project are presented in a geochemical atlas (Reimann and Birke, 2010), and in a special issue of the *Journal of Geochemical Exploration* (Birke *et al.*, 2010). Here, only some key results are presented in relation to Hellenic groundwater geochemistry.

* Former director, Division of Geochemistry and Environment, Institute of Geology and Mineral Exploration, Hellas, alecos.demetriades@gmail.com

Hellas (Greece) is a country with a diverse geology and climate. Climatic change is affecting the country to a variable degree; the average annual rainfall has decreased since 1930, i.e., (i) 1930-1960: 719.6 mm; (ii) 1960-1990: 686.5 mm; (iii) 1990-2009: 529.4 mm (World Bank Group). This has affected the bottled water industry, where natural spring water is used for bottling. Up to now two bottling companies have closed down, the first in Thrace in north-east Hellas, and the second in south Peloponnese, areas with a notable change in the average annual rainfall. However, because of increased demand for bottled water new companies have started operations in areas with a comparatively high average annual rainfall, especially in western mainland Hellas, and in western and central Crete (>1800 mm; see Climate data/Annual precipitation at *http://thermomap.edu-zgis.net/index.html*).

The Hellenic Republic has about 6,000 islands and islets. Many of the inhabited islands do not have a good quality potable water supply, and the islanders rely on bottled water for drinking and cooking; such islands include Aegina, some of the Cyclades and Dodecanese Islands, Zakynthos (an Ionian Sea island), etc. There are also some areas on mainland Hellas that resort to bottled water, because of the poor quality of their groundwater resources: e.g.,

Parameter	Unit	DL	$P_{95\%}$	European bottled water (n=884)			Hellenic bottled water (n=41)			Hellenic tap water (n=51)		
				Min.	Median	Max.	Min.	Median	Max	Min.	Median	Max.
Ag	µg/L	0.002	13	<0.002	<0.002	112	<0.002	<0.002	0.112	<0.001	<0.001	0.00231
Al	µg/L	0.5	5	<0.5	1.2	966	<0.5	0.77	5.48	0.379	1.32	185
As	µg/L	0.03	10	<0.03	0.24	90	<0.03	0.198	2.52	0.0509	0.317	9.2
B	µg/L	2	4	<2	39	120000	2.81	14.6	143	2.52	13.8	609
Ba	µg/L	0.1	5	<0.1	29	26800	<0.1	0.019	7.38	5.45	27	127
Be	µg/L	0.01	5	<0.01	<0.01	64	<0.01	<0.01	0.0127	<0.001	0.00265	0.0831
Bi	µg/L	0.01	-[(b)]	<0.005	<0.005	0.69	<0.005	<0.005	0.0041	<0.0005	<0.0005	0.00192
Br^-	µg/L	3	nd	<3	35	21700	<3	32	174	<3	7	2070
Ca	mg/L	0.01	nd	0.43	66	611	2.87	55.4	101	4.6	60.2	101
Cd	µg/L	0.003	29	<0.003	0.0032	1.1	<0.003	<0.003	0.0231	0.00158	0.0105	1.43
Ce	µg/L	0.001	13	<0.001	<0.001	6.2	<0.001	<0.001	0.00305	<0.0005	0.00181	0.12
Cl^-	mg/L	0.01	nd	0.18	13	3627	1.03	12.8	81.4	1.52	10.7	458
Co	µg/L	0.01	5	<0.01	0.023	16	<0.01	0.0126	0.0792	0.00315	0.0156	0.0905
Cr	µg/L	0.2	7	<0.2	<0.2	27	<0.2	0.627	32.9	0.108	0.518	17.7
Cs	µg/L	0.002	3	<0.002	0.039	415	<0.002	0.0045	4.52	<0.001	0.00784	5.19
Cu	µg/L	0.1	2	<0.1	0.27	100	<0.1	0.398	3.99	0.0598	2.42	34.8
Dy	µg/L	0.001	16	<0.001	0.0012	0.39	<0.001	<0.001	0.0107	0.000155	0.000876	0.0222
EC	µS/cm	-	nd	18	588	26500	177	434	891	45	340	1811
Er	µg/L	0.001	13	<0.001	<0.001	0.77	<0.001	<0.001	0.0141	0.00017	0.000585	0.0119
Eu	µg/L	0.001	18	<0.001	<0.001	0.45	<0.001	<0.001	0.005	0.000339	0.0018	0.00699
F^-	mg/L	0.003	nd	<0.003	0.19	11	<0.003	0.05475	0.337	0.028	0.09	0.621
Fe	µg/L	0.5	4	<0.5	0.69	13500	<0.5	0.238	0.711	0.336	1.53	153
Ga	µg/L	0.01	4	<0.005	<0.005	3.9	<0.005	<0.005	0.0339	0.119	0.515	2.39
Gd	µg/L	0.002	22	<0.002	<0.002	0.66	<0.002	<0.002	0.0102	0.000227	0.00127	0.0223
Ge	µg/L	0.03	6	<0.03	<0.03	110	<0.03	<0.03	0.0465	<0.005	0.012	0.238
Hf	µg/L	0.002	28	<0.002	<0.002	1.6	<0.002	<0.002	0.00396	<0.0005	0.000727	0.00402
Hg	ng/L	5	most values <DL							<5	<5	59
Ho	µg/L	0.001	19	<0.001	<0.001	0.12	<0.001	<0.001	0.0046	<0.0001	0.000314	0.00419
I	µg/L	0.2	15	<0.2	4.8	4030	0.555	3.28	12.2	0.952	3.26	41.3
K	mg/L	0.1	nd	<0.1	2.1	558	<0.1	0.6	7.3	0.1	0.9	20.5
La	µg/L	0.001	9	<0.001	0.0023	10	<0.001	<0.001	0.0267	<0.0005	0.00187	0.0971
Li	µg/L	0.2	5	<0.2	10	9860	<0.2	1.15	14.3	0.114	1.62	45.1
Lu	µg/L	0.001	16	<0.001	<0.001	0.41	<0.001	<0.001	0.00266	<0.00005	0.000171	0.00198
Mg	mg/L	0.01	nd	<0.01	16	4010	0.764	11.6	91.2	1.61	12.1	60.4
Mn	µg/L	0.1	2	<0.1	0.54	1870	<0.1	<0.1	0.236	<0.1	0.172	8.15
Mo	µg/L	0.02	4	<0.02	0.28	74	<0.02	0.225	2.55	0.0438	0.51	13.2
Na	mg/L	0.1	nd	0.4	16	8160	0.7	7.1	77.2	1.3	7	363
Nb	µg/L	0.01	15	<0.01	<0.01	0.54	most values <DL			<0.001	0.00241	0.0199
Nd	µg/L	0.001	18	<0.001	0.0021	5.1	<0.001	0.0012	0.0152	0.000236	0.00191	0.118
NH_4^+	mg/L	0.01	nd	<0.005	<0.005	60	<0.005	<0.005	0.008	<0.005	<0.005	0.026
Ni	µg/L	0.02	4	<0.02	0.18	95	<0.02	0.136	2.4	0.036	0.338	9.11
NO_2^-	mg/L	0.1	most values <DL							<0.005	<0.005	0.084
NO_3^-	mg/L	1.0[(a)]	nd	<1	1.3	995	<1	3.76	18.8	0.1	3.76	21.3
P	µg/L	6.5	nd	<6.5	33	2863	<6.5	9.65	48.24	3.25	6.522	169.6
Pb	µg/L	0.01	6	<0.01	0.016	2.3	<0.01	0.0206	0.393	0.00354	0.142	0.953
pH	-	-	nd	4	6.8	9.9	7.08	7.9	9.2	6.91	7.7	8.05
Pr	µg/L	0.001	15	<0.001	<0.001	1.5	<0.001	<0.001	0.00363	0.0000653	0.000544	0.0271
Rb	µg/L	0.01	6	0.015	2.1	631	0.084	0.34	5.82	0.0972	0.425	44.4
Sb	µg/L	0.01	6	<0.01	0.27	4.4	0.094	0.201	0.76	0.00828	0.06	3.16
Sc	µg/L	0.02	nd	most values <DL			<0.02	0.0483	0.192	0.0182	0.0607	0.359

Para-meter	Unit	DL	$P_{95\%}$	European bottled water (n=884)			Hellenic bottled water (n=41)			Hellenic tap water (n=51)		
				Min.	Median	Max.	Min.	Median	Max	Min.	Median	Max.
Se	µg/L	0.02	19	<0.02	0.054	371	0.038	0.18	0.743	0.0699	0.195	1.49
Si	mg/L	0.03	nd	0.42	6.5	59	1.36	4.11	20.8	1.36	3.69	36.9
Sm	µg/L	0.001	23	<0.001	0.0013	0.67	<0.001	<0.001	0.0049	<0.0002	0.00117	0.0272
Sn	µg/L	0.02	12	<0.02	<0.02	1.8	<0.02	<0.02	0.041	0.00141	0.00781	0.0673
SO_4^{2-}	mg/L	0.01	nd	0.01	20	20342	1.65	8.38	89.7	4.43	15.5	190
Sr	µg/L	0.001	nd	2	326	25500	2	118	559	17	193	1600
Ta	µg/L	0.01	-[(b)]	<0.005	<0.005	0.037	most values <DL			<0.001	0.00163	0.0131
tAlk	mg/L	0.1	nd	<2	286	16110	112	235	472	19.3	224	485
Tb	µg/L	0.001	23	<0.001	<0.001	0.077	<0.001	<0.001	0.00167	<0.00005	0.000172	0.00411
TDS	mg/L			11.52	376	16960	113	285	570	28.8	218	1159
Te	µg/L	0.03	-[(b)]	<0.03	<0.03	0.32	most values <DL			<0.005	0.0102	0.0286
Th	µg/L	0.001	33	<0.001	<0.001	0.15	<0.001	<0.001	0.00265	<0.0001	0.000698	0.0194
Ti	µg/L	0.08	52	<0.08	<0.08	6.3	<0.08	<0.08	0.0899	<0.01	0.0656	1.27
Tl	µg/L	0.002	6	<0.002	0.0041	2.2	<0.002	0.00675	0.0248	0.000993	0.00353	0.105
Tm	µg/L	0.001	22	<0.001	<0.001	0.19	<0.001	<0.001	0.00215	<0.00005	0.000191	0.00207
U	µg/L	0.001	2	<0.001	0.23	229	<0.001	0.307	10	0.0693	0.664	20
V	µg/L	0.1	6	<0.1	0.17	49	0.147	0.676	7.45	0.182	0.63	11.8
W	µg/L	0.05	1	<0.05	<0.05	28	<0.05	<0.05	0.106	<0.002	0.0171	1.06
Y	µg/L	0.001	7	<0.001	0.012	3.5	<0.001	0.0043	0.267	0.000663	0.00904	0.117
Yb	µg/L	0.001	17	<0.001	<0.001	1.8	<0.001	<0.001	0.0165	<0.0002	0.000937	0.0119
Zn	µg/L	0.2	3	<0.2	0.89	651	<0.2	1.11	651	0.327	34.9	411
Zr	µg/L	0.001	7	<0.001	0.0075	165	<0.001	0.0016	0.297	<0.001	0.0052	0.0518

Notation: EC - Electrical conductivity; tAlk - total alkalinity; DL - Detection limit; P_{95}% - Precision at the 95% confidence level; Min. - Minimum; Max. - Maximum; ([a]) depends on TDS; ([b]) insufficient number of values above detection for the reliable estimation of precision; nd – not determined

Table 1: Statistical parameters of European bottled water and Hellenic bottled and tap water.

Argholidha (north-east Peloponnese) and Thessaly (eastern central Hellas) because of high nitrates, and some parts of Elia Prefecture (north-west Peloponnese) due to elevated concentrations of iron and manganese. This is in fact a minor drawback of using bottled mineral water as a proxy to groundwater geochemistry, because groundwater with high nitrates, iron and manganese are excluded.

It is stressed at the outset that it was never the intention of this project to assess the overall quality of bottled and tap water, since for such an assessment many more parameters should be analysed, and specifically organic compounds and microbiological components. However, since readers may be interested in the quality of Hellenic bottled and tap water (***Table 1***), it can be safely stated that the concentrations of determined inorganic parameters are below the recommended statutory guideline values. The analytical data of this study are included on the CD-rom accompanying the atlas of the "*Geochemistry of European Bottled Water*" (Reimann and Birke, 2010).

Geology of the Hellenic Republic

Hellas is comprised from sediments and igneous rocks of the Tethys Sea that are grouped into geotectonic zones, consisting of rocks that have a similar development, and represent a unified geomorphological entity (***Fig. 1***); almost all geotectonic zones end stratigraphically with flysch, which consists of a rhythmic sequence of sandstone, marl, clay, and more rarely conglomerate or limestone. North-eastern Hellas is occupied by the Rhodope Massif, a stable block of gneiss, schist and marble; palaeogeographically it belongs to the European craton and existed before the opening of Tethys. The dominant sedimentary rock, making up most of western and southern Hellas, is limestone and dolomitic limestone. Granite and felsic intrusives occur mostly in the north, and on some islands of the Aegean Sea. The most notable geological feature is the extensive occurrence of ophiolite sequences, and their weathering and erosion resulted in the widespread distribution of their detritus in subsequent sedimentary formations.

Materials and methods

Sampling

A total of 61 still bottled waters were purchased from supermarkets, representing 41 different locations (***Fig. 2***); 57 bottled waters were in soft polyethylene terephthalate (PET) and four in clear glass bottles; eight PET bottles were duplicates, purchased from different Hellenic supermarkets, and another eight were from the same location, but marketed under a different brand name. A total of 53 tap water samples were collected covering geographically the whole of the country (***Fig. 2***). In this account the tap water samples from Athens and Thessaloniki are excluded from the statistics, because their water is from surface water reservoirs. The remaining tap water samples come from either natural springs or boreholes representing, therefore, groundwater conditions.

Typical water treatment in Hellas involves (a) chlorine addition for initial disinfection; (b) addition of aluminium sulphate to facilitate flocculation-coagulation and settling of particles in tanks

Figure 1: Simplified lithology map of Hellas (modified from Vassiliades, 2010, Map 2.3, p.22).

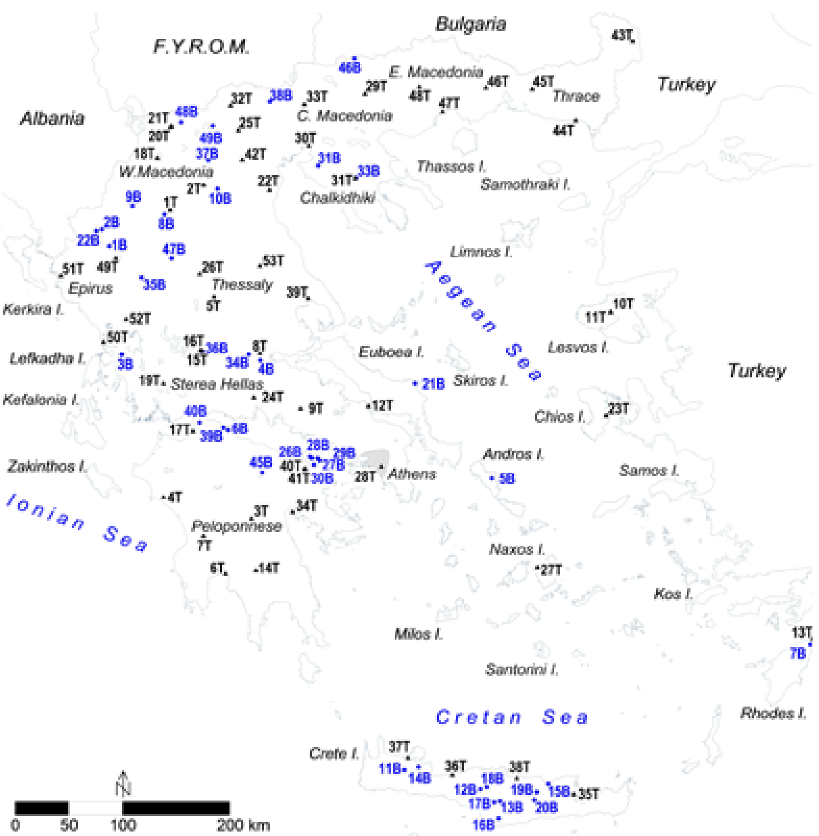

Figure 2: Map showing the sample sites of bottled and tap water samples in Hellas. B - bottled water, T - tap water. See **Table 2** *for sample codes and locations.*

where the water is cleaned to about 80%; (c) passing of water through special sand filters for removing the remaining 20% of very light particles and colloids, and (d) addition of chlorine before the water is released into the municipal distribution network in case the prechlorination is not satisfactory. Hence, the inorganic chemical quality of tap water may be slightly modified with respect to chlorine, aluminium and sulphate.

All bottled and tap water samples were sent to the Federal Institute for Geosciences and Natural Resources (BGR) in Germany, where they were kept refrigerated until their analysis. Before shipping, the 'official' analytical results recorded on bottle labels were transferred to an Excel worksheet together with other pertinent information. It is worth mentioning that there is a good correlation between the results of this study and those displayed on bottled labels going back to 1998. Stable chemistry of the source aquifers is in fact a requirement of the Natural Mineral Waters Directive.

Analysis

The bottled and tap water samples were analysed at the chemical laboratory of the Federal Institute for Geosciences and Natural Resources (BGR) in Berlin. Details of sample preparation and the extensive analytical programme are reported in Reimann and Birke (2010) and Birke *et al.* (2010). Thus, only an outline of the analytical methods employed is provided below:

- Inductively coupled plasma atomic quadrupole mass spectrometry (ICP-QMS): Ag, Al, As, B, Ba, Be, Bi, Cd, Ca, Ce, Co, Cr, Cs, Cu, Er, Eu, Fe, Ga, Gd, Ge, Hf, Hg, Ho, I, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, Pb, Pr, Rb, Sb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr;
- Inductively coupled plasma atomic emission spectrometry (ICP-AES): Ba, Ca, K, Mg, Mn, Na, Sr, P, Si;
- Ion Chromatography (IC): Br^-, Cl^-, F^-, NO_2^-, NO_3^-, SO_4^{2-};
- Atomic fluorescence spectroscopy (AFS): Hg;
- Titration: total alkalinity - HCO_3^-;
- Photometric: NH_4^+;
- Potentiometric: pH, and
- Conductometric: Electrical Conductivity (EC).

Quality control

A very strict quality control programme was installed and reported by Reimann

Bottled water	*Tap water*
Field 1: $Ca^{2+}$and HCO_3^- are the dominant ions and indicate shallow aquifers in recharge areas occurring in limestone (bottled water 70.73%, N=29; tap water 70.59, N=36)	
(1B) Vikos, (2B) Zagori, (3B) Korpi, (4B) Ioli, (6B) Avra, (8B) Pindos, (10B) Drosoula, (11B) Nera kritis, (12B) Mythical, (13B) Rouva's, (14B) Samaria, (15B) Lyttos, (18B) Rizitiko, (19B) Krini, (20B) Dikti, (21B) Kimi, (22B) Eviva, (33B) Athos, Iro, (34B) Evdoro, (35B) Tzoumerka, (36B) Velouhi, (37B) Seli, (38B) Pigi Paikou, (39B) Krinos, (40B) Zefiros, (45B) Hyas, (46B) Beles, (47B) Klinos and (48B) Vitsi	*(1T) Grevena, (2T) Kozani, (3T) Tripoli, (4T) Pirgos, (5T) Karditsa, (6T) Kalamata, (7T) Chalkia, (8T) Lamia, (9T) Livadhia, (12T) Chalkidha, (14T) Sparti, (15T) Karpenisi-1, (16T) Karpenisi-2, (17T) Patra, (18T) Kastoria, (19T) Agrinio, (22T) Katerini, (23T) Chios, (24T) Amfissa, (27T) Naxos, (29T) Serrae, (31T) Poligiros, (32T) Aridhaea, (34T) Nafplion, (36T) Rethimno, (37T) Chania, (39T) Volos, (42T) Veria, (44T) Alexandroupolis, (46T) Xanthi, (47T) Kavala, (48T) Drama, (49T) Ioannina, (50T) Preveza, (51T) Igoumenitsa and (52T) Arta*
Field 2: $Mg^{2+}$and HCO_3^- are the dominant ions; Mg^{2+} dominance or Mg^{2+} and Ca^{2+} importance indicates water often associated with dolomite; Mg^{2+}-Ca^{2+}-HCO_3^- shallow fresh groundwater aquifers occurring wholly or partly in dolomite; where Ca^{2+} and Na^{2+} with important partial ion exchange may be indicated (bottled water 12.2%, N=5; tap water 17.65, N=9)	
(9B) Samarina, (16B) Gortys, (17B) Zaro's, (31B) Ydor Sourotis and (49B) Drossia	*(13T) Rhodos, (20T) Florina-1, (21T) Florina-2, (25T) Skidra, (26T) Trikalla, (33T) Kilkis, (35T) Aghios Nikolaos, (38T) Iraklio, (53T) Larissa, (10T) Kalloni-1 and (11T) Kalloni-2*
Field 3: Na^+ and HCO_3^- are the dominant ions; shallower portions of regional confined aquifers; water deduced to have been affected by ion exchange, although the generation of CO_2 at depth can produce HCO_3^- where Na^+ is dominant under certain circumstances (bottled water 14.63%, N=6; tap water 1.96%, N=1)	
(7B) Aqua Vita, (26B) Loutraki, (27B) Loutraki Hydria, (28B) Loutraki Karadanis Provis, (29B) Loutraki ivi and (30B) Iris Loutraki	*(43T) Orestias*
Field 5: There is no dominant anion or cation and, therefore, no clear facies indicating water exhibiting simple dissolution or mixing (bottled water 2.44%; N=1; tap water 1.96%, N=1)	
(5) Sariza	*(45) Komotini*
Field 6: $Na^+$and SO_4^{2-} dominant water is rare and indicates probable mixing of ancient Na-rich groundwater with pyrite oxidation water; also formed by intensive evaporation of water which has previously lost its Ca^{2+} and HCO_3^- to calcite precipitation (tap water 1.96%, N=1)	
	*(40T) Korinthos-1**
Field 8: Mg^{2+}-(Na^+)-(Ca^{2+})-Cl^-: Mixing of fresh and saline water; Cl^- dominant and no dominant cation indicate that the groundwater may be related to reverse ion exchange of Na^+-Cl^- water (tap water 3.92%, N=2)	
	*(10T) Kalloni-1 and (11T) Kalloni-2**
Field 9: Na^+ and Cl^- dominant indicating end-point water. Influence of sea water, ancient saline groundwater or dissolution of halite (NaCl); Cl^- and Na^+ dominant frequently indicates end-point waters. The Durov diagram does not permit much distinction between Na and Cl waters (tap water 1.96%, N=1)	
	*(41T) Korinthos-2**

**Note: Chloride concentrations in the tap water samples of (40T) Korinthos-1 (458 mg/L), (41T) Korinthos-2 (414 mg/L), (11T) Kalloni-2 (112 mg/L) and (10T) Kalloni-1 (111 mg/L) may be due to sea water intrusion and dissolution of salts within the marine sediments.*

Table 2: Grouping of Hellenic bottled and tap water samples according to the expanded Durov diagram fields (see **Figs. 2, 3 and 4***).*

and Birke (2010) and Birke *et al.* (2010). A general problem of analysing so many elements, as in this unique study, is that there are no suitable reference materials to cover all elements, e.g., Hg, Ho, I, Lu, Nb, Nd, Pr, Sc, Sm, Ta, Tb, Te, Th, Tm, W, Y, Yb and Zr.

The Canadian standards (SLRS-4, TM-26.3, TM-27.2, TM-28.2 and TM-28.3) have the advantage of covering different concentration ranges for a number of elements, and were used to identify elements that presented problems at low concentrations (e.g., Hf, Nb, Sn, Ta and W), but delivered reliable results at higher values (i.e., over ten times the detection limit).

Overall, certified values and the generated project results agree for most elements. However, there were a number of elements not covered by any standards, and this drawback was solved by evaluating reliability of results with respect to blank values and coefficient of variation.

Results

General geochemistry of source aquifers of Hellenic bottled and tap water

The general statistics of parameters determined on Hellenic bottled and tap water samples are tabulated in ***Table 1*** together with the corresponding European data for bottled water. Overall, most parameters vary by up to four orders of magnitude, and a few up to five. The high Cl^- values in tap water, up to 459 mg/L, are most likely due to dissolution of salts from marine sedimentary sequences (***Table 2***).

Each groundwater has a unique hydrochemical fingerprint that reflects the balance of all the various processes during its evolution, the initial rainfall composition, soil zone processes, its residence time in the aquifer, and the mineralogy of rocks and sediments that it comes into contact with. The expanded Durov diagram allowed the identification of four- and seven-chemical groups for the bottled and tap water samples, respectively (Al-Bassam and Khalil, 2012). According to the results shown in ***Figs. 3 and 4*** and ***Table 2*** the source aquifers of the majority of bottled and tap water samples fall in Field 1, the calcium bicarbonate type, at 70.73% and 70.59%, respectively, which is in accordance with the dominance of groundwater in shallow calcium carbonate dominant or limestone aquifers in recharge areas; Equation 1 below indicates the dissolution process.

$$CO_2 + H_2O + CaCO_3 \rightarrow Ca^{2+} + 2HCO_3^- \quad (1)$$

The second most dominant hydrochemical facies for bottled water is the sodium bicarbonate (Na–HCO_3) (Field 3) at 14.63% of the total, which is characterised by either Ca-Na cation exchange or aluminosilicate weathering according to Equation 2, resulting in the formation of clay minerals. The bottled water samples falling in this field occur in an area where, apart from limestone, there are mafic-ultramafic rocks.

$$6CO_2 + 9H_2O + 2NaCaAl_3Si_5O_{16} \rightarrow [2Ca^{2+} + 6HCO_3^- + 4SiO_2] + 2Na^+ + 3Al_2Si_2O_5(OH)_4 \quad (2)$$

For tap water, the second most dominant facies is the magnesium and calcium bicarbonate (Field 2) at 17.65%, which is associated with either hydrolysis of ultramafic rocks (rich in Mg) or dolomite dissociation as given by Equation 3.

$$2CO_2 + 2H_2O + CaCO_3.MgCO_3 \rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^- \quad (3)$$

In the above three cases the significance of CO_2 in the dissolution of limestone, dolomite and aluminosilicate minerals is noted.

The pH of Hellenic bottled water samples varies from 7.08 to 9.2, with a median of 7.9, and for tap water 6.91 to 8.05, with a median of 7.7 (***Table 1, Figs. 1 and 2***). Hence, bottled and tap water samples range from near-neutral to moderately alkaline. Most bottled water samples with high pH tend to be in the sodium bicarbonate group (***Table 2***).

Total dissolved solids (TDS) in bottled water vary from 113 to 570 mg/L, with a median of 285 mg/L, and in tap water from 29 to 1159 mg/L, with a median of 218 mg/L. Thus, Hellenic bottled waters belong to low (50-250 mg/L) to moderate (250-800 mg/L) mineral content waters. Since, most bottled and tap water samples have TDS<1000 mg/L they are classified as fresh water, according to Hem (1985), and it may be assumed that the residence time of groundwater, and distance travelled, are comparatively short.

Total alkalinity in bottled water varies from 112 to 472 mg HCO_3^-/L, with a median of 235 mg HCO_3^-/L, and for tap water from 19 to 485 mg HCO_3^-/L, with a median of 224 mg HCO_3^-/L. Since the main aquifers are within carbonate rocks (karstic aquifers) and coarse-grained Neogene and Quaternary deposits (porous aquifers), the majority of bottled and tap water samples are saturated with respect to calcium carbonate, and the alkalinity corresponds to calcite saturation.

Trace element geochemistry

Two trace elements, chromium and uranium, are selected for discussion because they are significant to the geology of Hellas and affect the chemical composition of groundwater.

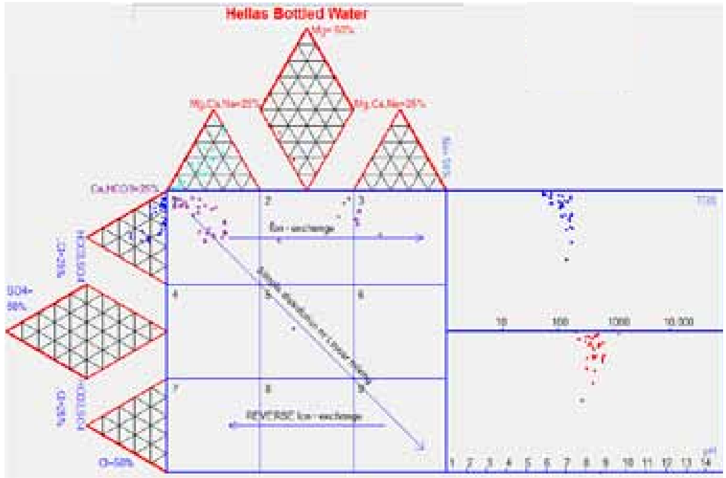

Figure 3: Expanded Durov diagram of bottled water major ion analysis results (N=41); plotted with DurovPwin (Al-Bassam and Khalil, 2012).

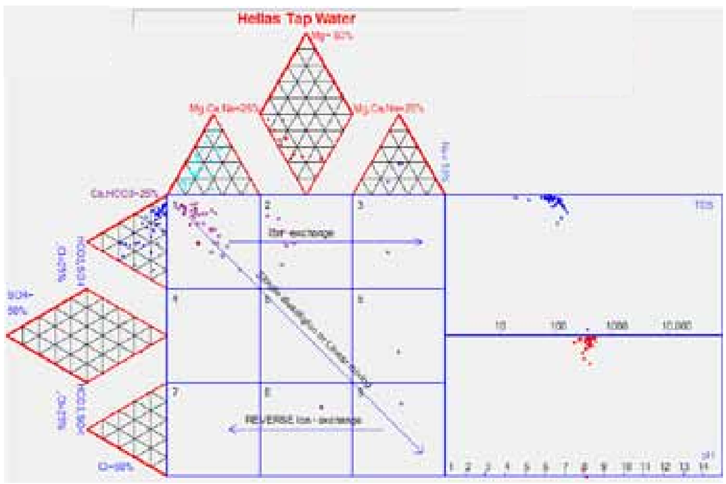

Figure 4: Expanded Durov diagram of tap water major ion analysis results (N=51); plotted with DurovPwin (Al-Bassam and Khalil, 2012).

Chromium distribution

Chromium in Hellenic bottled water varies from <0.2 to 32.9 μg/L, with a median of 0.627 μg/L, while tap water has a narrower range, from 0.108 to 17.7 μg/L, with a median of 0.518 μg/L.

High Cr values occur in bottled and tap water samples in areas with ophiolite occurrences, and in sedimentary rocks with ophiolitic detritus (***Figs. 5 and 6***), e.g., bottled water: Drossia-49B (32.9 μg/L), Ydor Sourotis-31B (27.2 μg/L), Iris Loutraki-30B (23.6 μg/L), Loutraki-26B (22.4 μg/L), Loutraki Karadanis Provis-28B (20.1 μg/L), Loutraki Hydria-27B (19.6 μg/L) and Loutraki Ivi-29B (17.8 μg/L), while the two highest Cr values in tap water are Rhodos-13T (17.7 μg/L) and Larissa-53T (12 μg/L).

The European Union limit for chromium in drinking and mineral water is 50 μg/L (EU directive 2003/40/EC-16.5.2003). Even the maximum concentration found in Hellenic bottled water (32.9 μg/L) is well below this limit.

Uranium distribution

Uranium in Hellenic bottled water varies from <0.001 to 10 μg/L, with a median of 0.307 μg/L, while in tap water it ranges from 0.069 to 20 μg/L, with a median of 0.664 μg/L.

The four highest U values in Hellenic bottled water are Vitsi-48B (10 μg/L), Beles-46B (2.8 μg/L), Drosoula-10B (1.5 μg/L) and Athos or Iro-33B (1.47 μg/L), and the five highest U values in tap water are Skidra-25T (20 μg/L), Serrae-29T (20 μg/L), Kilkis-33T (7.26 μg/L), Naxos-27T (6.1 μg/L) and Aridhaea-32T (4.61 μg/L). In all cases, there are granitic masses nearby

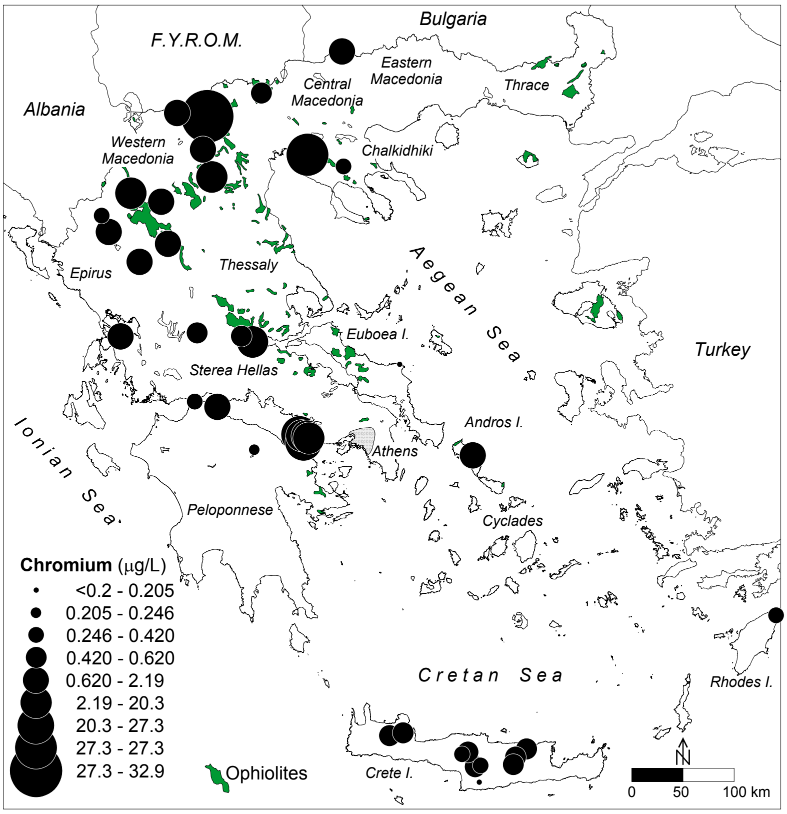

Figure 5: Distribution of chromium (Cr) in Hellenic bottled water samples (see **Fig. 2** *for sample location and brand names).*

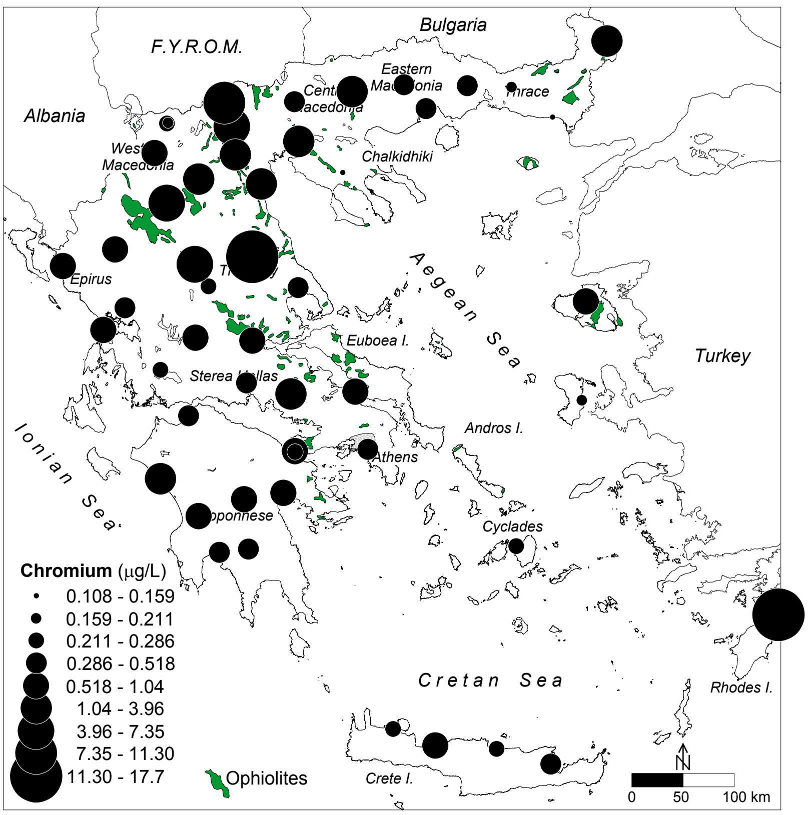

Figure 6: Distribution of chromium (Cr) in Hellenic tap water samples (see **Fig. 2** *for sample location and town names).*

(*Figs. 2, 7 and 8*).

A drinking water standard for U is under discussion in the European Union; currently, a limit of 15 µg/L U appears probable. The U.S. Environmental Protection Agency has defined a drinking water limit of 30 µg/L. In Germany, an upper limit of 2 µg/L U has been defined for bottled water used to prepare baby food and 10 µg/L for drinking water. Russia has defined a limit of 1.8 µg/L U for mineral water (see Appendix A in Reimann and Birke, 2010).

Discussion and conclusions

The processes contributing to the concentration of major ions in groundwater depend on carbonate dissolution and precipitation, cation exchange, and in some cases to dissolution of aluminosilicate minerals. Most of the Hellenic bottled and tap water samples are classified in the Ca^{2+}-HCO_3^- and Ca^{2+}-Mg^{2+}-HCO_3^- and Na^+-HCO_3^- hydrochemical facies, and this is due to the lithology, which is dominated by dolomitic limestone, limestone, marble, and mafic-ultramafic rocks. Geology is, therefore, one of the key factors influencing the observed Hellenic element concentrations in bottled and tap water samples for a significant number of trace elements. Examples include the high values of Cr, clearly related to mafic-ultramafic rocks (ophiolite), and U, associated with granitic intrusions. The source aquifers of Hellenic bottled water are apparently continuously replenished by fresh water, a conclusion supported by modest TDS and alkalinity values.

It can be concluded that the idea of using bottled and tap water as a first proxy for groundwater geochemistry and quality was not as absurd as it might have appeared at first glance. Despite all potential problems, it is shown that natural variation in groundwater quality is much larger than the impact of any secondary consideration. Thus, on most element distribution maps, the importance of geology and other natural processes on the chemical composition of groundwater is clearly visible.

Acknowledgements

Panagiotis Sampatakakis, Constantinos Nikas, Athanasios Hatzikirkou, Eleftheria Poyiadji, Natalia Spanou, Georgios Vrachatis, Dimitris Dimitriou, Michalis Vavrados, and Evangelos Nicolaou (Institute of Geology and Mineral Exploration, Hellas) are thanked for the provision of bottled water samples from different parts of the country, and Sotiris Lambropoulos for arranging the sampling of tap water from different towns. Manfred Birke and the laboratory staff of BGR (Hans Lorenz, Wolfgang Glatte, Bodo Harazim, Fred Flohr, Anna Degtjarev, Jürgen Rausch) are thanked for their dedicated work on the analysis of the bottled and tap water samples. Finally, Professor A.M. Al-Bassam is thanked for the provision of the DurovPwin program, and David Banks for his constructive comments on the original manuscript.

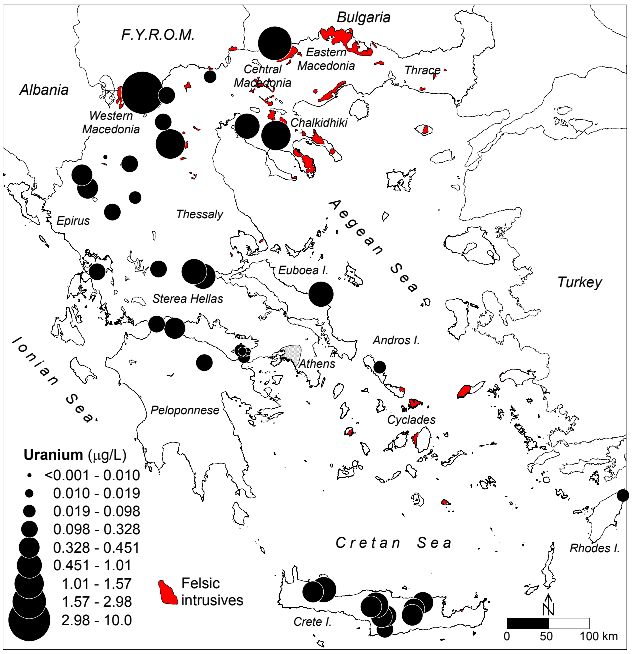

Figure 7: Distribution of uranium (U) in Hellenic bottled water samples (see **Fig. 2** *for sample location and brand names).*

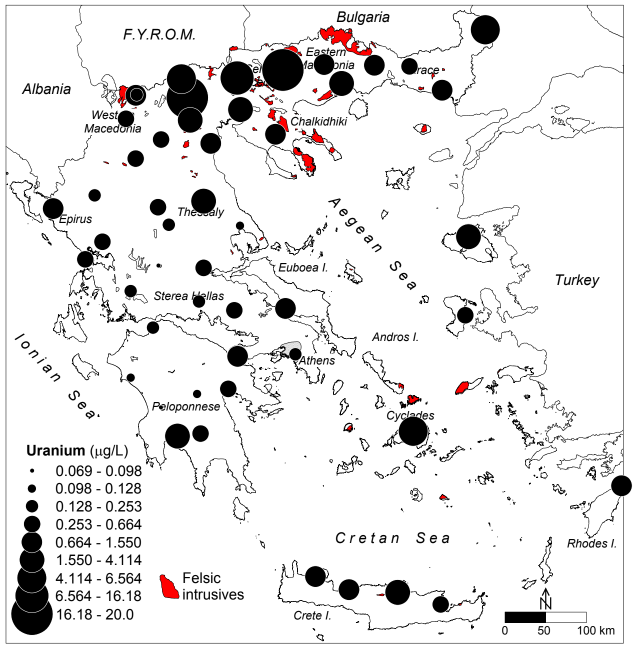

Figure 8: Distribution of uranium (U) in Hellenic tap water samples (see **Fig. 2** *for sample location and town names).*

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Hydrogeology in the Carpathian basin - how to proceed?

Peter Szucs and Tamas Madarasz*

This review gives some general details and facts about the hydrogeological setting of Hungary and the Carpathian basin. This region can be considered a special groundwater "laboratory", where many different interesting hydrogeological phenomena can be found close to each other. This rather complicated natural situation inside the Carpathian basin requires special solutions from the experts to achieve sustainable groundwater management practice in line with the EU Water Framework Directive and the Blueprint to Safeguard Europe's Water Resources document. Groundwater resources play a major role in Hungary's drinking water supply system. More than 95% of our drinking water is provided from groundwater sources, while Hungary is famous for its mineral, medicinal and thermal water supplies.

Cet article rend compte de quelques résultats principaux et de faits concernant les conditions hydrogéologiques prévalentes en Hongrie et dans le bassin des Carpates. Cette région peut être considérée comme un laboratoire spécifique des eaux souterraines où l'on peut rencontrer, cote à cote, un grand nombre de phénomènes hydrogéologiques différents. Cette situation naturelle particulièrement complexe, à l'intérieur du bassin des Carpates, requiert des solutions spécifiques de la part d'experts pour la mise en pratique d'une gestion durable des eaux souterraines en conformité avec la Directive Européenne de l'Eau et le document de Projet touchant la sauvegarde des ressources en eau, en Europe. Les ressources en eau jouent un rôle déterminant en Hongrie pour l'alimentation en eau potable. Plus de 95% de notre eau potable provient des eaux souterraines tandis que la Hongrie est réputée pour sa richesse en eaux minérales, médicinales et thermales.

Este estudio proporciona detalles generales y hechos sobre el entorno hidrogeológico de Hungría y la cuenca de los Cárpatos. Esta región se puede considerar un "laboratorio" especial del agua subterránea en el que se pueden encontrar muchos fenómenos hidrogeológicos uno un lado de otro. Esta situación bastante complicada en la cuenca de los Cárpatos requiere soluciones especiales de los expertos para conseguir unas prácticas de gestión sostenible del agua subterránea en línea con la Directiva Marco de Aguas Subterráneas y el Anteproyecto para Proteger los Recursos de Agua de Europa. Los recursos de agua subterránea juegan un papel principal en el sistema de suministro de agua potable de Hungría. Más del 95% de su agua subterránea procede de fuentes subterráneas y al mismo tiempo es famosa por sus aguas minerales, medicinales y termales.

Groundwater resources play a major role in Hungary's drinking water supply system. Hydrogeologists have a highly responsible professional role in safeguarding our groundwater resources and managing their sustainable utilisation in quantitative and qualitative terms. Over the past several years hydrogeologist experts had to face numerous global or local environmental and social threats, that have significant adverse effect on environmental elements, especially on groundwater. Hydrogeologists of our day and of the future have to provide new and effective answers to new types of technical problems using innovative solutions. When searching for these answers one reliable source is the high quality technical papers published in the framework of the Strategic Programs of the Hungarian Academy of Sciences. In 2008 the Hungarian Academy of Sciences accepted its eight strategic programs in the topics of special importance for Hungary. Hydrogeologists play a special role in three of these already prepared papers: "Water management of Hungary" (Somlyódy, 2011); "Environmental and climate security" (Bozó *et al.*, 2010) and "Utilization of renewable energy sources" (Büki and Lovas, 2010).

* DSc, Head, Department of Hydrogeology and Engineering Geology, University of Miskolc, Hungary , hgszucs@uni-miskolc.hu

Hydrogeological conditions in the inner Carpathian basin

Hungary is located on the Danube watershed in the Carpathian basin, which is one of the most closed basins of the world (***Fig. 1***). The fact that our relatively small country is bordered by seven other countries creates special conditions in groundwater management, with Hungary having the highest number of transboundary aquifers in Europe. The watershed management plan of Hungary contains 185 groundwater bodies, of which 40 are officially registered as transboundary aquifers, although the actual number is even higher. Approxi-

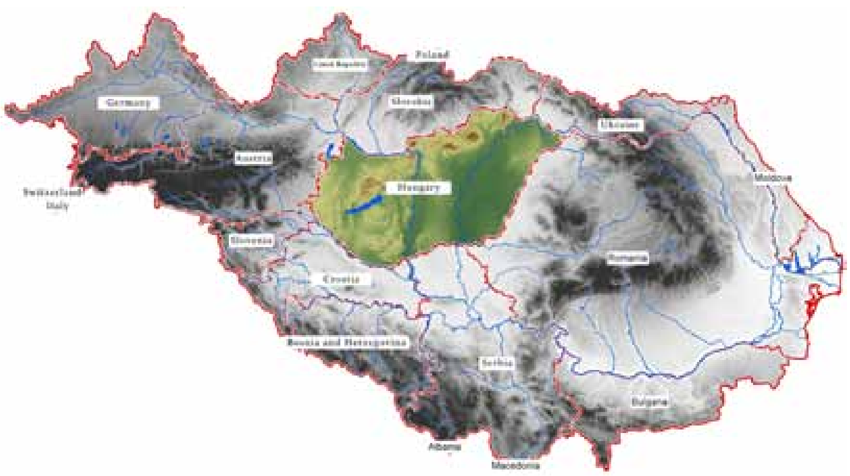

Figure 1: Location of Hungary on the Danube watershed in the Carpathian Basin (Source: VKKI).

mately 50% of the groundwater bodies are divided by a national border; thus, external effects influence the quantity and quality of our groundwater resources. Hungarian groundwater bodies near the borders have downstream characteristics. Many of our neighbours are members of the European Union: Austria (since 1995), Slovakia and Slovenia (since 2004) and Romania (since 2007). Technical collaboration is smoother with these countries, due to the harmonised legal framework, than with the non-member countries of Croatia, Serbia and Ukraine, although they have joined the Danube program.

The hydrogeological settings of Hungary, which on one the hand are considered to be very good, also mean that hydrogeologists can expect a variety of geological, hydrogeological, meteorological and geothermal conditions in the Pannonian basin, as detailed below. In rather large areas of our country within the same year one can observe flooding, inland water and drought, all of which also affect groundwater resources, and thus experts dealing with water resources must be prepared not just for the proper utilisation practices of resources but also for protection against water-related threats.

Hungary shows a rather diverse geological and hydrogeological scene, where almost every unique and interesting feature can be observed in close vicinity. In addition to the hydrogeological features of our karstic mountains (that have a significant role in our water supply system) one can study the rather interesting water bearing parameters of fractured volcanic, plutonic and metamorphic rocks. The geographical units of the Great Hungarian Plain – which attracts international attention – and the Little Hungarian Plain provide several problems to be solved by hydrogeological experts. Reasons for the unique natural variations include the relative thinness of the Earth' crust under the Pannonian Basin and the tectonic compression (observed even recently) causing increasing pore pressure in deeper reservoirs and fluid containing strata of the basin.

To interpret the reconstructed subsurface flow pattern of the Great Plain we must divide the role of two driving energy sources. A gravity-driven flow system is found at shallow depths and beneath it is a pressurized flow system controlled by the tectonic compression. The anticlines of the pre-Neogene basin are the source areas of these highly pressurised regions. The pressure conditions are driven by sedimentation, raising fluid temperature and tectonic compression. The contact zone of the two flow systems is very complex, and its depth is still unknown at certain points of the Great Plain. The geological matrix of the Great Plain consists of a complex, at some points 7,000 m thick Neogene overburden above the pre-Neogen basin bottom. The porous structures in Hungary contain approximately 5,000 km^3 of water at a given time. This volume is called the static groundwater resource. Dynamic groundwater resources play a more important role in sustainable groundwater utilisation; the estimated volume is approximately 2-3 km^3/year.

Groundwater for water supply

Groundwater resources now surpass surface water resources in drinking water supply all over the world (Szűcs *et al.*, 2006). The share of groundwater in Europe has reached 74%, while in Hungary drinking water supply is provided from groundwater at the rate of 95%. Although the total nominal capacity of drinking water supply systems in Hungary is approximately 4.5 million m^3 per day, the total annual production volume is only around 700 million m^3. Beyond the threats caused by changing natural conditions there are unfortunate anthropogenic impacts on the groundwater resources, such as the contamination of environmental elements or our human impacts on climate change.

Practical groundwater classification in Hungary follows the following groundwater categories: riverbank filtered water resources that are closely related to gravel terraces of rivers are also classified as groundwater in the Hungarian nomenclature. These resources – providing almost 40% of the domestic water supply – prove the interconnection of surface waters and groundwater bodies. The protection of these water sources is crucial, for the almost two million inhabitants of Budapest are supplied through riverbank-filtered sources. Besides such sources, mainly in the flat areas of the country deeper groundwater bodies provide the key resources for water supply. In the vicinity of the Trans-Danubian Mountains and the Bükk Mountains the vulnerable karst water has a remarkable share in water supply systems. Unfortunately, our shallow groundwater aquifers are contaminated to such a level that they cannot be utilised in drinking water supply systems.

To maintain a safe national water supply network we must continue to implement the national water resource protection program, applying it both to operating and prospective water aquifers. More than half of the 1,700 domestic water bodies are considered to be vulnerable, thus our strategic national interest of a safe drinking water supply can only be guaranteed by proper diagnostics, and by well-head protection of our water resources.

Within the drinking water quality improvement programme we must apply hydrogeological and water management solutions that do not depend significantly on expensive water treatment technologies. It is in the public interest to raise the technical standard of the water supply network significantly in the future, which will serve to further improve drinking water service quality and reliability, and lead to renewal of the aging infrastructure of waterworks and distribution networks. As far as prospective water resources are concerned Hungary is in a rather good situation. Our country has approximately 1 million m^3/day total capacity in prospective water resources, delineated mostly along the gravel terraces of the Danube and Tisza rivers.

Utilisation of mineral waters, medicinal waters and thermal waters

Hungary's mineral, cure, and thermal water resources are outstanding even in a global context, and have remarkable potential even on a macroeconomic scale. This natural resource can provide further progress and labour market development for several settlements and regions. Medicinal water is a mineral water that has a medicinal effect due to its dissolved gas or mineral content. The health benefits have been proved for specific health infirmities according to strict medical professional protocols. According to the registry of the National Directorate of Health Resorts and Spas, Hungary has 195 registered mineral waters and 220 accredited medicinal water sources. Even the Healing Hungary and Health Industry Program of the New Széchenyi Plan includes the effective and diverse utilisation of Hungary's especially rich thermal, mineral and medicinal water resources and its geothermal capabilities. In the last 20 years the consumption of mineral water has increased significantly, not just in Hungary but worldwide. Domestic mineral water consumption in 2011 and 2012 was around 115 liter/capita/year (***Fig. 2***).

The remarkable government-financed developments that have taken place during the last decade have high importance in domestic health tourism. More than one hundred thermal spa development projects were subsidised. According to the registry of the National Directorate of Health Resorts and Spas, Hungary has approximately 1200 thermal wells, 70 medical spas, 5 medical caves, 5 locally extracted mud sources, 1

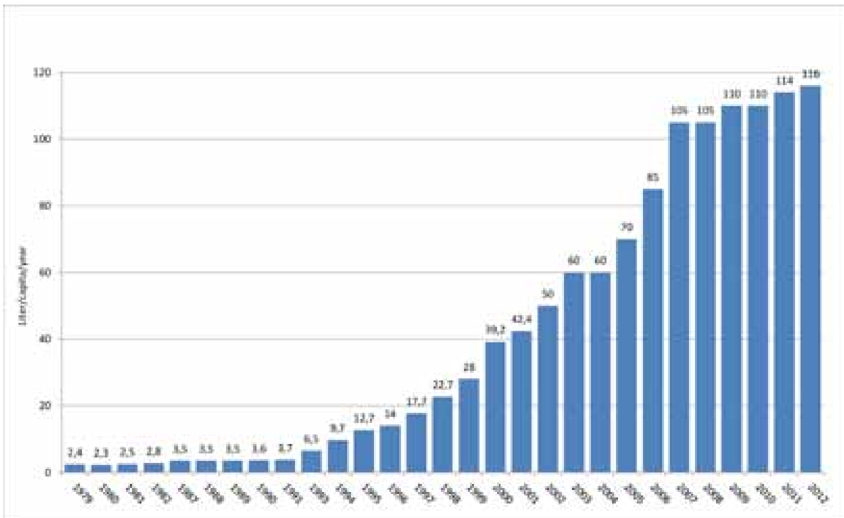

Figure 2: Consumption of mineral water per capita in Hungary (source: Hungarian Association and Product Union of Mineral Waters).

mofetta and 13 health resorts can be found. In an international context, Hungary is considered to be in the top five countries in terms of thermal water resources. Our medicinal water resources have a unique value on a global scale, considering the variety of medical benefits they can offer.

In the future hydrogeology must play a major role in increasing the use of geothermal energy sources. Thermal waters with temperature above 30 °C have a significant role in utilisation of their heat and energy. The excellent geothermal potential of our country and the Carpathian basin, its hydrogeothermal systems and thermal water utilization options have been introduced in numerous remarkable studies published during the past years (Mádlné Szőnyi, 2006; Szanyi and Kovács, 2010; Székely, 2010). In Hungary, under the surface the average geothermal heat flux is approximately 90 mW/m^2, while the geothermal gradient ranges between 30–50 °C/km. From these data one can determine the theoretically available total dynamic heat reserve, which exceeds geothermal 8000 MW. In spite of this the present day actual utilisation of geothermal energy is very low. The very heterogeneous geological and hydrogeological situations provide a good basis for extending the scope of various types of geothermal energy utilisation methods (Bobok and Tóth, 2010).

The waters of medium enthalpy systems (temperature range 30-100 °C) are utilised mainly in cascade-type municipal heating systems, municipal and industrial hot water supplies, in wellness and themal spas and in agricultural facilities (glass greenhouses, plastic tunnels, stables, and dryers). In the most favorable locations at the Southern part of the Great Plain, from a geological point of view practically every settlement could install medium enthalpy heat utilisation units. However, it is also clear that the production rate of our thermal water resources at several locations is above sustainable production volumes. At these sites we can register continuously decreasing water heads. Thus, when utilising thermal water discharge for energy it is very important – and a legal requirement for new wells – to set up reinjection systems, although this might cause conflicts of interest in some areas, especially where the lack of injection (the former practice) resulted in significant financial benefits.

For the larger thermal water users (e.g. municipal public works) the financial benefit remains even if the infiltration system is installed. The protection of our groundwater systems must however have higher priority than protection of local financial interests. From a water management perspective it is not tolerable however, that out of the appr. 50 million m^3/year energy driven thermal water production, only approximately 1 million m^3 is reinjected into the underground formations. In the past the cooled waters, often with very high salt content, have caused a severe environmental load and flowed out of our country through our major rivers.

The ultimate purpose of high enthalpy system installations (where water temperature is above 100 °C) is electricity generation, or the joint utilisation of the 6-8 units of wasted heat produced during generation of 1 unit of electricity. Although there are numerous locations in the country (e.g. Fábiánsebestyén, the Makói Trough, the Békési Basin, the Derecskei Trough) where the available groundwater temperatures are suitable for energy production with the temperatures of 180-200 °C, but such investments have not yet been implemented in the Carpathian basin.

Future challenges for hydrogeologists in the Carpathian Basin

There are numerous unsolved challenges awaiting hydrogeologists, not just in the Carpathian Basin, but all over the world (Galloway, 2010). Due to the newness of a significant share of the groundwater related problems, there is a need for new types of educational programs and technical competences for future generations of hydrogeologists. Due to the transboundary feature of the groundwater resources in the area, Hungarian hydrogeologists must collaborate more intensively with hydrogeologists from the neighbouring countries. A part of our future tasks is related to the implementation of the goal system of the domestic watershed management plan based on the Water Framework directive. For our groundwater systems we must reach the good quality and quantity status by 2015. Currently 68% of our groundwater bodies meet the qualifications of good status. The strengthening of the ecological aspects requires a new type of technical thinking from our hydrogeologists. The collaboration in the EU Danube region strategy can act as a forum for international collaboration also in the field of groundwater resources.

Recent climate change is causing more extreme weather phenomena, which strongly impacts the natural water cycle. These effects naturally influence the quality and quantity aspects of natural discharge, especially in the synclinal type areas. Due to the increasing demand for safe drinking water, one area of high priority is that technical experts have proper knowledge about the possible near-future changes in our water resources. From estimates on the impact of climate change on our watersheds (Hungarian and cross-border), we can expect a decrease in surface runoff and infiltration driven discharge and as a result we can expect a decrease in dischargeable (usable) groundwater resources.

It is no longer satisfactory for hydrogeologists to deal with groundwater only. Due to the water cycle everything is interrelated. Due to the effects of observed natural changes and anthropogenic intervention, the groundwater systems are evolving into a new equilibrium status. Dealing with water resources in such dynamic systems requires an interdisciplinary and holistic approach, which accommodates discussion about technical, scientific, economic, legal and social impacts on water resource management of the Carpathian Basin. Understanding the theory of subsurface flow systems and the description of depth material and heat transport requires more contributions from hydrogeochemistry and the detailed analysis of environmental isotopes. Environmental chemistry must receive a greater emphasis during the education of future hydrogeologists.

Summary

Our groundwater resources, which play an essential role in our drinking water supply, are important natural resources and worthy of long-term protection. The mineral, medicinal, and thermal water resources of Hungary are also remarkable, and their utilisation in a wider scope is a matter of macroeconomic interest. The joint marketing effort of our mineral waters and medicinal waters in the scope of the Carpathian basin can significantly improve our present European market position and utilisation options. We must be aware of the fact that our groundwater sources are finite; in fact, in some parts of the Great Plain the utilisation is already close to 100%. In the future it will be more important for hydrogeologists to forecast more precisely and more reliably the local or regional usable water resources. The reinjection of thermal water used for energy can guarantee a sustainable hydraulic and quality status of the deeper aquifer systems that contain mineral and medicinal waters. Although according to the prognosed climate change scenarios we can anticipate a small decrease in groundwater resources, a sustainable and safe water supply can be provided for future generations in Hungary by the operation of regional water supply networks and the application of the government supported National Water Management Strategy. A sustainable, safe supply is also ensured by the fact that, beyond our existing water resources, we have considerable accessible resources, such as prospective water resources. For the long-term drinking water supply, groundwater is preferred to surface water due to its higher predictability and more constant water quality parameters, as well as its better protection against surface contamination sources. Today political, professional and scientific circles generally agree that Hungary's groundwater resources have strategic importance.

Highly educated hydrogeologists will be even more necessary in the future, in Hungary and in the Carpathian basin. Numerous traditional and new tasks are awaiting future generations of groundwater specialists. Due to the interdisciplinary of the tasks, it is important that our education programs integrate international trends (Voss, 2005) and the special hydrological and hydrogeological features of the Carpathian basin.

Acknowledgement

The described work was carried out as part of the TÁMOP-4.2.2.A-11/1/KONV-2012-0049 project in the framework of the New Hungarian Development Plan. The realisation of this project is supported by the European Union, and co-financed by the European Social Fund.

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Groundwater Vulnerability and the EIA/EIS Process

Kevin T. Cullen and Catherine Buckley*

The Institute of Geologists of Ireland (IGI) has developed a set of guidelines regarding the preparation of the soils, geology and hydrogeological sections of environmental impact statements (EISs). The Guidelines include a flow chart, consisting of four elements subdivided into 13 steps, that describes the recommended procedure. A matrix is also included that relates activities associated with development with the vulnerability of geological and hydrogeological environments found in Ireland. The matrix indicates the range of works and studies required to identify and quantify the residual impacts associated with each activity depending on the vulnerability of the receiving subsurface environment. The flow chart and matrix are generic and could be adapted for use in other EU countries for the preparation of Environmental Impact Assessments.

L'Institut Irlandais des Géologues (IGI) a établi une série de directives concernant l'aménagement des sols, la Géologie et les chapitres relatifs à l'Hydrogéologie, au sein de rapports évaluant l'impact environnemental (EISs). Les recommandations comprennent un organigramme qui décrit la procédure conseillée et comportent 4 Eléments subdivisés en 13 paliers. Un registre est aussi inclus pour rendre compte des Activités associées aux Projets de développement avec mention de la vulnérabilité des environnements géologiques et hydrogéologiques rencontrés en Irlande. Le registre liste l'éventail des travaux et études nécessaires pour identifier et quantifier les impacts résiduels associés à chaque Activité en fonction de la vulnérabilité environnementale spécifique des sols. Organigramme et Registre sont génériques et pourraient être adaptés pour une utilisation dans d'autres pays européens, dans le cadre d'un Projet d'évaluation de l'impact environnemental.

El Instituto de los Geólogos de Irlanda (IGI) ha desarrollado una serie de Normas para la elaboración de los cortes de suelos, geológicos e hidrogeológicos de las Declaraciones de Impacto Ambiental (DIA). Las normas incluyen un diagrama de flujo que consiste en 4 elementos subdivididos en 13 pasos que describen el procedimiento recomendado. Se incluye también una matriz que relaciona las actividades asociadas con las operaciones y la vulnerabilidad de los ambientes geológicos e hidrogeológicos que se encuentran en Irlanda. La matriz indica el rango de estudios y trabajos que se precisan para identificar y cuantificar los impactos residuales asociados a cada actividad, dependiendo de la vulnerabilidad del ambiente subterráneo receptor. El diagrama de flujo y la matriz son genéricas y se podrían adaptar a cualquier otro país de la UE en la elaboración de las Evaluaciones de Impacto Ambiental.

The Institute of Geologists of Ireland (IGI) convened a Working Group in 2012 to review the Institutes' earlier 2002 guidelines on the preparation of Environmental Impact Statements (EISs). The recently published 2013 IGI EIS Guidelines reflect legislative changes and members' experiences in the production of EIS chapters on Soils, Geology and Hydrogeology since the 2002 Guidelines were produced.

The Environmental Impact Assessment Directive (Council Directive 85/337/EEC as amended by Directive 97/11/EC) requires Member States of the EU to carry out assessments of the environmental impact of certain projects before they are allowed to proceed. The aim of the Environmental Impact Assessment (EIA) process is to ensure that projects which are likely to have a significant effect on the environment are assessed in advance. As part of the EIA process, some projects may require the developer to assess the likely effects (good and bad), of a proposed development on the environment. In Ireland, this document is referred to as the Environmental Impact Statement (EIS), while in other European countries it is simply referred to as the Environmental Impact Assessment (EIA).

* On behalf of the Institute of Geologists of Ireland EIS Guidelines Working Group, kevintcullen@yahoo.ie

In Ireland, only the Competent Authority (e.g. the Planning Authority, An Bórd Pleanala, etc.) carries out an EIA. An EIS is prepared by (or on behalf of) the developer of the proposed project. The cost of producing the EIS is borne by the developer and the expenditure involved will reflect both the scale of the development and the sensitivity of the local environment.

Some developments may also require the consideration of other environmental legislation to be taken into account, e.g. an Appropriate Assessment (AA) or a Strategic Environmental Assessment (SEA) may be required. When considering the environmental impacts of a development, all relevant legislation should be considered and the appropriate level of assessment undertaken.

The IGI publication is entitled *Guidelines for the Preparation of Soils, Geology and Hydrogeological Chapters of Environmental Impact Statements, 2013*. The Guidelines provide a methodology for the assessment of potential impacts which proposed developments may have on soil, geological and hydrogeological environments. The recommended procedure outlined in the Guidelines requires that the information provided in an EIS should reflect the vulnerability of the receiving geological and hydrogeological environments to activities associated with the construction and/or the operation of a development.

The 2013 IGI EIS Guidelines draw upon experience, regulatory guidance and legislation in the Republic of Ireland. The IGI Guidelines will be circulated to the relevant planning and licensing agencies for use within the Irish regulatory and permitting processes. However, the recommended procedure and methodology for the preparation of the EIS outlined in the 2013 IGI Guidelines are generic and could be adapted for use in any EU Member State for the preparation of EIA.

This article describes the principle components of the IGI Guidelines. Information on the availability of the published document is provided at *www.igi.ie*.

Recommended Procedure

Many developments which require an EIS will have no significant impact on the geological/ hydrogeological environment, such as developments which are removed from areas of geological heritage and which are connected to services. On the other hand, developments such as mines, quarries, significant groundwater abstractions and discharges to groundwater would naturally impact on subsurface resources.

It is important therefore to identify at the outset the:

- relative scale of the development;
- range of activities associated with the development;
- type of the receiving geological/hydrogeological environment;
- vulnerability of the receiving geological/hydrogeological environment;
- interaction/relationship between the development site and nearby protected environments.

By compiling the above information, and where necessary carrying out appropriate site investigations and studies, it should then be possible to determine:

- whether the development has the potential to impact on the receiving geological/hydrogeological environment;
- the significance, type, duration and quality of any potential impacts;
- mitigation measures;
- the significance, type, duration and quality of any residual impact.

The IGI recommended procedure is described in a Flow Chart (***Fig. 1***) and consists of four elements subdivided into 13 steps, as follows:

1. Element 1: Initial assessment (Steps 1 to 5)
2. Element 2: Direct and indirect site investigation and hydrogeological studies (Steps 6 to 9)
3. Element 3: Mitigation measures and residual impacts (Steps 10 to 12)
4. Element 4: Completion of the EIS (Step 13)

An accompanying matrix (***Fig. 2***) aligns the type of investigations to be carried out with the nature and vulnerability of the receiving subsurface environment.

1st Element - Initial Assessment

Step 1 – Establish the Location, Type and Scale of Proposed Development

The objective of Step 1 is to compile the available and relevant information which, together with a site visit, would allow for the determination of the type and scale of the proposed development, the range of related activities, and the type and vulnerability of the receiving geological/hydrogeological environment.

At a minimum, maps identifying the site boundary and any related discharge points should be provided, together with a plan outline and levels of any proposed earth works or deep excavations. Information should be provided on the nature, location and volume of any groundwater development for dewatering, water supply or on-site energy production.

Professional judgement will be required to determine the amount of studies to be undertaken in line with the type and scale of the proposed development and related activities in the context of the local environmental baseline conditions. Clearly, the works and studies required for a proposed aggregate quarry covering 40 hectares will be much greater than those required for a similar excavation covering 5 hectares. Similarly, the details required for a basic on-site groundwater supply normally would be significantly fewer than those required for the development of a regional groundwater supply.

Step 2 – Establish Baseline Conditions

The objective here is to place the proposed development site within the context of the local or regional soil, geological and hydrogeological regimes and allow for an initial assessment of how the development and/or related activities might impact on the existing subsurface environment.

The compilation of the available geological and hydrogeological information into a preliminary Conceptual Site Model (CSM) for the development site and its environs is central to establishing baseline conditions.

The CSM will consist of a series of maps centred on the development site together

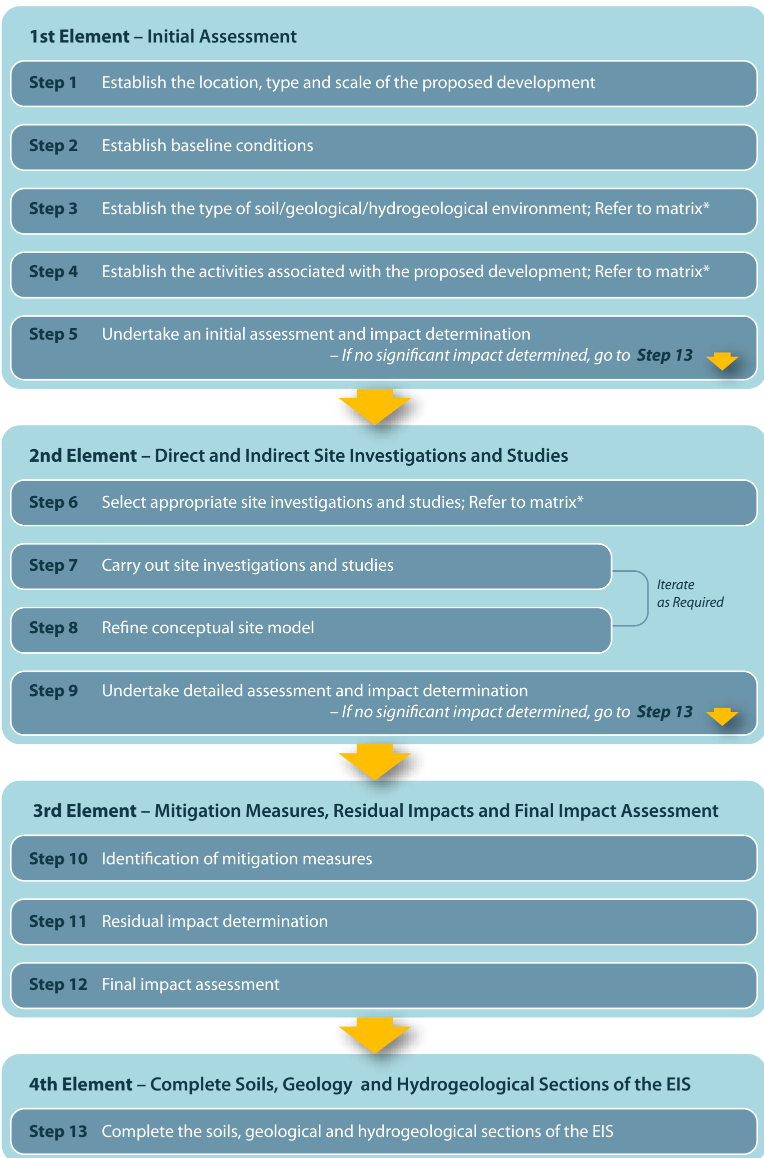


Figure 1: Flow Chart for the preparation of the soils, geology and hydrogeological chapters of Environmental Impact Statements, IGI Guidelines.

	Activities							
	Earthworks	**Storage / transmission of leachable and/or hazardous materials**	**Lowering of groundwater levels by pumping or drainage**	**Discharges to ground**	**Excavation of materials above the water table**	**Excavation of materials below the water table**	**Land-spreading**	**Abstraction / Discharge of energy (heat) from/to the ground**
Environments Type A	Invasive site works to characterise nature1 and thickness of soil and subsoil e.g. trial pits or augering.	Establish nature and quantity of leachable materials.	Establish details of borehole /spring construction or drainage system structure details (as appropriate).	Complete a Risk Assessment as per EPA (2011) Guidance on the Authorisation of Discharges to Groundwater; Apply Tier 1, 2 or 3 Assessment as appropriate	Site works to characterise nature, thickness, permeability and stratification of soils and subsoils e.g. trial pits, augering.	Site works to characterise nature, thickness, permeability and stratification of soils and subsoils e.g. trial pits, augering.	Establish the type of waste to be landspread.	Provide details of type of system (open/closed, shallow/deep). The site works required and described below will reflect the design parameters of the system being installed.
		Site works to characterise nature1, thickness, permeability and stratification of soils, subsoils and bedrock geology e.g. trial pits, boreholes.	Establish sustainable yield and proposed daily abstraction rate or drainage system invert levels (as appropriate).		Site works to fully characterise the bedrock geology and in order to to define the resource volume/weight according to The PERC Reporting Standard e.g. trenching, drilling, geophysics.	Site works to fully characterise the bedrock geology and in order to to define the resource volume/weight according to The PERC Reporting Standard e.g. trenching, drilling, geophysics.	Undertake a walkover survey of the site.	Site works to characterise nature, thickness, permeability and stratification of soils, subsoils and bedrock geology.
		Works to determine groundwater level, e.g.mapping, monitoring in stand pipes, piezometers, or boreholes.	Works to determine summer level of the water table, annual actual recharge and proposed maximum drawdown.		Works to determine groundwater level, flow direction and gradient; e.g.monitoring in stand pipes, piezometers, or boreholes.	Works to determine groundwater level, flow direction and gradient; e.g.monitoring in stand pipes, piezometers, or boreholes.	Review Groundwater Protection Responses for Landspreading, and apply Departmental and Regularory guidelines and best practice.	Design parameters for the system will be required to be collected, however these are out of the remit of this document - although any information gathered for design purposes should be used in the EIS.
			Measurement of effects of change in water level on nearby abstractions.			Characterisation of groundwater chemistry and quality.	Assign a response category.	
						If lowering of groundwater levels is required, then proceed also as for activity Lowering of water levels by pumping of drainage.		
Environments Type B	*In addition to all the above;*	*In addition to all the above;*	*In addition to all the above;*	*As above;*	*As above;*	*As above;*	*In addition to all the above;*	*In addition to all the above;*
	Works to determine groundwater level, flow direction and gradient; e.g. monitoring in stand pipes, piezometers, or boreholes.	Works to determine groundwater flow direction and gradient; e.g. monitoring in stand pipes, piezometers, or boreholes.	Works to determine aquifer properties, seasonal variations in water levels, extent of cone of depression or drawdown of surrounding water levels (as appropriate) and alterations in groundwater flow pattern.				Site works to characterise subsoil/soil characteristics e.g. trial pits or augering.	Characterise baseline temperature of soil / groundwater and groundwater hydrochemistry and quality.
	Works to determine groundwater - surface water interactions.	Works to determine groundwater - surface water interactions.	Works to determine groundwater - surface water interactions and measure effects of drawdown in water levels on hydraulically connected surface waters and springs.					Works to determine groundwater level e.g.monitoring in stand pipes, piezometers, or boreholes.
								If it is proposed to discharge to surface water, then characterisation surface water quality, baseline temperature and flow rates.
Environments Type C	*In addition to all the above;*	*In addition to all the above;*	*In addition to all the above;*	*As above;*	*As above;*	*As above;*	*In addition to all the above;*	*In addition to all the above;*
	Identify location and abstraction rate of nearby groundwater abstractions.	Measure or determine rate of groundwater flow/travel time.	Installation of sufficient monitoring wells to provide groundwater flow direction, gradient, pattern and rate of flow/travel time.				Confirm subsoil permeability in laboratory. Delineate inner and outer source protection areas and source protection zones.	Works to determine thermal and hydraulic conductivity of soil, subsoil and bedrock.
			Identify nearby geothermal systems, and discharges to groundwater				Establish water quality of groundwater abstraction. Undertake risk assessment if appropriate.	Identify location and abstraction rate of nearby groundwater abstractions.
Environments Type D	*In addition to all the above;*	*In addition to all the above;*	*In addition to all the above;*	*In addition to all the above;*	*In addition to all the above;*	*In addition to all the above;*	*As for Type C above*	*In addition to all the above;*
	Regional study of karst in an area, including identified karst features (both mapped and identified during site walkovers).	Full detailed hydrogeological assessment required in this situation.	Geotechnical assessment of risk of landslide or subsidence.	Geotechnical assessment of risk of landslide or subsidence.	Full detailed hydrogeological assessment required in this situation.	Geotechnical assessment of risk of landslide or subsidence.		Geotechnical assessment of risk of landslide or subsidence.
	Map bedrock topography. Geotechnical assessment of risk of landslide or subsidence.	Geotechnical assessment of risk of landslide or subsidence.			Geotechnical assessment of risk of landslide or subsidence.			
Type E	Full detailed hydrogeological assessment required in this situation.	Full detailed hydrogeological assessment required in this situation.	Full detailed hydrogeological assessment required in this situation.	Complete a Risk Assessment as per EPA (2011); Apply Tier 1, 2 or 3 Assessment as appropriate.	Full detailed hydrogeological assessment required in this situation.	Full detailed hydrogeological assessment required in this situation.	*As for Type C above*	Full thermogeological and/or hydrogeological assessment required in this situation.

Figure 2: Matrix accompanying the IGI Guidelines on the preparation of the soils, geology and hydrogeological chapters of Environmental Impact Statements.

with interpretative cross-sections passing through the development site and a textual description.

a. Sources of Information

The information required to construct the initial CSM should be obtained from a combination of:

- published reports and maps;
- a site visit and walk-over survey;
- a list of sources of geological and hydrogeological information relevant to the Republic of Ireland, which accompanies the Guidelines.

b. Extent and Scale of Data

Maps should be sourced to allow for the review of the geological and hydrogeological conditions that exist within a minimum of 2 km of the site boundary and presented at a scale of 1:25,000, i.e. from the outer limit of the planning and/or licence area. The recommended minimum distance of 2 km should be reviewed in the context of the geological/hydrogeological environment, as well as the scale of the development, and increased to reflect the vulnerability of the subsurface, for example where limestone karst systems are present.

c. Required Information

The output from Step 2 should contain maps and information including:

- ordinance survey topographic base mapping and, where possible, aerial photography;
- designated conservation sites, including Geological Heritage Sites, Natura 2000 Sites and proposed and candidate Special Areas of Conservation, Special Protection Areas and Natural Heritage Areas;
- bedrock geology, including all known outcrops, karst features, quarries and identified faults and formation boundaries;
- overburden geology, thicknesses and overburden types with depositional descriptions such as glacial, fluvial, marine, etc. where this information is available;
- soils, both natural and man-made;
- groundwater bodies and surface water bodies, including current qualitative and quantitative status and related objectives and measures;
- aquifers, showing groundwater abstractions and any related protection zones and discharges to groundwater;
- groundwater vulnerability;
- surface water drainage, including areas at risk of flooding;
- sites with waste licences and permits, both current and historical;
- sites where illegal dumping has been recorded/reported;
- sites with recorded/reported contaminated land;
- sites with recognised aggregate potential and/or which contain economic minerals.

The maps should clearly show the outline of the site and demonstrate how the proposed development site relates spatially to conservation sites, aquifers (both bedrock and overburden), groundwater abstraction and discharge areas, surface watercourses, groundwater vulnerability and areas prone to flooding. The known or assumed direction of groundwater flow in the vicinity of the site should be indicated. These maps and cross-sections should inform the CSM.

Step 3 - Establish the Type of Geological/ Hydrogeological Environment:

From the matrix (***Fig. 2***) and the CSM completed in Step 2 it is now possible to identify the generic type of geological/ hydrogeological environment into which the proposed development is to be placed.

A range of generic geological/hydrogeological environments has been assembled in the accompanying matrix (***Fig. 2***) to describe and encompass the variety of subsurface environments likely to be found in Ireland. The generic types classified in the matrix are:

- Type A - Passive hydrogeological environments, e.g. areas of thick low permeability subsoil, areas underlain by poor aquifers, recharge areas, historically stable geological environments;
- Type B - Naturally dynamic hydrogeological environments e.g. groundwater discharge areas, areas underlain by regionally important aquifers, nearby spring rises, areas underlain by permeable subsoils;
- Type C - Man-made dynamic hydrogeological environments, e.g. nearby groundwater abstractions, nearby quarrying or mining activities below the water table, nearby waste water discharges to ground, nearby geothermal systems;
- Type D - Sensitive geological/ hydrogeological environments, e.g. potentially unstable geological environments, groundwater source protection zones, karst;
- Type E - Groundwater-dependent ecosystems, e.g. wetlands, nearby rivers with a high groundwater component of base flow.

Step 4 – Establish the Range of Activities associated with the proposed development

A range of generic activities which could impact on the geological/hydrogeological environment has been assembled in the matrix (***Fig. 2***).

The generic activities identified are:

- earthworks;
- storage/transmission of leachable or hazardous materials;
- lowering of groundwater levels by pumping or drainage;
- discharges to ground;
- excavation of materials above the water table;
- excavation of materials below the water table;
- landspreading;
- abstraction/discharge of energy (heat) from/to the ground.

Step 5 – Undertake an Initial Assessment and Impact Determination

An initial assessment and impact determination should now be prepared that summarises the information compiled so far and then reviews it to determine whether the proposed development would result in any impact on the receiving geological/ hydrogeological environment. The significance of any impact should be determined with particular reference to national guidance documents based on the importance of the feature to be protected and the magnitude of the impact on the receiving geological/hydrogeological environment.

Where there is a determination that:

- none of Activities identified in Step 4 above will take place at the development site, or
- where the determined level of impact is capable of measurement but without noticeable consequences (EPA, 2002),

then the impact assessment proceeds directly to the 4th element in the Flow Chart (***Fig. 1***) to inform the Soils and Geological/ Hydrogeological sections of the EIS. In all other cases additional site-specific studies will be required, and these form the 2nd element of the recommended procedure.

2nd Element –Direct and Indirect Site Investigations and Studies

Step 6 – Site Investigations and Studies

Professional judgement will be required to select the necessary range of direct and indirect site investigations and studies required to further inform the CSM and to quantify the impact of the proposed development on the receiving geological/ hydrogeological environment. The range and scope of the planned investigations must reflect:

- the scale of the proposed development,
- the range of activities likely to occur during the construction and operation of the development and
- the type and vulnerability of the receiving geological/hydrogeological environment.

Critically, the selected range of direct and indirect site investigations and studies must be sufficient to quantify the impacts associated with each relevant activity associated with the development.

The matrix (*Fig. 2*) provides a useful basis on which to select a suitable range of direct and indirect site investigations and hydrogeological studies that could be carried out to further develop the CSM. A key aspect of the matrix is that the scope of the recommended works and studies increases both in variety and complexity as the receiving environment becomes more vulnerable to potential impacts.

Step 7 – Carry out Site Investigations and Hydrogeological Studies

Every effort should be made to undertake as many of the recommended works and studies as is necessary to establish the geological/hydrogeological conditions existing at the development site and in its environs. Critically, they must be sufficient to quantify the impacts associated with each relevant activity associated with the development.

Step 8 – Refine the Conceptual Site Model

The continuous updating of the CSM is an integral aspect of the recommended procedure. The updating of the CSM is an iterative process, with each new piece of information adding to the previous version of the CSM.

Step 9 - Undertake Detailed Assessment and Impact Determination

A detailed assessment and impact determination should now be prepared that describes the full range of site investigations and hydrogeological studies carried out together with the revised CSM and a full assessment of any potential impacts.

Where the impact determination now concludes that the level of potential impact is capable of measurement but without noticeable consequences, the detailed assessment and impact determination should be prepared and the assessment will proceed directly to the 4th element so as to inform the soils and geological/hydrogeological sections of the EIS as detailed in *Fig. 1*.

In all other cases the detailed assessment and impact determination should be carried forward into the 3rd element of the recommended procedure, where mitigation measures are designed and the significance of any residual impact is assessed.

3rd Element –Mitigation Measures, Residual Impacts and Final Impact Assessment

The 3rd element of the recommended procedure builds on the outcome of the preceding two elements by identifying mitigation measures to address potential impacts and then assessing the significance of any residual impacts.

Step 10 – Identification of Mitigation Measures

Appropriate mitigation measures should be identified that would avoid, remedy or reduce the potential impacts identified in the detailed assessment and impact determination. This process is likely to be iterative with Step 11.

Step 11- Residual Impact Determination

The development, with proposed mitigation measures assumed implemented, is then subjected to impact assessment, to identify any residual impacts.

Step 12 – Final Impact Assessment

The output from the detailed assessment and impact determination from Step 9, a description of the proposed mitigation measures from Step 10 and the residual impact determination from Step 11 will then be included in a final impact assessment.

The significance of any residual impact should be determined with particular reference to national guidance documents based on the importance of the feature to be protected and the magnitude of the residual impact on the receiving geological/hydrogeological environment.

The final impact assessment will inform the soils and geological/hydrogeological sections of the EIS.

4th Element –Completion of the Soils and Hydrogeological Sections of EIS

Step 13 – Complete the Soils and Hydrogeological Sections of the EIS

At a minimum, the information gathered for the completion of the initial assessment and impact determination (Step 5), including the CSM, should be described in the body of the EIS, and where appropriate the maps and cross sections should be included in appendices to the EIS.

Where site investigations and hydrogeological studies have been carried out then the conclusions outlined in the detailed assessment and impact determination (Step 9) should be included in the EIS with the relevant field data included in appendices to the EIS.

In the case where potential impacts which will require mitigation are identified, then the conclusions outlined in the final impact assessment (Step 12) should be documented in the EIS.

Where a residual impact is identified in the Final Impact Assessment then the significance of the residual impact on the receiving geological/hydrogeological environment should be described in the body of the EIS. The significance of any residual impact should be determined with particular reference to national guidance documents based on the importance of the feature to be protected and the magnitude of the impact on the receiving geological/hydrogeological environment.

Non-Technical Summary

In Ireland, a Non-Technical Summary (NTS) is required to accompany the EIS. It should include, in layman's language, a brief summary of the geological and hydrogeological environments present, how the activities associated with the proposed project could impact on these environments, and their vulnerability. It should briefly describe the works and studies carried out to determine the likely impact of the activities, together with proposed mitigation measures. Finally, the NTS should include a description of the residual impacts, if any, on the geological and hydrogeological environments present, including an assessment of the capacity of the geological and hydrogeological environments to absorb the predicted residual impacts of the proposed project.

Reference

EPA. 2002. Guidelines on the information to be contained in Environmental Impact Statements. Environmental Protection Agency, Ireland. http://www.epa.ie/pubs/advice/ea/guidelines/EPA_Guidelines_EIS_2002.pdf

On a dialogue between hard-rock aquifer mapping and hydrogeological conceptual models: insights into groundwater exploration

Helder I. Chaminé, José Martins Carvalho, Maria José Afonso, José Teixeira and Liliana Freitas*

Groundwater is a dynamic and renewable resource, but in hard-rock terrains its availability is rather limited compared to other types of aquifer formations. Groundwater systems require a comprehensive understanding of geology, morphotectonics and hydrology, which are controlled by ground characteristics like weathering grade, fracturing degree, permeability, slope, drainage pattern and density, land cover, and climate. GIS-based integrative cartography provides an accurate way to improve knowledge on water circulation models and on the global functioning of aquifer systems. The groundwater conceptual model based in Earth systems has proven its value in water resource studies. This approach highlights the importance of groundwater exploration mapping as a useful tool to support hydrogeological conceptualisation of fractured hard-rock terrains, contributing to the sustainability of water resources.

Les eaux souterraines constituent une ressource dynamique et renouvelable, mais leur présence dans les roches du socle est plus limitée que dans d'autres types de formations aquifères. Les systèmes d'eaux souterraines étant contrôlés par des caractéristiques du sol comme l'altération, la fracturation, la perméabilité, la pente, le drainage, la couverture du sol et le climat, leur compréhension exige une connaissance approfondie de la géologie, de l'hydrologie et de la morphotectonique. La cartographie SIG intégrative fournit un moyen précis d'améliorer les connaissances portant sur les modèles de circulation d'eau et le fonctionnement global des systèmes aquifères. Les modèles hydrogéologiques conceptuels ont fait leur preuve dans l'étude des ressources hydriques. Contribuant ainsi à la conservation de ces ressources, cette approche met en évidence l'importance de la prospection des eaux souterraines dans la conceptualisation hydrogéologique des roches dures fracturées.

Las aguas subterráneas son un recurso dinámico y renovable, pero en formaciones de rocas duras su disponibilidad es muy limitada, en comparación con otras formaciones acuíferas. Los sistemas de aguas subterráneas requieren un conocimiento profundo de la geología, hidrología y morfotectónica, controladas por las características del terreno, como: grado de alteración, grado de fracturación, permeabilidad, pendiente, patrón de drenaje y densidad, cobertura del suelo y clima. La cartografía SIG integradora proporciona una forma precisa para mejorar el conocimiento de los modelos de circulación del agua, y el funcionamiento global de los sistemas acuíferos. Los modelos conceptuales basados en los sistemas geológicos han demostrado su valor en los recursos hídricos. Este enfoque pone de relieve la importancia de la cartografía de las aguas subterráneas, como herramienta útil para apoyar la conceptualización hidrogeológica de rocas duras fracturadas, contribuyendo a la sostenibilidad de los recursos hídricos.

Geosciences, Water and Modelling

In 1802 J. B. Lamarck wrote: *"En un mot, l'écoulement des eaux vers les lieux bas, comme celui des torrens, des ruisseaux, des rivières, des fleuves, des eaux pluviales de tous les genres; enfin, des sources et des fontaines."* [*"In short, they correspond to the downflow of water toward the lowlands, as done by torrents, brooks, streams, rivers, rain water, and finally, by springs and rock springs." – translated by A.V. Carozzi*, 1964, Univ. Illinois Press]. This impressive quote about the action of terrestrial waters in Earth, from the interesting book under the title of *Hydrogeólogie*, illustrates the conceptual framework of this paper: water dynamic systems. On this aspect, ***Fig. 1*** represents the main water flows affecting groundwater in a hydrogeological reservoir.

* Laboratory of Cartography and Applied Geology (LABCARGA), Department of Geotechnical Engineering, School of Engineering (ISEP), Polytechnic of Porto, Portugal, hic@isep.ipp.pt

Understanding the role of conceptual site models is essential to accurately assess hydrogeological systems and water resources. Hard-rock watersheds are essentially limited to fractured and weathered horizons, and they are a source of valuable water resources on a regional level, namely for domestic, industrial and agricultural purposes, and also for public supply. In particular, hydromineral and geothermal resources have a relevant economic value in the bottled water/thermal bath industry and in energy supply, respectively. Groundwater conditions are also of primary significance for the construction and maintenance of subsurface engineering structures (e.g., tunnels, sewers, underground storage facilities and building foundations) and may additionally influence urban drainage. Recent technological advances have brought remote sensing and geographic information system (GIS) techniques to the forefront as tools to develop and recommend sustainable conservation and management measures of geosciences (e.g., Kresic and Mikszewski, 2013; Teixeira *et al.*, 2013). GIS tools are also useful in providing accurate ways to improve knowledge about groundwater, surface water circulation models and the overall functioning of aquifer systems.

In the past decades, the practise of intensive water resource exploitation has had a large impact on hydrological systems on several scales. Thus, accurate evaluation of

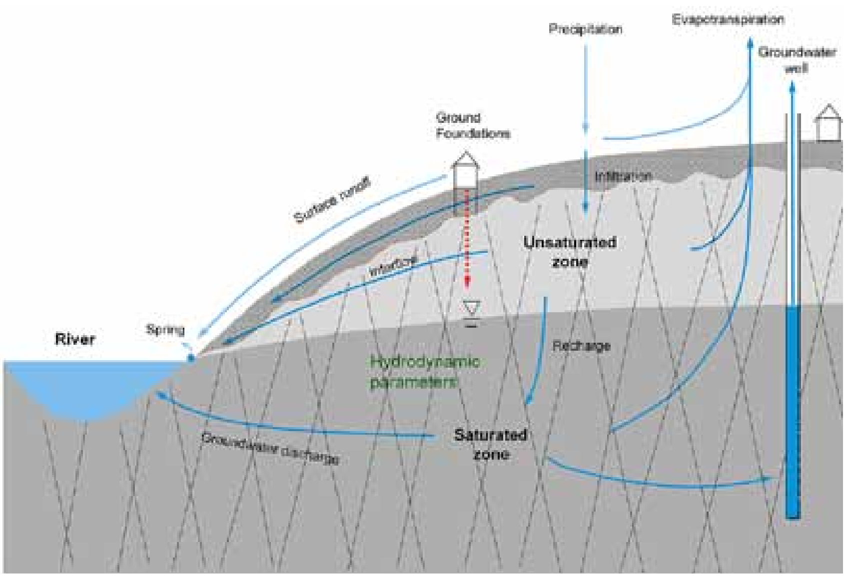


Figure 1: Water flows affecting the groundwater in a hard-rock fissured framework: an outlook for water resources and geoengineering issues (updated from Fitts, 2013).

the present state of these systems requires studies ranging from hydrogeological site investigations to watershed scales. Particularly, hydrogeological modelling plays a key role in the protection and management of groundwater resources.

Understanding the complexity of Earth systems is possible through the use of ground models (Griffiths and Stokes, 2008). Several types of model approaches can be used (e.g., Bredehoeft, 2005; Carvalho *et al.*, 2005; Marsily *et al.*, 2005; Renard and Allard, 2013; and references therein): geologic, analytic, numeric, deterministic and stochastic. These approaches differ in various aspects, though they also show some feature similarities, depending on their use and application domains. According to Kresic and Mikszewski (2013), a conceptual site model accomplishes an overall knowledge of the features and dynamics of the system based on existing data interpretation. The key elements are conceptual development based on available information, data collection at the site-specific level, spatial data analysis, and data visualisation to achieve the study conclusions (Kresic and Mikszewski, 2013). A model additionally involves the assumption of practical simplifications, which are crucial to enable its applicability despite of geologic variability and uncertainty (Keaton, 2013). Nevertheless, simplification should be restricted as far as possible to ensure the accuracy of the conceptualisation.

The conceptualisation process is an initial main step in the hierarchical analysis of groundwater flow. In addition to this, there is a clear need to accommodate the relationship between hard-rock aquifer mapping and conceptualisation of hydrogeological systems, for an effective construction of the groundwater models (Teixeira *et al.*, 2013). A hydrogeological conceptual model is primarily a description of various natural and anthropogenic factors that govern and contribute to movement of groundwater in the subsurface (Kresic and Mikszewski, 2013). The conceptualisation of hard-rocks aquifer systems involves an overall balanced understanding of geological behaviour, petrophysical features and hydraulic processes. The standardisation of procedures, methodologies and techniques addresses many such hydrological issues. Hence, groundwater modelling has become standard practice for professional hydrogeologists.

The modelling techniques have been used to achieve several goals (e.g., Bredehoeft, 2005; Marsily *et al.*, 2005; Kresic and Mikszewski, 2013, Teixeira *et al.*, 2013; and references therein): i) to predict short-term recharge/discharge areas and assess their role in relation to the evaluation of water resources; ii) to identify constraints related to groundwater management towards long-term sustainable exploitation, iii) to identify potential groundwater contaminants and estimate their transport in space and time; and iv) to aid better decision making about climate change and variability.

Hard rocks occupy large regions throughout the world, particularly in Africa, Europe, America, Asia and Oceania. The crystalline rocks have a very low porosity; the secondary porosity is thus developed across the geological and geomechanical characteristics of the discontinuities (i.e., fissures, fractures, joints, faults, shear zones, vein-structures, etc.), which are responsible for most permeability and groundwater path flows (e.g., Assaad *et al.*, 2004; Carvalho *et al.*, 2005; Fitts, 2013). On a local scale, the main factors that control the groundwater flow in saturated zones are: fracture network density and tectonic patterns (which promote crustal fault damage zones), opening and filling of discontinuities, weathering grade, and lithology features.

The hard-rock hydrogeological conceptual model should include, at least: the geostructure of the reservoir, its lithological

Figure 2: Conceptual site model: a flow path for an integrated exploration hydrogeology approach.

heterogeneities, petrophysical properties, permeability, hydrodynamics, hydrogeological structures that affect the circulation and their distribution in space, hydrogeochemistry and isotopic behaviour, and evaluation of the water discharge conditions.

The conceptualisation of hydrogeological systems focused on groundwater exploration must be dynamic and should be continuously updated to reflect the latest advances in the knowledge of the groundwater reservoir. In addition, it is vital to outline possible scenarios for further interventions. The next step is to transform the information about the hard-rock fractured reservoir into mathematical modelling to check various scenarios using different approaches (i.e., probabilistic, deterministic or stochastic). All the models must be robust, calibrated and supported on a permanent retro-analysis scale based on a logical understanding of the real hydrogeological framework, as well as capable of communicating information to all agents (practitioners, researchers, stakeholders and decision makers) involved (*Fig. 2*).

In this work GIS-based mapping was used to produce groundwater exploitation models under different hydrogeological frameworks. The hydrogeological conceptualisation of these fractured hard-rock terrains was enhanced by this integrated approach and should contribute to the environmental sustainability of water resources in the study areas.

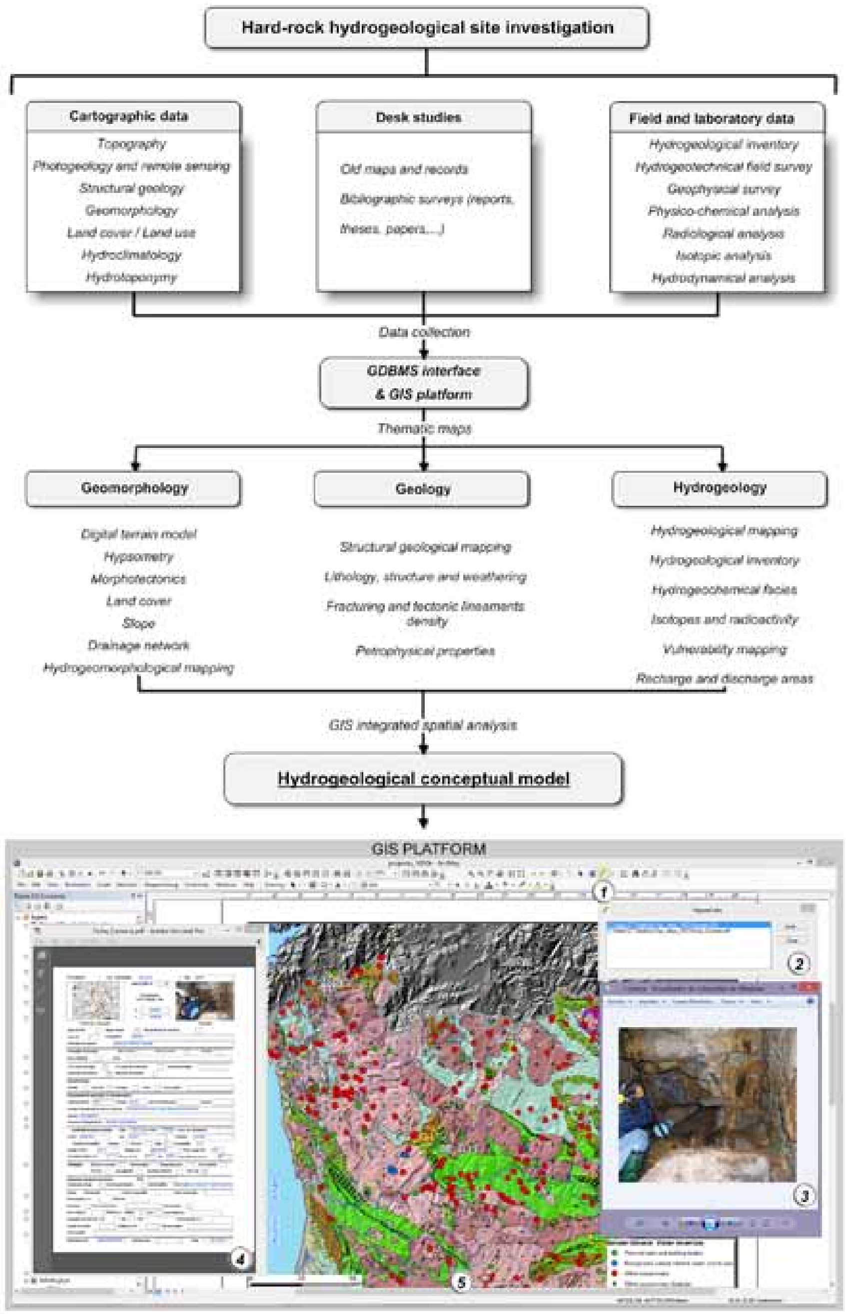


Figure 3: Conceptual flow chart of the hard-rock hydrogeological site investigation. 1. Application tool to create hyperlinks between features (line, point or polygon) and other files; 2. Hyperlink addressed to a file (image or text); 3. Visualisation of photo details for the water inventory; 4. Hydrogeological inventory datasheet (field and desk data); 5. Regional hydrogeological mapping.

Selected sites: examples from Iberian Peninsula

The thermal baths and bottled water industry are highly related to hard-rock hydrogeology in the Iberian Peninsula (Carvalho *et al.*, 2005). A comprehensive integrated study of groundwater resources was carried out at two selected sites of Portugal and Spain. The study coupled GIS-based mapping with hydrogeological assessments. Thematic maps were prepared from multi-source geodata, namely satellite imagery, topographic and geological mapping and hydrogeological field surveys. These maps were converted to GIS format and then integrated with the purpose of elaborating a hydrogeological map intended to support the groundwater conceptual site model and further exploration and exploitation drilling. The basic techniques of geology, geomorphology and hydrogeology were applied in the study sites (e.g., Assaad *et al.*, 2004; Teixeira *et al.*, 2013). ***Figure 3*** presents a flow chart of the hard-rock hydrogeological site investigation.

Herrera del Duque site (La Siberia, South-western Spain)

The studied site is located in the middle-upper Palaeozoic metasedimentary sequences of the south-western Spain, in the Dehesa de las Navas synclinorium area (Herrera del Duque municipality). The geotectonic background comprises a middle-upper Palaeozoic metasedimentary fissured basement which is deformed and overthrusted late Proterozoic Schist-Greywacke Complex. This megastructure with axis trending NW-SE is faulted, with the main regional faults being transversal and sub-parallel to the axial orientation. In "Neseuretus shale" richly fossiliferous beds (mainly trilobites, brachiopods, echinoderms and graptolites) brecciated quartz veins were mapped with a thickness of 0.5-1 m. The Ordovician megasequence disconformably overlies late Proterozoic rocks (Herrera del Duque plateau). The most famous and extensive lithological unit is the Armorican quartzite, which occurs also in other regions of the Iberian Peninsula (e.g., the Valongo anticline and Monfortinho syncline, in Portugal; the Tamames syncline, in Spain) and in the Armorican Massif of western France. This unit consists mainly of light-coloured thick-bedded mature sandstone and orthoquartzite with some grey shaly or silty intercalations. The drainage network reveals this tectonic control, which imposed morphostructural features on the region.

At the hydrogeological level the main aquifer is placed over the Armorican quartzite, containing hyposaline water and transmissivities values of up to 25 m^2/day, determined using pumping tests in drilled wells. All the other metasedimentary units have an aquitard performance, probably with productivities generally lower than 1 L/s and with a very low rate of success. Quartz veins increase locally the hydraulic conductivity of the aquitard formations and allow the occurrence of thermal water resulting from the deep circulation in Armorican quartzite aquifer (*Fig. 4*).

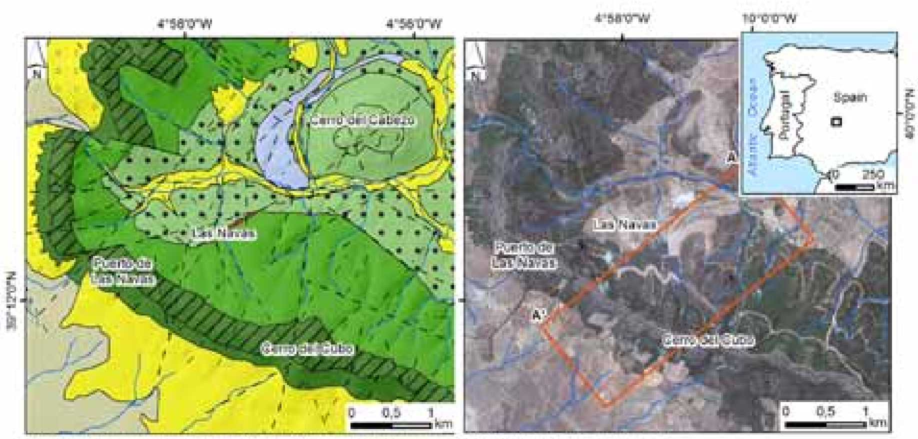
Vimeiro site (Torres Vedras, Central Portugal)

Hydrogeological studies were performed at the Vimeiro hydromineral discharge and the surrounding Maceira–Porto Novo area (Torres Vedras municipality). The studied site encompasses an area of about 23 km^2, including the Alcabrichel River catchment. Vimeiro has a balneological and balneotherapy tradition which dates back to the early 18th century. The studies were due to the need to increase the supply from the thermal springs and former shallow well for therapeutic uses at the thermal bath, as well as to provide additional drinking water in the surrounding area for domestic use.

The thermal water from the Vimeiro diapiric structure is characterised by: i) output temperatures around 26 ºC; ii) relatively high pH values (6.9 to 7.1), iii) TDS content in the range of 900 to 1100 mg/L, but TDS content ranging from 3300 to 6000 mg/L (Frades Spring) was also reported, iv) electrical conductivity (EC) measurements ranging from 1.550 to 4.830 µScm^{-1} (Santa Isabel Spring and Frades Spring), indicating the presence of high mineralised water. The groundwater belongs to sodium bicarbonate-chloride facies. This chemical composition and the existing thermal waters denote deep circulation and a final circulation trough in the karstified hard limestone at the contact with the evaporitic marls. In the area the only regional aquifer is placed in the karstified hard limestone (with transmissivity up to 900 m^2/day), the other units acting for practical purposes as aquitards (*Fig. 5*).

Concluding remarks

This work highlights the importance of groundwater GIS mapping as a useful tool to support hydrogeological conceptualisation, as well as for decision-making at the



Geological background: updated from ITGE 1989, Mapa geológico de España, 1/50.000, Nº 733/15-29; Castilblanco and Carvalho et al, 2010. Proceedings V Congresso Nacional de Geomorfologia, APGEOM, Porto. pp. 257- 259

Hydrogeological units	Type of media		Transmissivity (T, m^2/day)	Long-term well capacity * (Q, L/s)		
	Porous	Fissured		Q < 1	1 < Q < 2	2 < Q < 10
Sedimentary cover						
Aluvia, sand and gravel	X		n.a.	n.a.	n.a.	n.a.
Hillslope deposit	X		n.a.	n.a.	n.a.	n.a.
Metasedimentary rocks						
Quartzite, interbedded shale and siltstone		X	n.a.	Aquitard, Q<1		
Shale, siltstone and sandstone		X	n.a.	Aquitard, Q<1		
Shale and quartzite		X	n.a.	Aquitard, Q<1		
"Neseuretus" shale and sandstone		X	n.a.	Aquitard, Q<1		
Black shale, sandstone and siltstone		X	n.a.	Aquitard, Q<1		
Amorican Quartzite		X	25			X
Conglomerate, sandstone and quartzite		X	n.a.	Aquitard, Q<1		
Schist and greywacke complex		X	n.a.	Aquitard, Q<1		
Veins						
Quartz vein		X	Locally increase the hydraulic conductivity.			

* Median long-term well capacity n.a. - not available

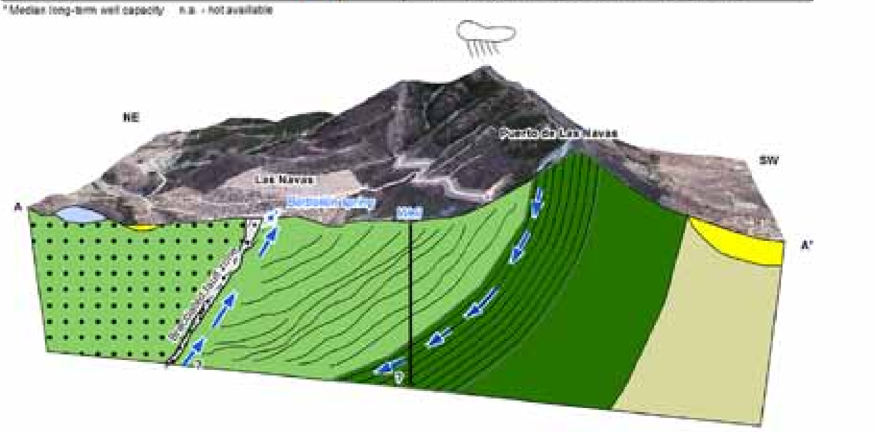
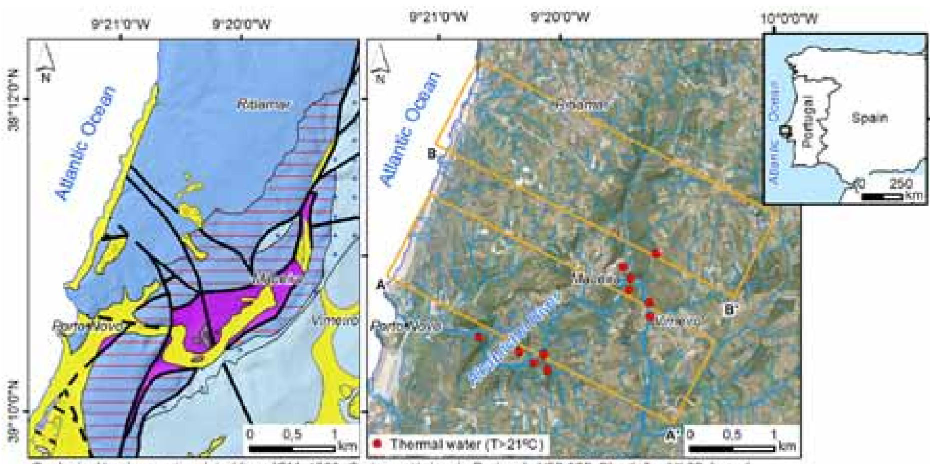


Figure 4: Herrera del Duque site (La Siberia, South-western Spain) framework: hydrogeological conceptual model site.



Geological background:updated from IGM, 1999. Carta geológica de Portugal, 1/50.000, 2ª edição, Nº 30-A, and Chaminé et al. 2004. Cadernos Lab. Xeol. Laxe, A Coruña, 29, 9-30

Hydrogeological units	Type of media			Transmissivity (T, m^2/day)	Long-term well capacity* (Q, L/s)		
	Porous	Karstic	Fissured		Q < 1	1 < Q < 2	2 < Q < 20
Sedimentary cover							
Alluvia, beach and dune sand	X			n.a.	n.a.	n.a.	n.a.
Undifferentiated coarse deposit	X			n.a.	n.a.	n.a.	n.a.
Karstic and hard limestone rocks							
Sandstone, marl and conglomerate			X	5-10		X	
Marl sandstone and limestone			X	n.a.	X		
Sandstone, claystone and arkose			X	n.a.	X		
Marl and sandstone			X	n.a.	X		
Hard-limestone		X	X	30-90			X
Grey dolomite		X		n.a.		X	
Evaporitic/gypsiferous pelite and marl			X	Confining bed	-	-	-

* Median long-term well capacity n.a. - not available

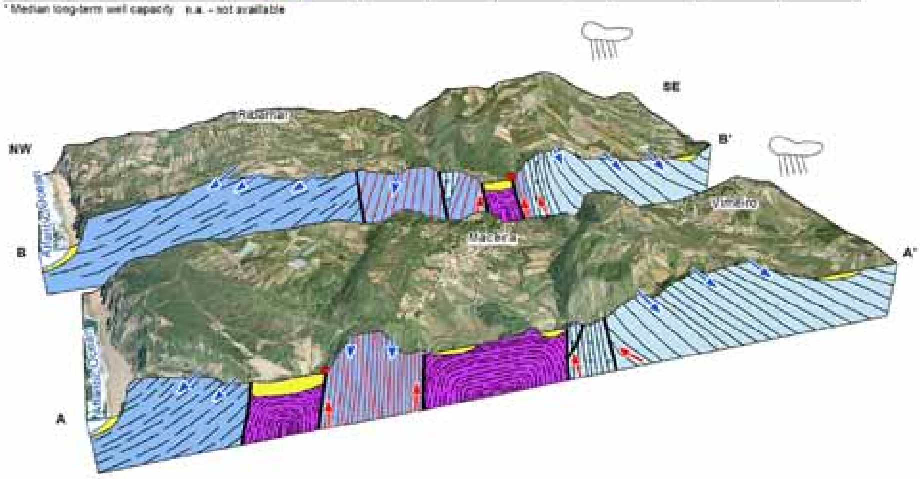


Figure 5: Vimeiro site (Torres Vedras, Central Portugal) framework: hydrogeological conceptual model site.

basin master plan level regarding land use, water resources and sustainability. In hydrogeological practice an accurate conceptual modelling process is the basic tool for developing a correct and essential understanding of site conditions. This multidisciplinary approach involves decision making regarding water supply, ecosystems and environmental protection.

The conceptual model provides the primary understanding of how a hydrogeological system or process operates, which is usefully expressed quantitatively as a mathematical approach. According to Konikow and Bredehoeft (1992), models cannot be proven or validated, but only tested and invalidated. Nevertheless, because of its ability to synthesise and model a wealth of information, if used cautiously a model is quite advantageous to groundwater exploration (Bredehoeft, 2005; Carvalho *et al.*, 2005). The conceptual site model serves as the basis for modelling groundwater flow systems. Many difficult questions that arise in the development of hydrogeological investigations have been answered using groundwater modelling. At present, hydrogeological conceptualisation has become an indispensable tool in understanding and effectively managing hard-rock aquifer systems (***Fig. 6***).

New challenges are emerging related to conceptualising and modelling heterogeneities in aquifer connectivity. Under this framework, connectivity metrics are becoming significant tools to describe subsurface flow and transport (Renard and Allard, 2013). Thus, innovative approaches are needed in the collection and integration of data. This will improve the simulation of real conditions for a better development of models for hard-rock aquifer systems (Teixeira *et al.*, 2013).

Last, but not least, a hydrogeological conceptual model is an invaluable instrument for communication with practitioners, researchers, other professionals (e.g., stakeholders and decision makers) and society. These groups can jointly contribute to identifying strategies, policies, targets, and funding for implementing water resources programmes within an environmental, sustainable and ethical framework.

Acknowledgements

This work was partially funded under the framework of the LABCARGA|ISEP re-equipment program (IPP-ISEP| PAD'2007/08) and Centre GeoBioTec|UA (PEst-C/CTE/UI4035). JT was supported by a doctoral scholarship from the Portuguese Foundation for Science and Technology (FCT-SFRH/BD/ 29762/2006). Special thanks are due to M. Gastaldin and R. Fernández-Rubio for kindly reviewing the French and Spanish version of the abstract, respectively. We acknowledge Nestlé Waters España SA, Empresa das Águas do Vimeiro SA and Terra, Ambiente e Recursos Hídricos Lda for all support. The authors would like to thank the reviewer for their helpful comments to improve the manuscript. The present paper is dedicated to Professor J. M. Cotelo Neiva (1917-), outstanding Geologist, who launched Applied Geology in the geological resources and engineering geosciences in Portugal.

Figure 6: Hydrogeological conceptual model: a general outlook on an integrated exploration groundwater framework.

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Limestone quarries and a Portuguese karstic aquifer – A contribution to environmental impact assessment

Pedro Duarte and Sara Domingues*

*Portugal has thirty karstic aquifers, mainly hosted by Jurassic limestones. The Ota–Alenquer aquifer system (35 km north of Lisbon) shows one of the smallest outcrop areas with only 9.4 km², having at least two uncharacteristic features: the principal recharge area (*Serra de Montejunto*) is about 5 km north of the outcrop, and about 25% of the aquifer surface area is occupied by limestone quarries. To better identify and minimise environmental impacts to the groundwater (which contributes to Lisbon region public supply), systematic piezometric level measurements have been performed during the last three years as well as a hydrochemistry survey with nine sampling points and 17 physical-chemical parameters. Groundwater fluxes were identified to the northern sector of the aquifer, based on a pumping test with water level measurements in three piezometers. These data have unequivocally improved our knowledge of the aquifer and contributed to an accurate impact assessment.*

*Le Portugal dispose de trente aquifères d'origine karstique, la plupart au sein de calcaires jurassiques. Le système aquifère d'Ota Alenquer (35 kilomètres au Nord de Lisbonne) montre l'un des affleurements les plus réduits, sur la seule surface de 9,4 km², offrant au moins deux particularités caractéristiques : la zone principale de recharge (*la Serra de Montejunto*) est située à environ 5 kilomètres au Nord de l'affleurement, et environ 25% de l'aire aquifère est occupée par des carrières de calcaire. Pour mieux identifier et réduire les impacts environnementaux affectant l'eau souterraine (elle participe à l'alimentation des populations de la région de Lisbonne), des mesures systématiques du niveau piézomètrique ont été effectuées pendant les trois dernières années ainsi qu'une étude hydro chimique, à partir de 9 secteurs d'échantillonnage et 17 paramètres physico-chimiques. Les circulations d'eau souterraine ont été reconnues dans la partie nord de l'aquifère, basées sur des tests de pompage et des mesures de niveau statique à hauteur de trois piézomètres. Sans ambiguïté, ces données ont amélioré notre connaissance de l'aquifère et contribué à une évaluation précise de l'impact environnemental.*

*Portugal tiene treinta acuíferos kársticos, fundamentalmente en calizas Jurásicas. El acuífero Ota-Alenquer (a 35 km al norte de Lisboa) es el que tiene una superficie aflorante más pequeña, con solo 9,4 km² y tiene, al menos, dos características poco convencionales: su área principal de recarga (*Serra de Montejunto*) está situada a unos 5 km al norte del afloramiento y alrededor del 25% de la superficie aflorante del acuífero está ocupada por canteras de calizas. Para identificar mejor y minimizar los impactos ambientales al agua subterránea (que contribuye al suministro público de la región de Lisboa), se han realizado medidas piezométricas sistemáticas durante los últimos tres años, así como una investigación hidroquímica con nueve puntos de muestreo donde se ha analizado 17 parámetros físico-químicos. Se identificaron los flujos de aguas subterráneas hacia el sector norte del acuífero, en base a ensayos de bombeo con medida de niveles de agua en tres piezómetros. Estos datos han mejorado inequívocamente nuestro conocimiento del acuífero y han contribuido a una evaluación del impacto muy precisa.*

In the Alenquer region (35 km north of Lisbon) there occurs an important group of limestone quarries that supply aggregates used in the construction industry across the region. These quarries have been active for more than 60 years and play an important role in the regional social and economic frame.

This region also contains the Ota-Alenquer aquifer, which contributes to the Lisbon region water supply. The public supply water wells are managed by the company Empresa Portuguesa das Águas Livres (EPAL). These wells have legal protection areas, defined by the Portuguese legislation "Portaria nº1187/2010", which distinguishes three types of protection zones: inner zone, intermediate zone and outer zone. The intermediate zone contains almost the entire Ota – Alenquer aquifer system outcrop area (***Fig. 1***) and the quarry areas.

* Visa Consultores, SA external consultant, pedroduarte71@gmail.com

Since 2005, hydrogeological data has been collected within the Environmental Impact Assessment (EIA) for the Alenquer quarries exploitation plans (Visa Consultores, 2010). This article presents those data in order to provide information about the supposed paradox of groundwater quality versus quarry exploitation.

Geological and Hydrogeological Setting

The Ota–Alenquer aquifer system exhibits a small outcrop area of 9.4 km². The main aquifer formation is the "Ota and Alenquer formation", supported by oolitic limestone, dolomitic limestone, sandy limestone, marl-sandy limestone and coralic limestone from the Upper Jurassic. These formations show thicknesses from 4 meters (southern region) to 200 meters (northern region).

This aquifer system shows typical behaviour for a karstic aquifer, with known cavities and springs that constitute its natural drainage. The most significant springs are near Ota and Alenquer and are used to supply Lisbon. Currently the water supply is obtained from water wells managed by EPAL.

In geometric terms it is supposed that the outcrop area only corresponds to a small visible fraction of the aquifer system. The more plausible hydrogeological model assumes a hydraulic connectivity between the Ota and Alenquer formation and an aquifer hosted by Middle and Upper Jurassic limestones from Montejunto Mountain

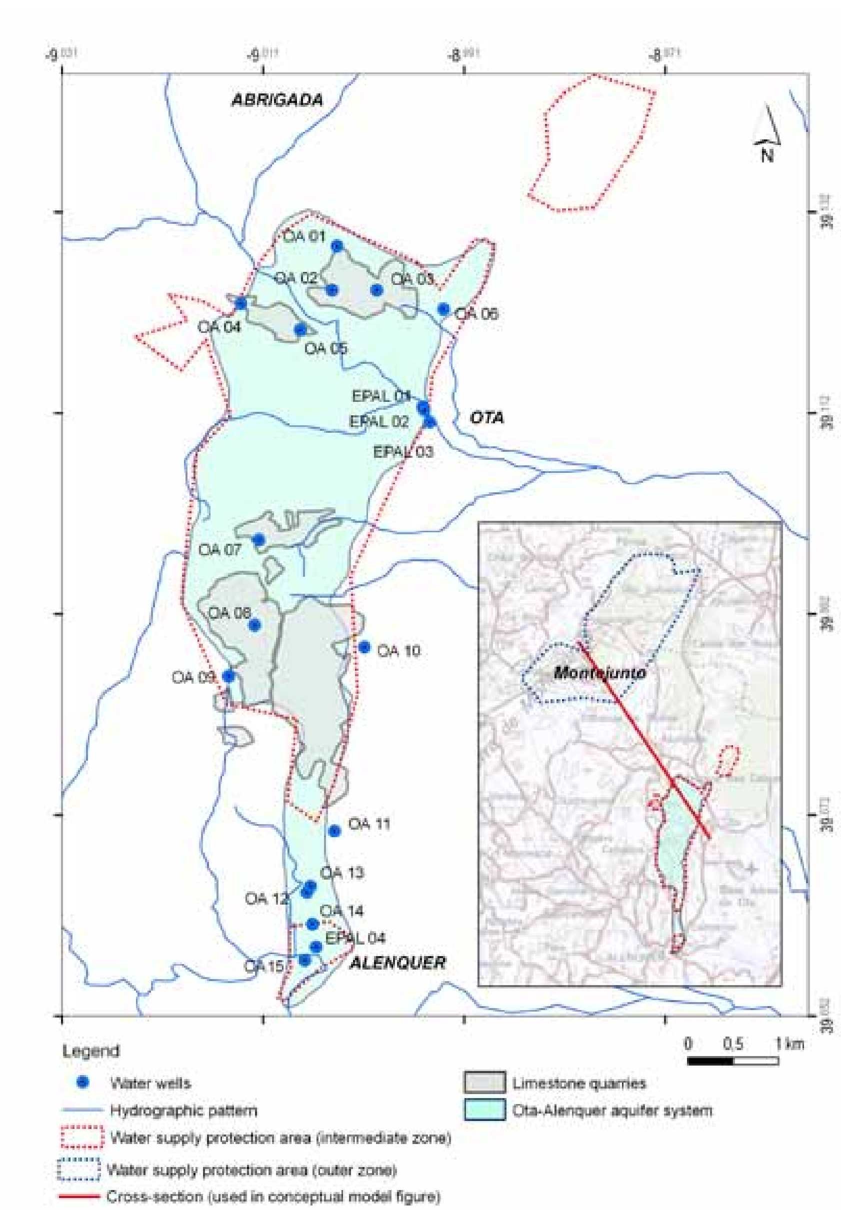

Figure 1: Ota-Alenquer aquifer system geometry and other relevant data.

to the north (***Fig. 2***). In fact, most of the Montejunto Mountain surface area corresponds to a lapiés, with numerous cavities, representing high water recharge and intensive groundwater flow. However, there are no significant natural discharges, so it is plausible to consider the Ota-Alenquer outcrop the main discharge area.

Tritium analysis (taken on EPAL wells water samples) corroborates this theory, indicating water mixing: modern waters arising from local recharge (the Ota–Alenquer outcrop) and "old" waters (with recharge before 1952) arising from Montejunto Mountain (Almeida *et. al.*, 2000).

Additionally, direct recharge is artificially enhanced by the almost 2 km^2 limestone quarries, corresponding to 25% of the aquifer system outcrop area (***Fig. 1***). The non-saturated thickness on quarry areas (vertical distance between the floor of the quarries and the regional water table level) ranges between 24 meters (worst scenario) and 118 meters (best scenario) (***Fig. 3***).

Hydraulic parameter knowledge is scarce and not recent. Data from 1947 to 1962 indicate well productivity ranging from less than 140 up to 280 litres per second, and estimated transmissivity (from specific yield) between 1,000 and 14,700 m^2 per day. Similarly, there is only one water monitoring point managed by the Portuguese Water Institute (*http://snirh.pt*), unfortunately out of service since 2001 September, so there are no data to establish the groundwater flow direction.

Data from EPAL indicates extraction volumes of 12.2 Mm^3/y in 2009 (Maria, 2010), 12.8 Mm^3/y in 2010 and 12.7 Mm^3/y in 2011 (EPAL, 2011). These volumes correspond to the main water consumption of the aquifer. Additionally, we should consider water volumes, not measurable, which correspond to discharges at natural springs. The images in ***Fig. 4*** (obtained in January 2011) illustrate this situation.

Experimental procedures

Experimental procedures have been undertaken since 2005, and more regularly since 2009. These procedures consisted of: 1) integration of different databases from Portuguese public institutions; 2) field campaigns, with water level measurements and *in situ* water quality parameter evaluation; 3) groundwater sampling for laboratory analysis.

In April 2012, a 24 h pumping test was performed in the aquifer's northern region. The production well was EPAL 02, with a pumping rate of about 514 m^3/h. During the test, water level measurements were manually taken at 3 quarry wells and automatically registered at the EPAL wells (***Fig. 5***). All the wells were previously georeferenced with high precision.

Results and discussion

The piezometric level evolution obtained from the water level measurements is indicated in ***Fig. 6***. The pumping test showed the piezometric behaviour displayed in ***Figure 7***.

With these results it is possible to conclude that:

1. The regional water level is below 36 m.a.s.l. (measurements performed at wells OA 01 and OA 12) (***Fig. 6***);
2. High hydraulic connectivity exists between the north and the south regions of the aquifer. Three sequential measurements at two wells (OA 01 and OA 12), located 7 km from each other, exhibit the same piezometric evolution, with almost the same piezometric levels;
3. Hydraulic connectivity exists between the three EPAL wells (proved with the EPAL 02 induced withdrawal during the pumping test – 0.41 m at EPAL 01 and 0.74 m at EPAL 03) and between EPAL 02 (EPAL well) and OA 01 (quarry well), although the last one was only incipient (0.03 m). The likely time of travel between OA 01

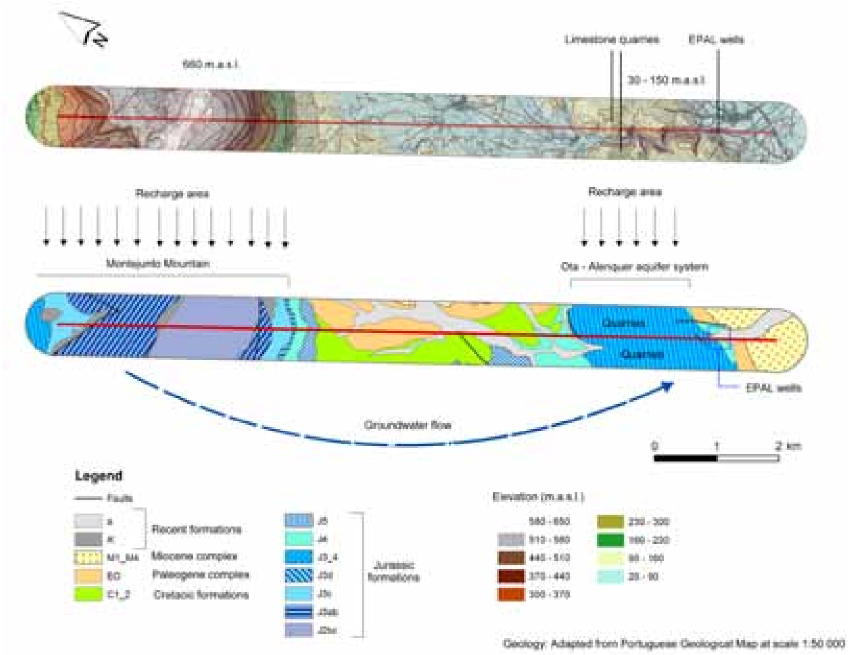

Figure 2: Conceptual model of the aquifer recharge.

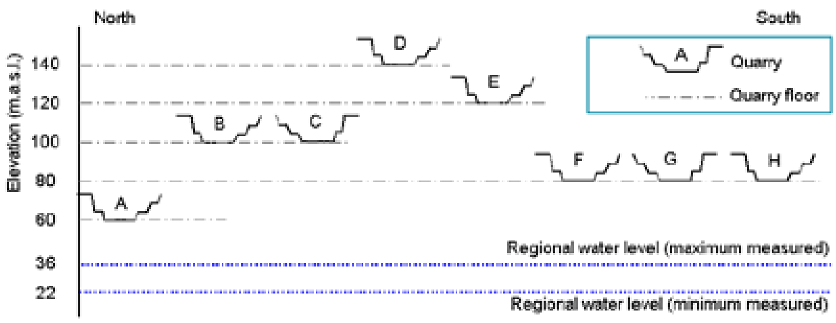

Figure 3: Unsaturated zone below the quarries.

and EPAL 02 is estimated at 14 hours;

4. Each EPAL well has its own hydraulic head, different from the other two wells;
5. The aquifer shows karstic behaviour. Although with non-continuous measurements, between October 2009 and January 2010 water level rose 12.99 meters during a period of only three months (measured at well OA 01);
6. The specific yield at EPAL 02 is 163.7 $m^3/(h.m)$, considering a constant pumping rate of 514 m^3/h, static water level at 26.22 m and equilibrium water level at 23.08 m (m.a.s.l.);
7. The estimated transmissivity of the northern region was measured at 7,273 m^2/day by the Logan method and 7,786 m^2/day by the Cooper–Jacob method;
8. The hydraulic gradients observed within the quarry area range between 0.2 ‰ and 0.8 ‰, suggesting groundwater flow from East to West.

In addition, a specific water sampling campaign was performed on 17 May 2010. This campaign included nine sampling points (water wells) and the laboratory analysis of 17 parameters (HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, COD, biochemical oxygen demand (BOD_5), electrical conductivity, pH, turbidity, total suspended solids, Pb, Cr and total hydrocarbons).

Sampling points are mapped on ***Fig. 1*** and analytical results are shown in ***Table 1***. From these results the following conclusions were drawn:

- All the samples exhibit calcium bicarbonate facies with high homogeneity in terms of hydrochemical facies (***Fig. 8***);
- When comparing the results with reference values of the Portuguese laws (namely Annex I and XVI of the Decree-Law nº236/98) the exceptions reported in Almeida *et. al.* (2000) regarding the chloride, sulphate and sodium ions are not confirmed;
- The observed transgressions are related to biochemical oxygen demand and total suspended solids in a single sampled point, OA 08;
- Within the observed concentration homogeneity we can distinguish three sub-groups of samples:
  - Water with higher mineralisation (sampling points OA 02 and OA 04) - Located in the northern region of the aquifer system, with bicarbonate, chloride, nitrate and calcium slightly differing from remaining sample points;
  - Water with lower mineralisation (sampling point OA 08) – Located at central region of the aquifer system, with bicarbonate, sulphate, chloride and calcium concentrations distinguished from remaining sample points;
  - Water with intermediate mineralisation (the remaining six sampling points) – Characterized by short concentration range to the ions bicarbonate, sulphate, chloride, nitrate, calcium, magnesium and sodium (respectively 30; 6; 4; 3; 17; 7; 7 mg/L).
- All samples exhibit lead and chromium concentrations below detection limit (0.005 and 0.01 mg/L, respectively);

	Bicarbonate	*Sulphate*	*Chloride*	*Nitrate*	*Calcium*	*Magnesium*	*Sodium*	*Potassium*	*BOD_5*	*Electrical conductivity*	*pH*	*Turbidity*	*TSS*
Minimum	*210*	*6*	*13*	*2*	*59*	*< 4*	*10*	*< 2*	*< 2*	*325*	*7.2*	*< 0.7*	*< 5*
3rd quartile	*310*	*26*	*35*	*5*	*91*	*10*	*26*	*< 2*	*< 2*	*542*	*7.6*	*< 0.7*	*< 5*
Maximum	*430*	*29*	*56*	*9*	*110*	*15*	*47*	*3*	*4*	*738*	*7.8*	*230*	*170*
Units: Electrical conductivity (µS/cm @ 20ºC); pH (pH units); Turbidity (NTU); all other parameters (mg/L)													

Table 1: Lab statistics (water samples gathered 17 May 2010).

Figure 4: Groundwater discharges from Ota–Alenquer aquifer system.

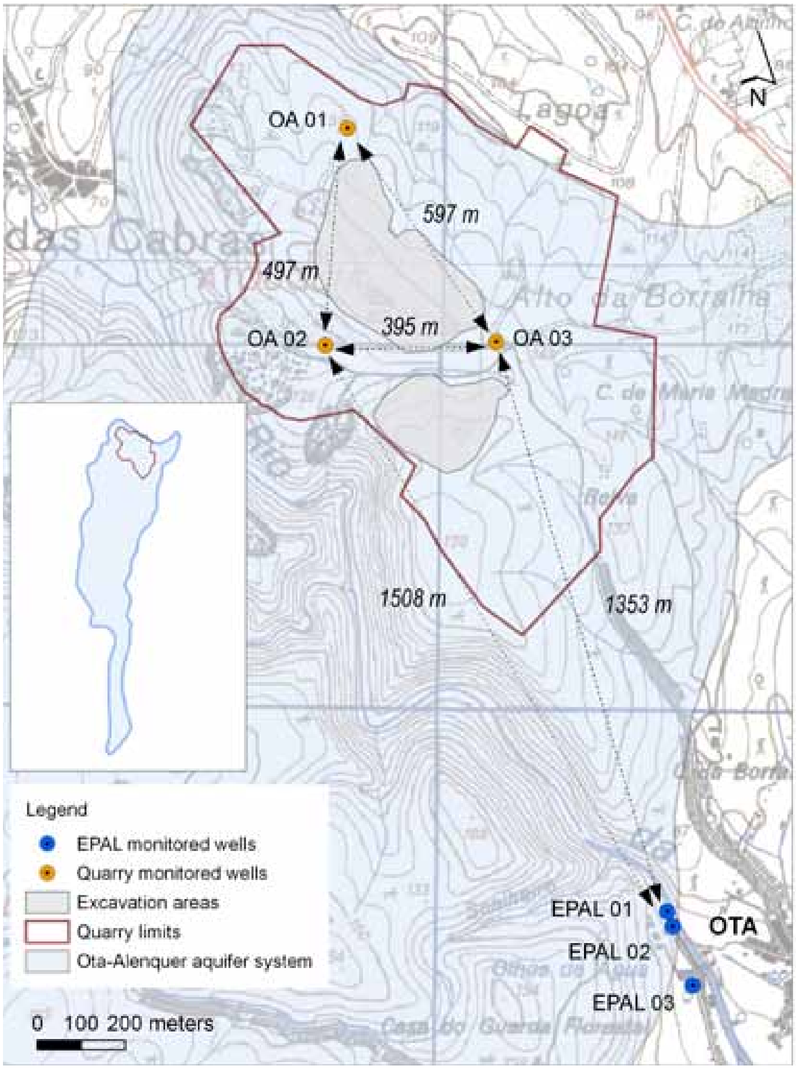

Figure 5: Wells monitored in pumping and interference tests.

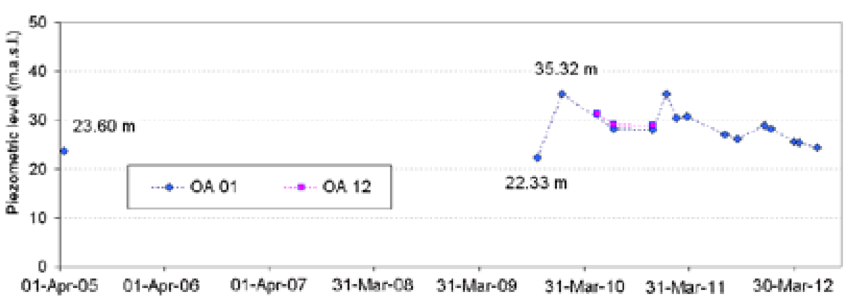

Figure 6: Piezometric level evolution at two non-equipped wells.

- All samples exhibit total hydrocarbons and COD concentrations below detection limit (0.05 and 10 mg/L, respectively).

Since 2005, other sampling campaigns have been conducted regarding the EIA of the quarries; while fewer sampling points were used, the results were within the range of values shown here.

Final comments

To the best of our knowledge, the information obtained from the experimental work that has been undertaken on the Ota–Alenquer aquifer for the EIA of the quarries is quite original.

Positively, these studies make a valuable contribution to improving the quarries' exploitation plans by establishing the maximum excavation depth needed in order to protect the aquifer. This is intended to assure a satisfactory non-saturated thickness (preferably more than 30 m) as a buffer to protect groundwater quality. Additional measures were implemented to protect water quality: all the vehicles and equipment used in quarries are submitted to a periodic inspection to detect potential damage which could lead to oil and other spills; the oil tank is weekly inspected to detect possible leaks; the perimeter drainage systems of the quarries were improved in order to reduce the amount of water with suspended soils in the base of the quarry; the quarries' septic tanks were isolated; specific training was provided to quarry workers on how to prevent spilling accidents and the procedures to undertake in case of a spill; and finally implementation of a monitoring plan in quarry boreholes with groundwater analysis of at least the following parameters: ammonium, pH, Total Suspended Soils (TSS), PAHs, Germ number (at 22 °C and 37 °C).

Although the quality of groundwater monitoring wasn't continuous, the obtained data does not reveal, in general, a contaminant signature. The data obtained (e.g. aquifer test results, with slight water levels interference between EPAL wells and quarry well OA01 or, the relatively high homogeneity of hydrochemical results observed at nine sampling points) corroborates that conclusion that the Ota–Alenquer aquifer main recharge area is located in Montejunto Mountain.

Finally, the authors consider that the data presented above brings important environmental input to the co-existence of quarry exploitation and groundwater public supply in a high vulnerability aquifer domain.

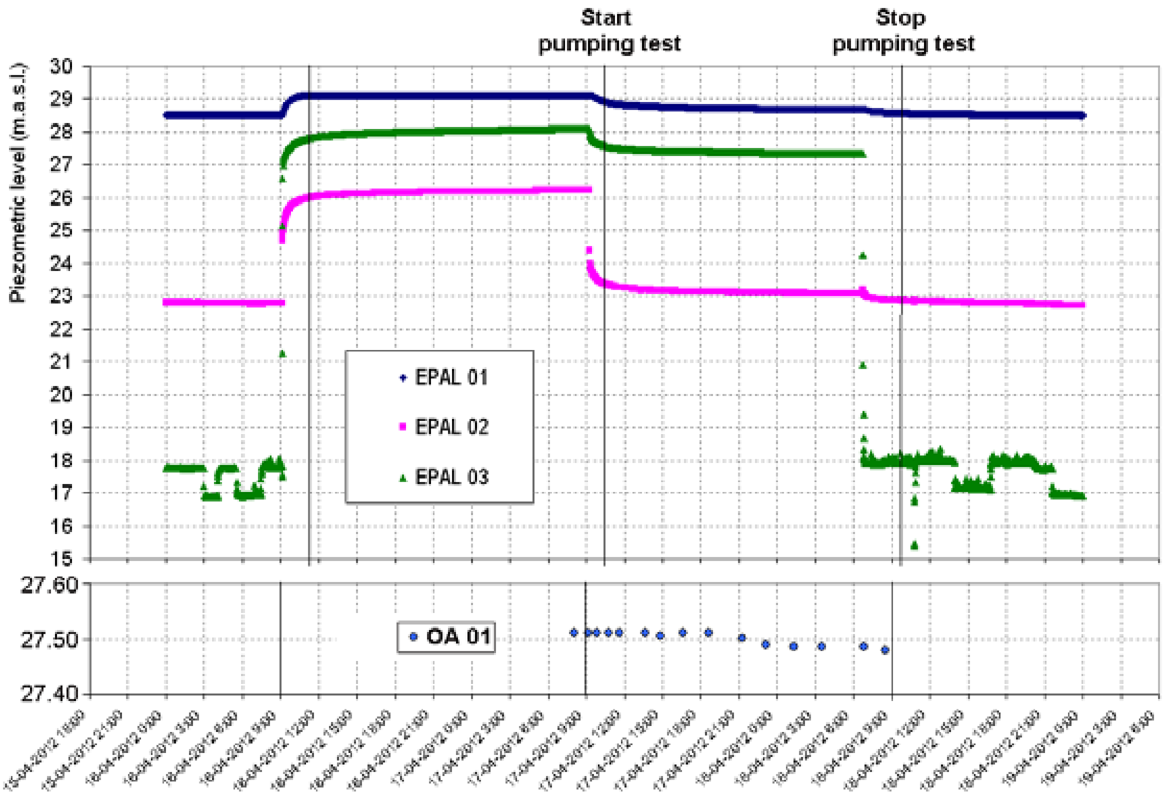

Figure 7: Piezometric level evolution during pumping test (April 2012)

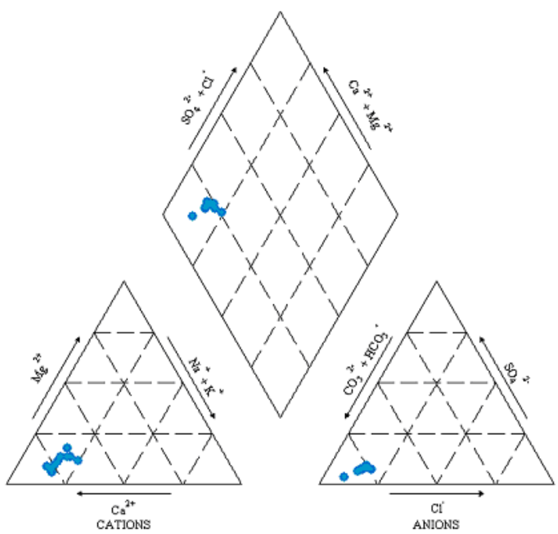

Figure 8: Piper diagram (sampling performed 17 May 2010).

Acknowledgments

This work was supported by a set of Environmental Impact Assessments conducted by Visa Consultores, SA. The authors are also grateful to their colleague, euro geologist and friend Carlos Almeida (Visa Consultores, SA) for challenging us, as well as to Eng.º Pedro Martins (SecilBritas, SA) and EPAL team, Eng.º Sérgio Rodrigues, Eng.ª Vanessa Martins, Eng.ª Patrícia Duarte, Sr. Domingos Nunes and Sr. António Gonçalves, for their logistical assistance and cooperation in the pumping and interference tests.

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The groundwater of Russia

V.M. Lukianchikov, R.I. Plotnikova, L.G. Lukianchikova and Yu.B. Chelidze*

This paper describes the degree to which groundwater (for drinking and technical, mineral, industrial and heat-energetic use) is studied in Russia, the status of its resources and quality depending on natural conditions and anthropogenic loading. The focus is on drinking and mineral groundwaters, *which are of special importance for supporting social stability and a nation's health. We discuss the characteristics of the groundwater resources and the changes in quality caused by social "shocks" during the last decade of the twentieth century and by their intensive and long exploitation. Top-priority natural and anthropogenically produced pollutants of groundwater are listed. Actual problems of maintenance and reproduction of the groundwater resource base in connection with political and economic situation in this country and in the world are briefly considered.*

L'article expose le niveau d'études atteint en Russie concernant l'eau souterraine, (eau utilisée pour la boisson ou les besoins industriels : techniques, miniers et chauffage) ainsi que l'état des ressources en eau et de leur qualité, tributaires des conditions humaines et de la pression exercée par l'homme. Le point de focalisation porte sur l'eau potable et les eaux minérales souterraines *qui jouent un rôle prépondérant dans le maintien de la paix sociale et la santé de la population. Sont examinées les caractéristiques des ressources en eau souterraine et les variations de leur qualité, provoquées par les « chocs sociaux » pendant la dernière décade du vingtième siècle et par une utilisation extensive et de longue durée. Les polluants majeurs naturels ou d'origine humaine affectant les eaux souterraines sont listés. Les problèmes actuels de maintenance, de conservation et de suivi des ressources en eau en connexion avec la situation politique et économique en Russie et dans le monde, sont brièvement abordés.*

Este artículo describe el nivel con que se estudian las aguas subterráneas en Rusia (para consumo humano, técnico, mineral, industrial y usos energéticos), el estado y la calidad de sus recursos dependiendo de las condiciones naturales y la presión antropogénica. Se hace especial énfasis en las aguas subterráneas potables y minerales, *que tienen especial importancia para soportar la estabilidad social y la salud de la nación. Se discute las características de los recursos de aguas subterráneas y los cambios en calidad causados por las conmociones sociales que se han producido durante la última década del siglo veinte y su explotación intensiva y duradera. Se incluye una lista de los principales contaminantes de las aguas subterráneas, tanto los naturales como los generados por el hombre. Se analizan también brevemente los problemas reales del mantenimiento y la gestión de la base de recursos de aguas subterráneas en relación con la situación política y económica de este país y en el mundo.*

Groundwater, by its quality and type of use, is classified as *drinking and technical (fresh and low-brackish), mineral (curative), industrial (i.e. containing useful components in extractable concentrations)* or *heat-energetic*.

The geological study of reproduction of the raw-mineral base of basic groundwater types is carried out in the Russian Federation in the following basic directions:

- regional hydrogeological and geoecological studying and mapping;
- geological studies and evaluation of resources and reserves of drinking, technical, mineral, heat-energetic and industrial groundwater;
- monitoring of groundwater state;
- scientific and normative-methodical supply of geological-prospecting works for groundwater.

The paper concerns predominantly the geological study of the groundwater resource problem. This is implemented through carrying out research-prospecting works funded by the federal budget, the budgets of territorial regions of the Russian Federation and extra-budget sources.

The basic resource base of groundwater in the country was created as a result of the geological-prospecting work carried out during the 1950s through the 1980s. The scaled national prospecting and exploring works made it possible to reveal and explore a great number of fresh groundwater fields, including those used for the water supply of large cities, including Vladivostok, Samara, Tomsk, Norilsk and Magadan.

The same period includes also fundamental scientific-methodical developments that continue to be used today for the study of resources and reserves of groundwater, formation of its chemical composition, improvement of principles and methods for carrying out prospecting and exploring works, sanitary protection of water-intake sites, assessment of the impact of groundwater extraction upon the environment, etc. In present-day conditions the reproduction of the groundwater mineral resources base is regulated by a long-term state program (up to 2020) for studying mineral resources and the reproduction of the mineral resources base (Decree 151, 2008).

Fresh groundwater is the most reliable source of supplying the population with high-quality drinking water, protected against pollution from the earth's surface. The current resource potential of drinking and technical groundwater in the country is evaluated at 870 million m^3/day. This value includes not only fresh groundwater (defined as mineralisation up to 1 g/l), but also the groundwater with mineralisation of to 3 g/l.

Groundwater resources are distributed over the Russian territory rather unevenly. Predicted resources for drinking and technical groundwater are most abundant in the Siberian, Far Eastern and Ural Federal Regions, while the most developed regions in the European part of the country – the Southern, Central and Volga Federal Regions – are provided to a lesser degree (***Fig. 1***).

Provision of the country's regions with the explored drinking water groundwater reserves is also rather uneven. Those areas best provided with water reserves are some republics of the North Caucasus, West Siberia and Trans-Baikal areas and the Far East (***Fig. 2***). The densely populated and intensively economically developed regions of the European part of the country (Central, Volga Area, Southern Federal Regions); the Central and Southern Ural, and southern areas of West Siberia are provided with explored water reserves at a level close to 250-300 l/day per capita.

The structure of groundwater use has not changed for a long time: over three-quarters of the consumed waters are used for drink-

* Russian Research Institute of Hydrogeology and Engineering Geology, vsegingeo@rambler.ru

ing and domestic water supply; the rest are used in industry. In Russia over 9,000 drinking groundwater fields are explored, with total reserves of about 90 million m^3/day (State Report, 2011), which is approximately one-tenth of the total predicted resources.

During the last six years prospecting-estimating work on more than 200 new objects has been carried out within the federal budget for the purpose of supplying Russian regions that are in need of water. Results of geological exploration work have revealed groundwater fields for the water supply of such large cities as N.Novgorod, Saratov, Omsk, Orenburg, Murmansk, etc. Prospective planning up to the 2020s and 2030s envisages solving the problem of water supply of small towns by using underground water sources.

In spite of the significant drinking groundwater potential, in a number of regions of the country the exploitation of groundwater has been followed by its depletion and pollution. In the Central part of Russia several regional cones of depression were formed. The most extensive depression, caused by water pumping for iron ore mining at the Kursk Magnetic Anomaly, covers a part of the Belgorod and Kursk regions. The water level decline in the center of the depression reaches 8090 m. Local depression cones are forming around all the regional centers and large mineral deposits.

The decrease in groundwater extraction, which began in the 1990s, has led to a slowdown in the decline of the groundwater level (pressure head), to its stabilisation, and even in some cases to its restoration. Recovery of the groundwater state is occurring not only in industrial centers but also in the regions where ore-mining enterprises are temporarily stopped or closed.

According to the existing estimates, groundwater pollution in Russia, caused by human activities, has mainly a local character. Deterioration of the groundwater quality occurs predominantly within the areas of polluting sources and has mainly a point (local) character. The areas with unregulated quality of groundwater vary from a few square kilometers in area to a few hundred km^2 in the worst cases.

The dominant pollution type is chemical. Among pollutants the following are most often found: chlorides, sulfates, compounds of iron and nitrogen and also hydrocarbons (mainly oil products, rarely phenols and surface-active substances (SAS)). In some industrial and agricultural regions of Russia, the human activities have led to formation of a changed hydrogeochemical background in the upper layers of the underground hydrosphere. In the influence zone of industrial and agricultural objects the local sources of beyond-limit groundwater pollution are being formed. The number of deposits with the pollution-induced reduction of exploitable fresh groundwater reserves became three times higher within a quarter of the century (1975-2000). In most cases this is connected with the natural conditions of groundwater quality formation.

Mineral groundwater. Russia possesses considerable resources of different types of mineral groundwater, suitable for drinks or medical care in sanatoria and health resorts, and for industrial bottling. The explored mineral groundwater reserves in Russia amount to over 300,000 m^3/day (State Report, 2011). The mineral waters that are used in hospitals and policlinics (curative drinks and balneological uses) are predominant. Basic types of mineral waters and their proportions in the reserve structure are shown in ***Fig. 3***. The increase of mineral water reserves is achieved mainly at the expense of waters for industrial bottling; in recent years the share of mineral water has considerably increased. Today in Russia intense growth in mineral water bottling is observed. Till the mid-1980s the consumption of natural mineral waters amounted to 2 l per person per year; by the year of 2010 it had increased to 60 l.

The explored mineral groundwater deposits are distributed unevenly within Russian territory. Almost three quarters of them are concentrated in the European part of the country. The highest mineral groundwater reserves are at the disposal of the North-Caucasian Federal Region. During the last five years new deposits of mineral waters in the Central, Southern and Volga Federal Regions have come under intensive development. In the Asian part of Russia such work is being carried out mainly in West Siberia.

The market in investment proposals for the organisation of mineral water extraction is presently in the formation stage.

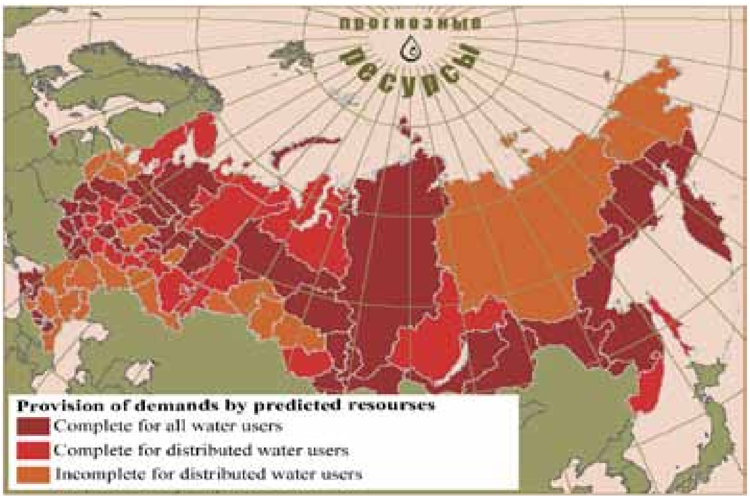

Figure 1: Provision of the Russian regions with predicted resources of drinking and technical groundwater.

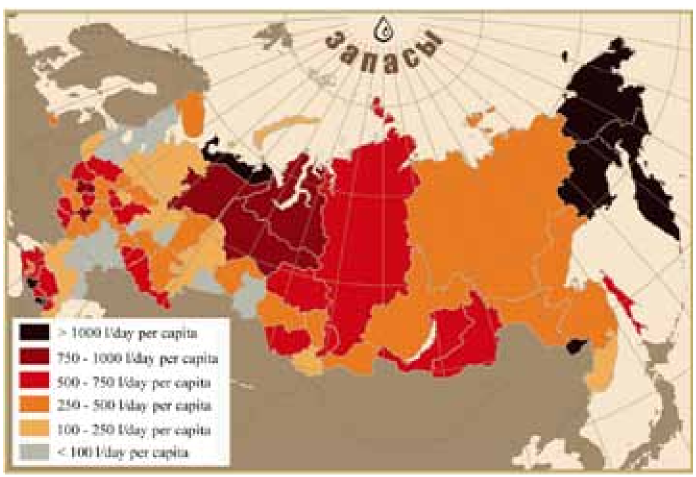

Figure 2: Provision of the Russian regions with explored drinking groundwater reserves.

The managing authorities of the mineral resources foundation are trying to exert influence upon their state through involving investments into the geological study of new areas and valuable curative types of water. The mechanism that governs reproduction of the mineral groundwater resources base is the system of licensing, which, as experience has shown, is not sufficiently effective and requires legislative support. As a rule, investors direct their attention to those types of mineral water that are popular among the population, i.e., territories and areas where such mineral waters have already been marketed. This leads to a concentration of exploited areas within a small territory, which is extremely undesirable for many mineral groundwater deposits from the view of protecting their resources and quality.

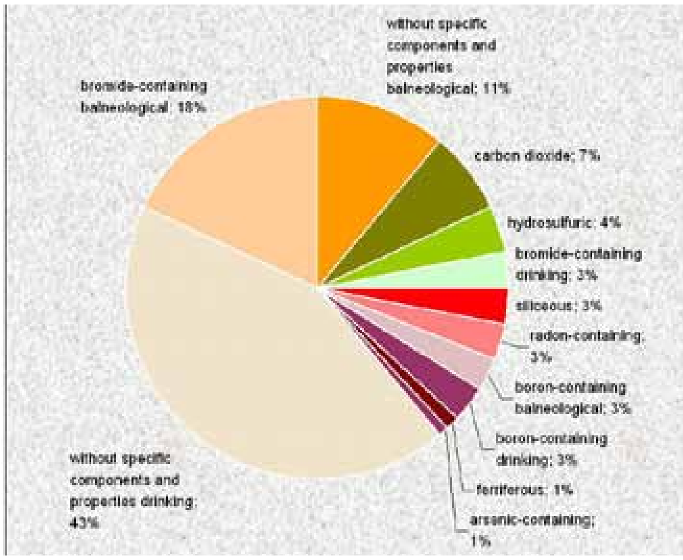

Figure 3: Basic types of mineral waters and their portions in the reserves structure.

Heat-energetic (thermal) groundwater, used as a natural heat-carrier for producing thermal and/or electrical power, is distributed unevenly over the Russian territory. Basic resources of heat-energetic waters usable for heat supply (including hot water supply) are connected with the large artesian basins of the young Mesozoic plates and troughs – found in West Siberia, the East and Fore-Caucasian regions, and Azov-Kubansky – as well as with small basins of Alpine piedmont and intermont depressions. As a rule, these thermal waters have at the same time a curative value due to the content of specific components or increased mineralization, and are used in some places for both heat supply and balneological treatment. The reserves of thermal waters and vapor-hydrotherms (temperatures of 40-200 °C) are estimated as equal to over 300,000 m^3/day for the prospective regions of their distribution (State Report, 2011).

As for generating electricity, while resources of geothermal heat with 30-200 °C temperatures exist over the entire territory of Russia, nowhere besides Kamchatka are they used for obtaining electrical power. At the present time two unique geothermal electrical plants (GeoEP) are in operation: the Verkhnemutnovskaya trial-industrial GeoEP with a capacity of 12 MW, operating since 1999, and Mutnovskaya GeoEP-1 (put into operation in 2002). Both plants transform the thermal energy into electrical power using a vapor-water mixture from the Mutnovsk geothermal deposit (with an estimated potential of 300 MW).

On Kunashir Island a GeoEP with a capacity of 2.6 MW is in operation and several more plants are being planned, with a total capacity of 12-17 MW. Approval has been given to construct the Okeanskaya GeoEP on Iturup Island with a capacity of 34.5 MW and a planned annual output of 107 GWh.

The low level of geothermal energy in Russia is explained by low tariffs on natural gas. Growth in the cost of natural gas in the domestic market is activating interest in the use of heat-energetic groundwater and will promote the creation of up-to-date heat-technology equipment. It seems promising to use geocirculation technology for the production of natural heat-carriers with return injection after usage. This would enable not only a multiple increase in the extraction of heat-energetic groundwater (to 7.1 billion m^3/day) by means of maintaining stratum pressure and artificial renewal of groundwater resources, but also a solution to the problem of the ecologically safe disposal of wastewater.

Industrial groundwater occurs in the deepest parts of artesian basins in all platform-type areas (the Russian, West Siberian, East Siberian and Scythian Plates). The deposits of iodine-bromine waters in the Tyumen, Perm and Krasnodar regions represent the basic resource base of industrial groundwater, financed from federal funds. Recently two more deposits were explored: Astrakhanskoye, with reserves of to 200 t of iodine per year, and Severodvinskoye, in the Arkhangelsk Region, with reserves of iodine-containing waters equal to 120 t of iodine per year.

Directions of development and reproduction of groundwater mineral resources base of the Russian Federation

1. Periodic assessment of groundwater resources status in regions under the most intensive development, aimed at solving in proper time the problems of their rational use and at providing protection against pollution and depletion.
2. Prospecting and exploring works carried out with the aims of: (a) providing a drinking water supply for large populated settlements, including during emergency situations; (b) focusing on territories that have been poorly studied in terms of their hydrogeology and have a lack of drinking water; (c) providing water in ecologically poor regions where groundwater is the only source of drinking water.
3. Creation of the economic conditions necessary for increased and more effective use of deposits of heat-energetic (thermal) and industrial groundwater.

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Karst in Serbian hydrogeology: A tradition in research and education

Zoran Stevanović and Saša Milanović*

Serbia is a classical karst country. Its rough karst landscape and the large distribution of surface and underground karstic occurrences have always provoked interest in their study and description. This also accounts for the fact that the contributions of Serbian scientists to hydrogeology are most remarkable in the field of karst hydrogeology, particularly those contributions made by Jovan Cvijić. Thanks to Cvijić, karst explorers worldwide use the local Slavic terms polje, uvala, doline, *and* ponor. *The second half of the 20th century was a period when a new generation of karst hydrogeologists emerged and many successful projects were implemented in the engineering regulation of karst surface and groundwater. Today, the Centre for Karst Hydrogeology of the University of Belgrade is the leading national centre for research into karst aquifers.*

La Serbie est un pays de nature hydrogéologique typiquement karstique. Ses paysages sauvages et l'abondance des occurrences karstiques en surface et en souterrain ont toujours généré un vif intérêt pour leur étude et leur description. Cela est aussi la conséquence du fait que les contributions des scientifiques serbes en hydrogéologie sont les plus remarquables dans le domaine des karsts et, en particulier, les contributions provenant de Jovan Cvijic. Grâce à Cvijic, les explorateurs de karst dans le monde utilisent les termes locaux slaves polje, uvala, doline *et* ponor. *La seconde moitié du 20ème siècle a constitué une période qui a permis à une nouvelle génération d'hydrogéologues du karst, d'être reconnue et nombre de projets à succès ont été menés à bien dans le domaine de la réglementation des aquifères karstiques en surface et en souterrain. Aujourd'hui, le Centre d'études hydrogéologiques appliquées au karst, à l'Université de Belgrade, est le centre national en pointe pour les recherches en matière d'aquifères karstiques.*

Serbia es un clásico país kárstico. Su agreste paisaje kárstico y la amplia distribución de karsts subterráneos y superficiales, ha generado siempre el interés en su estudio y descripción. Esta es también la razón por la que la contribución de los científicos serbios a la hidrogeología, es mucho más importante en el campo de la hidrogeología del karst, especialmente la de Jovan Cvijić. Gracias a Cvijić los investigadores del karst del todo el mundo utilizan términos eslavos como polje, uvala, dolina, *o* ponor. *La segunda mitad del siglo 20 fue un período en el que emergió una nueva generación de hidrogeólogos del karst y se implementaron muchos proyectos exitosos en la reglamentación ingenieril de la superficie del karst y del agua subterránea. Hoy el Centro de la Hidrogeología del Karst de la Universidad de Belgrado es el principal centro nacional de investigación en los acuíferos del karst.*

Karst aquifers are of great importance to our planet: at present, on over 20% of the land surface, they provide drinking water to a similar percentage of the world's population. Karst itself is a paradox: it feeds the world's largest springs and many other bodies of water which serve as reliable sources of water supply, but due to the fast infiltration of rainwater and sinking streams in karst depths local populations often suffer from water shortages. Karst provides a safe haven to various living creatures in the mysterious world of caves. But because it is vulnerable to all kinds of pollution, karst may be a dangerous medium for consumers of its water. For all these reasons the karst environment and its groundwater have for millennia intrigued scientists, engineers, and the general public.

Serbia is a country with maturely developed classical karst. It is the only country where the Carpathian and Dinaric mountain arches – the two branches of Alpides – are present and extend close to each other. About 30% of the Serbian western (Dinarides) and eastern parts (Carpathians) is covered by carbonate rocks. Similarly to the global percentage, about 20% of the population consumes drinking water originating in karst aquifers. Karstified rocks and karstic groundwater have always been of interest to local scientists and residents.

* Professor of the University of Belgrade-Faculty of Mining & Geology, Department of Hydrogeology-Centre for Karst Hydrogeology, President of the Serbian Geological Society, zstev_2000@yahoo.co.uk

Jovan Cvijić's karst studies

Although the tapping of fresh or mineral water is a very ancient technique in Serbia, the beginning of the history of hydrogeology is formally associated with the 1890s, the masterpiece *Groundwater* by Svetolik Radovanović (1897), and works by Jovan Cvijić (whose portrait is shown in ***Fig. 1***). Both belonged to the first student generation of Jovan Žujović, who established the national geological school.

Jovan Cvijić completed his studies in Geographic Science at the University of Belgrade. Still as a student he completed a report on the Serbian geographical terminology and carried out his surveys in karst of the Carpathian-Balkan mountain arc in Eastern Serbia. The results of these surveys, conducted until 1895, were published in five extensive studies (Stevanović, 1997b, 2012).

Figure 1: Jovan Cvijić.

Cvijić completed his postgraduate study of geography at the University of Vienna in 1892 with the dissertation "Das Karstphaenomen", tutored by Professor Albrecht Penck. The dissertation – published by the Academy of Sciences in Vienna – aroused a great deal of interest among geo-scientists worldwide. In his dissertation and further studies Cvijić explained the morphogenesis of sinkholes and provided classifications of caves, karst rivers, poljes and other karst features. Praise from many European countries greatly encouraged and inspired Cvijić to do further field surveys throughout Europe.

Jovan Cvijić was appointed professor of geography at the University of Belgrade, and later became Rector, as well as president of the Serbian Royal Academy. He made an invaluable contribution to the development of education and sciences in Serbia (Mijatović, 1997; Stevanović, 2012).

Cvijić's most significant contribution is to the theory of water circulation and the function of karst aquifers (Mijatović, 1997). At that time there were the two contradictory theories: one created by Katzer and Martel, and one from Grund and Penck. Cvijić was the first who explained that arguments for both theories could be acceptable and tried to harmonise them, providing many case examples he had collected during his field work (Mijatović and Komatina, 1983; Stevanović and Mijatović, 2005).

Cvijić (1918) also described his own theory of superposition of "hydrographic zones in karst". He introduced three main super-positioned zones in specific dynamic coexistence with permanent lowering of the water table due to the dynamic evolution of the karst aquifer.

Figure 2: Jovan Cvijić's gold medal from the American Geographical Society, New York, 1924: "The recognition obtained for exceptional scientific results and published works in the field of physical geography of Balkan countries".

Cvijić's opus and exploration were fundamental to the foundation of karstology and karst hydrogeology (Stevanović, 2012). He created a very important and wide scientific base and tracked further investigation of karstic phenomena (Ford, 2005; Zojer, 2005). Thanks to his work many local Slavic terms such as *polje*, *doline*, *uvala* and *ponor* started to be widely used to explain morphological and hydrogeological processes in karst.

Cvijić received awards from the Royal Geographical Society of London, from the American Geographical Society (***Fig. 2***), and many other international academies, geographical societies and institutions.

Serbia and Belgrade, where Cvijić spent most of his life, have gratefully acknowledged his achievements. The Geographical Institute of Serbia, established in 1961 under the patronage of the Serbian Academy of Sciences and Arts, bears the name of Jovan Cvijić. The Museum Jovan Cvijić was established in 1965, while a large monument was erected near the entrance of the University of Belgrade headquarters (***Fig. 3***).

Karst hydrogeology in Serbia after WWII

Cvijić's works enabled the establishment of a strong karst geomorphology and hydrogeology school in Serbia. The centre of education is the University of Belgrade, a state-owned institution with a long tradition, today home to more than 70,000 students enrolled in 31 colleges and schools. Courses in hydrogeology were first introduced into the curricula of the Faculty of Mining and Geology. Postgraduate studies for hydrogeological sciences were introduced in 1960. Since then, the Faculty and its Department of Hydrogeology has educated over 700 graduated hydrogeologists, and 50 holders of doctorates in this science. This school has become not only a leading educational and scientific centre for hydrogeology for the former Yugoslavia but also one of the largest in south-eastern Europe (Filipović, 1997).

The late 1970's saw a new generation of karst hydrogeologists. Borivoje Mijatović and Miomir Komatina were among the founders of the Karst Commission of International Association of Hydroge-

Figure 3: Participants of the IAH international conference KARST 2005 at the monument of "the Father of karst hydrogeology" in downtown Belgrade.

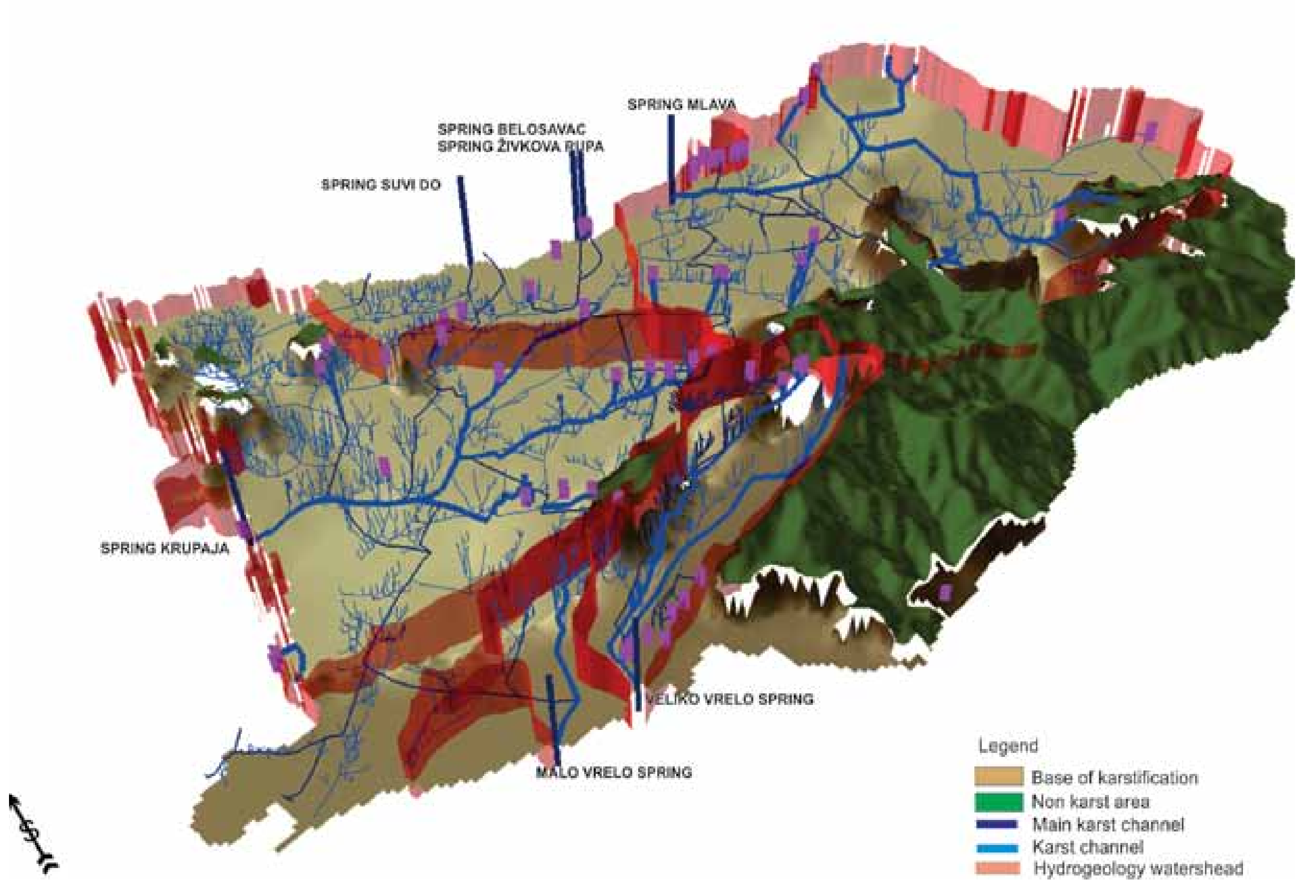

Figure 4: 3D model of karst channels in the Beljanica karst aquifer – a basis for a storage assessment and engineering regulation project (Milanović, 2010).

ologists (IAH); they were soon joined by Petar Milanović. They have been widely recognized on the international scene and their contributions have been published in numerous publications. For instance, a book concerning Dinaric karst published by IAH (Mijatović, 1984) helped to spread knowledge and information about this "classical karst", for hydrogeologists always an attractive area. Milanović's *Karst Hydrogeology* (published in 1979 in Serbian and 1981 in English) soon became an important reference dealing with the problems of distribution and circulation of karst groundwater and its research, and was the first book on the topic to be published in English (Krešić, 2013).

The most significant role in the hydrogeological research of 1970s was held by Geozavod (the Geological Survey of Serbia), established in Belgrade as a state institute after WWII. Its researchers made important contributions to national and international hydrogeology (Mijatović, 1997). The consulting services and contracting works of Geozavod and other Serbian organizations such as Energoprojekt, "Jaroslav Cerni",

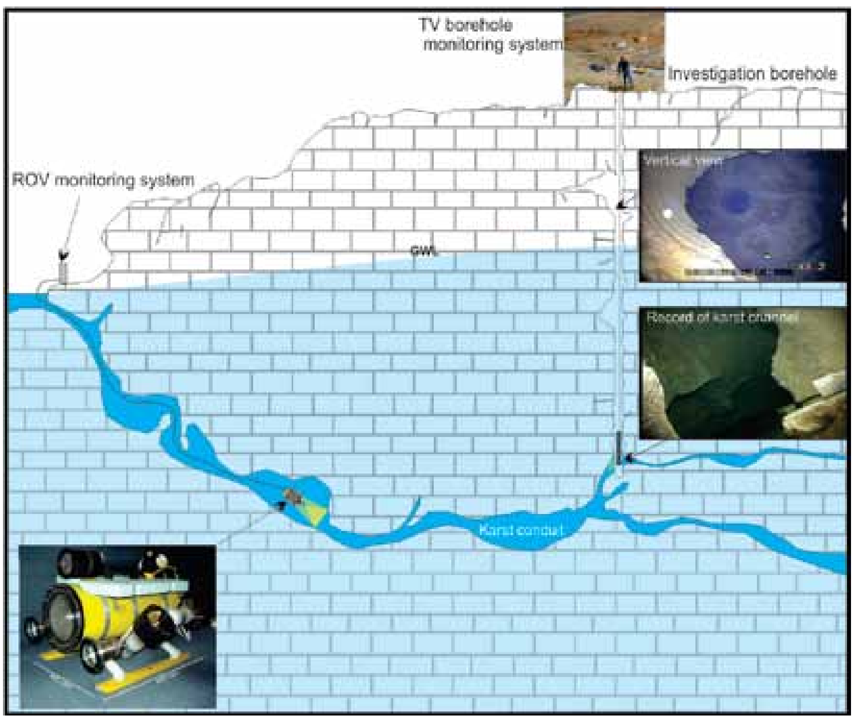

Figure 5: Research devices developed by CKH: cavities recorder ROV and logging video camera.

Figure 6: Group of MS students of the Department of Hydrogeology and experts of DIKTAS project in Trebinje.

Geosonda, Hidroprojekt, Jugofund have been provided in locations such as Cyprus, Morocco, Algeria, Tunisia, Libya, Egypt, Jordan, Iraq, Iran, and Peru (Zogović *et al.*, 1997).

Many large engineering projects and the construction of large and medium-sized dams in former Yugoslavia were also built with the support of Serbian companies and experts. For example, a large hydroenergy system to control the largest European sinking river, the Trebišnjica, was successfully implemented in eastern Herzegovina near the borders with Croatia and Montenegro (Milanović, 1981). It was one of the first successful karst projects of this kind.

Serbian karst hydrogeology today

The curriculum of the Faculty of Mining & Geology of the University of Belgrade (*www.rgf.bg.ac.rs/dhg*) has always included theoretical and practical engineering courses which deal with the conceptualisation and hydrodynamics of aquifers, including karst aquifers. Today, the Centre for Karst Hydrogeology (CKH; *http://www.karst.edu.rs*) of the Faculty of Mining & Geology of the University of Belgrade and the Karst Commission of the Serbian Geological Society (*http://www.sgd.rs*) undertake many research projects and activities and try to maintain the tradition of karst research. Several successful projects with technical applications for the control and engineering regulation of karst aquifer through the construction of galleries, batteries of wells, and groundwater reservoirs (storage) have been designed and constructed in Serbia (***Fig. 4***). Some of the CKH experts have also worked as consultants of the UN or specialised foreign companies. The results of their research on karstic terrains in Iraq, Iran, Turkey, Algeria, and Somalia represent an important contribution to international hydrogeological science.

In order to support new technologies, some innovative equipment and devices which provide new opportunities for the detailed survey of karst interior have been developed and tested in CKH. A small logging video camera with a rotary lens enables not only a vertical but, more importantly, also a horizontal recording of the cavities and joints present. The camera can be installed into boreholes in both the saturated and unsaturated parts of the aquifer, and in any open fissure with a diameter larger than that of the camera (~50 mm). Also, an underwater remote-controlled vehicle (ROV) supported by video camera can be used for surveying larger saturated channels which are inaccessible to cave divers (***Fig. 5***). The results and experience obtained from several of the projects conducted led to the adoption of these devices as standard investigation equipment.

With three permanent members, Serbia still contributes to the Karst Commission of the IAH. The three hydrogeology experts are also active on the Board of Karst and Speleology of the Serbian Academy of Sciences and Arts. Krešić's recently published textbook "Water in Karst" (2013) is an important new step in the education about and promotion of karst hydrogeology, while its introduction pays homage to the school that he graduated from and where he worked for more than a decade.

Today, thanks to its well-known history and former students, hydrogeology is the most popular discipline offered by the geology division of the Faculty of Science at the University of Belgrade. During the last five years an equal number of doctoral theses in karst hydrogeology have been defended by candidates from Serbia, Montenegro and Iraq. The topics considered modern methods and innovative techniques in time series analyses of spring discharges, water reserves and recharge component assessment, and the mathematical and physical modelling of karst.

In 2005 Belgrade hosted a large international conference sponsored by IAH and UNESCO, dedicated to Jovan Cvijić and the anniversary of the publishing of his doctoral dissertation "Karst" in Serbian. In 2014 the conference "Karst without Boundaries" (*http://diktas.iwlearn.org*) dedicated to Dinaric karst will be held in Trebinje, Bosnia & Herzegovina and Dubrovnik, Croatia with a considerable contribution by Serbian scientists and with the University of Belgrade as one of the co-organisers. The conference will mark the end of a large Global Environmental Fund project, *Protection and Sustainable Use of the Dinaric Karst Transboundary Aquifer System* (DIKTAS, ***Fig. 6***). Prior to the conference the international course and field seminar "Characterization and Engineering of Karst Aquifers" will be held. This course is among the certified regular courses of the MS Program of the Department of Hydrogeology, and will be organised in the field with the support of local and international organisations and lecturers beginning in 2014 (*http://www.karst.edu.rs/en/edukacija/skola-karsta-trebinje.html*). The course and field seminar are developed primarily for graduate students and students in their senior years of undergraduate studies in geology, environmental sciences, and engineering who are interested in research on karst environments and in the development and engineering of karst water resources. Professionals and decision makers involved in the engineering and management of karst waters or environments will also benefit from the course by improving their understanding of karst processes and sensitivity.

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Regional Values of Transmissivity Coefficient in Pre-Quaternary Rocks of Slovakia

Peter Malík and Jaromír Švasta*

Data on pumping tests were interpreted for 6,309 boreholes for hydraulically testing aquifers in pre-Quaternary rocks, maintained in a database of the Geological Survey of Slovak Republic. From the 125 general hydrogeological types of aquifers that were identified in pre-Quaternary rocks, 79 could be characterised by specific capacity values (limit of ≥3 wells with pumping tests). The transmissivity coefficient was derived from specific capacity by a complex re-interpretation process. Hydraulic parameters of pre-Quaternary rocks show a log-normal statistical distribution and high heterogeneity. Therefore, geometric mean values of transmissivity were evaluated. Results show that with a growing population of evaluated boreholes, mean regional values of various pre-Quaternary rock types are asymptotically approaching a relatively narrow interval between $3\cdot10^{-5}$ to $1\cdot10^{-3}$ $m^2\cdot s^{-1}$.

Les données sur les essais de pompage ont été interprétés de 6 309 forages, essais hydrauliques des aquifères en roches pré-Quaternaire, maintenus dans une base de données de la Commission géologique de la République Slovaque. 79 de la valeur totale de 125 types généraux de hydrogéologiques des aquifères qui ont été identifiés en pré-Quaternaire roches pouvaient être caractérisés par des valeurs de capacité spécifiques (≥ limite de 3 puits avec des essais de pompage). Coefficient de transmissivité a été dérivé de la capacité spécifique par le complexe processus de ré-interprétation. Paramètres hydrauliques de pré-Quaternaire roches montrent une distribution log-normale statistique et forte hétérogénéité. Par conséquent, les valeurs moyennes géométriques de la transmissivité ont été évalués. Les résultats montrent que la population croissante avec des trous de forage évalués, les valeurs moyennes régionales des différents types de roches pré-quaternaires sont asymptotiquement approche intervalle relativement étroit entre $3\cdot10^{-5}$ à $1\cdot10^{-3}$ $m^2\cdot s^{-1}$.

Los datos de los ensayos de bombeo se traducen para los 6 309 pozos, pruebas hidráulicamente acuíferos en rocas pre-Cuaternario, mantenidos en una base de datos del Servicio Geológico de la República Eslovaca. 79 a partir del valor total de 125 tipos generales hidrogeológicas de los acuíferos que se identificaron en las rocas pre-Cuaternario podría caracterizarse por valores de capacidad específicos (límite de ≥ 3 pozos con bombeo de pruebas). Coeficiente de transmisividad se deriva de la capacidad específica complejo proceso de reinterpretación. Los parámetros hidráulicos de pre-Cuaternario rocas muestran una distribución estadística log-normal y alta heterogeneidad. Por lo tanto, los valores de las medias geométricas de transmisividad fueron evaluados. Los resultados muestran que con la creciente población de pozos evaluados, los valores medios regionales de diferentes tipos de rocas pre-cuaternario se aproxima asintóticamente intervalo relativamente estrecho entre $3\cdot10^{-5}$ a $1\cdot10^{-3}$ $m^2\cdot s^{-1}$.

Rock-mass hydraulic properties are the key factor in controlling groundwater flow and thus are interesting from the point of view of groundwater supply and protection of groundwater resources. Estimation of transmissivity ***T*** (***Q/s***; discharge vs. drawdown ratio) from specific capacity is a quick method of acquiring information on hydraulic aquifer properties. Such an approach has been discussed mostly for porous aquifer media, but some authors have also dealt with with similar techniques applied for fractured or karst rocks (e.g., Malík and Švasta, 2010). In this study, specific capacity data were also used to determine mean transmissivity ***T*** by individual re-interpretation of individual pumping tests, using unified "standard" specific capacity data to eliminate influences of differently performed pumping tests. Calculation of "logarithmical conversion differences" – parameters concerning hydraulic resistivities of both wells and aquifers was also employed (Jetel 1964, 1985, 1995a, 1995b; Jetel and Krásný, 1968). The set of hydraulic parameters calculated in this way was then linked to various aquifer types.

* Štátny geologický ústav Dionýza Štúra – Geological Survey of Slovak Republic; Dpt. of Hydrogeology & Geothermal Energy, Mlynská dolina 1, 817 04 Bratislava 11, Slovakia, peter.malik@geology.sk

Data sources

A large database of hydrogeological boreholes (wells) containing more than 22,922 wells from all hydrogeological units of the Slovak Republic was developed (Malík *et al.* 2007). The spatial position of these boreholes is visible in ***Fig. 1***. From these, 16,250 pumping tests could be reinterpreted, using the data stored for each borehole. However, the tested wells were unequally distributed in different aquifer types: 9,941 well tests were in Quaternary porous aquifers, and only 6,309 well tests were performed in all other types of pre-Quaternary aquifers. In the process of database development, if possible, each borehole was linked to a certain geological type of pumped aquifer according to screen position (open casing interval), using the digital geological map of Slovakia in the scale of 1:50,000 (Káčer *et al.* 2005; Map server of the State Geological Institute of Dionýz Štúr 2012). It should be also stressed that wells with an ambiguous position of screen were excluded from further processing to obtain a distinct relation of pumped amount to lithological type. In total, 125 general hydrogeological types of aquifers were identified in pre-Quaternary rocks outcropping on the territory of the Slovak Republic. The list and characteristics of the individual pre-Quaternary aquifer types (Malík *et al.* 2007), as derived from the digital geological map of Slovakia in a scale of 1:50 000 (Káčer *et al.* 2005), is in ***Table 1***.

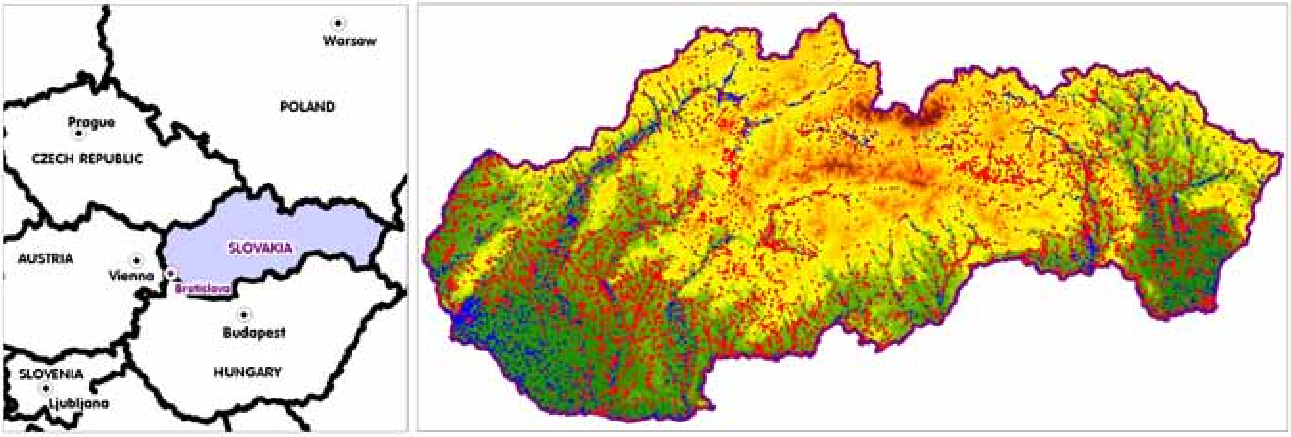

Figure 1: Location of all boreholes and wells (blue points) interpreted as pre-Quaternary boreholes and wells (red points) on the Slovak territory.

Data interpretation

Calculation of standard specific capacity

For the pumping test, which provided only discharge and drawdown data on a tested well (as in the majority of reports stored in the archives of the Geological Survey of Slovak Republic), the re-interpretation process should concentrate on specific capacity data, but one should firstly eliminate the influences of differently performed pumping tests by processing the standard specific yield of the pumped well, i.e. discharge at the first drawdown metre. ***Specific capacity*** value, a ratio between the discharge ***Q*** and corresponding drawdown s in a well, is calculated by Equation (1).

$$q = Q / s \qquad (1)$$

where:

- q – specific capacity [$L \cdot s^{-1} \cdot m^{-1}$]
- Q – (pumped) discharge [$L \cdot s^{-1}$]
- s – groundwater table drawdown in a well [m]

To derive the representative comparative value, discharge value under the same drawdown conditions is required. With respect to generally nonlinear dependency of ***Q*** on ***s***, it is recommended to use the unified value of discharge – e.g., at the first metre of drawdown (i.e., $s = 1$ m $= s^1$) in Equation (1) if available, or to substitute the measured one (pumped under real circumstances) by a recalculated value. In this case, unit drawdown specific capacity ^1q = "standard specific capacity" as defined by Jetel (1985, 1995a), stands for specific capacity. When measured drawdown values s^n differ from 1 m, in the case of a thick ($M > 10$ m) unconfined aquifer, specific capacity at unit drawdown will be calculated with Equation (2):

$$^1q = qn \cdot (2 \cdot M - 1) / (2 \cdot M - s^n) \qquad (2)$$

where:

- ^1q – standard specific capacity = specific capacity at unit drawdown [$L \cdot s^{-1} \cdot m^{-1}$]
- s^n – unconfined groundwater table drawdown, measured in a well [m]
- M – original thickness of an unconfined aquifer unaffected by pumping [m]
- q^n – specific capacity at drawdown s^n [$L \cdot s^{-1} \cdot m^{-1}$].

If, while performing the unconfined aquifer test, the drawdown exceeds a value of more than 1/10 of the original aquifer thickness ***M***, the measured drawdown should be adjusted as in Equation (3) (Jacob 1944, cited in Jetel 1985) and an adjusted drawdown s_c (Equation 4) should be used instead of measured drawdown ***s*** in specific capacity calculations. Such an adjustment is necessary due to the significant reduction of the groundwater flow cross-sectional area and subsequent transmissivity decrease.

$$s_c = s^n - s^2 / (2 \cdot M) \qquad (3)$$

where:

- s_c – adjusted unconfined groundwater table drawdown in a well [m].

$$^1q = Q / s_c \qquad (4)$$

In the case when standard specific discharge calculation was performed without drawdown adjustment (s to s_c), in spite of the fact that the drawdown in the well exceeded 1/10 of the unaffected unconfined aquifer thickness, according to Equation (3) the value of the adjusted standard specific discharge ^1q_c should be used to characterise the individual well/borehole and the exploited aquifer. The value of ^1q_c is obtained by)

$$^1q_c = {}^1q \cdot (2 \cdot M) / (2 \cdot M - 1) \qquad (5)$$

where:

- ^1q_c – adjusted standard specific capacity [$L \cdot s^{-1} \cdot m^{-1}$].

Under confined aquifer conditions, the dependency of discharge ***Q*** from drawdown ***s*** is less or more linear up to a certain threshold value of ***s***. For higher piezometric depressions, however, this relation becomes nonlinear. If sufficient pairs of ***Q*** and ***s*** values are available for identification of ***Q***=f(***s***) curve, the standard specific capacity can be derived graphically by interpolation or extrapolation to $s = 1$ m value. Without this possibility, an estimation of standard specific capacity can be performed using the relation of parabolic approximation of the curve (Equation 6):

$$^1q = q^n \cdot (2 \cdot H - 1) / (2 \cdot H - s^n) \qquad (6)$$

where:

- H – distance between the static water level in a well and lowest part of the open well casing [m].

The aforementioned algorithms serve for data unification from different wells with different drawdowns and discharges. Even though such procedure is only a rough approximation of an unknown nonlinear curve $Q = f(s)$, it allows objectively reproducible correction of the specific capacity decrease with drawdown to achieve data comparability. Basic statistical characteristics of the standard specific capacities (and derived values of the transmissivity coefficient *T*) calculated for individual pre-Quaternary aquifers in Slovak territory are shown in ***Table 2***. The aquifers are marked by the same numbers that correspond to their description in ***Table 1***. Hydraulic parameter ***T*** (transmissivity) was then derived from the value of specific capacity ***q*** by the set of equations defined by Jetel (1985, 1995a, 1995b) and applied also by Malík and Švasta (2010).

Results and discussion

Pre-Quaternary aquifer types within Slovakia can be divided into six basic groups according to their stratigraphical age. These are: (a) Neogene sedimentary aquifers; (b) volcanic Neogene aquifers (both lava and volcanoclastic sediments); (c) sedimentary aquifers of Paleogene age; (d) aquifers in Mesozoic sediments; (e) aquifers in Crystalline and (f) in Paleozoic rocks. Classification of the individual pre-Quaternary aquifer types into basic groups is shown in the final column of ***Table 1***. In total, 125 specific pre-Quaternary aquifer types were derived from the total number of 1,853 individual lithostratigraphical rock types described on the unified legend of the digital geological map of Slovakia. The process of unification of lithostratigraphical rock types into aquifer types was based on similarities in lithological content, considering features that were supposed to be the most important for groundwater circulation. In the interpretation process of linking wells and boreholes with pumping tests to individual aquifer types, however, we were able to find relevant available data from more than 3 objects (wells/boreholes) for 79 specific types of pre-Quaternary aquifer types (***Table 1***). Most of the data was obtained from the clay, silt, sand and gravel rock environments and from brackish, lake and fluvial sediments of Neogene age, where 1,364 pumping tests were performed. On the other hand, for 38 aquifer types it was not possible to find any relevant hydrogeological borehole or well. Basic statistical characteristics of the standard specific capacities ^{1}q (and derived values of the transmissivity coefficient *T*) calculated for individual pre-Quaternary aquifers on the Slovak territory are shown in ***Table 2***, where the aquifer types are marked by the same numbers that correspond to their description in ***Table 1***.

Data concerning the specific capacity transmissivity of well and boreholes in pre-Quaternary rocks generally show a log-normal statistical distribution and high heterogeneity. The statistical evaluation of these hydraulic parameters was therefore based on comparison of geometric mean values ***G(T)*** in ***Table 2***. Showing both median $Md(^{1}q)$ and arithmetical average $M(^{1}q)$ value of specific capacity ^{1}q in ***Table 2*** can indicate the type of statistical distribution of the data. From the relevant groups (≥ 30 pumping test performed), limestones, quartzitic limestones, bulbed limestones, limestones with cherts (Middle and Upper Triassic; No. 58 in ***Tables 1 and 2***) showed the highest mean values ($M(^{1}q)$ and $Md(^{1}q)$ in ***Table 2***) of specific capacity ^{1}q as well as of transmissivity ***T*** (3.236 $L{\cdot}s^{-1}{\cdot}m^{-1}$; $3.52{\cdot}10^{-3}$ $m^{2}{\cdot}s^{-1}$ from 34 evaluated pumping tests). Dolomites of the Middle and Upper Triassic (No. 62) were in the second place (0.589 $L{\cdot}s^{-1}{\cdot}m^{-1}$; $1.04{\cdot}10^{-3}$ $m^{2}{\cdot}s^{-1}$; 438 pumping tests), followed by (No. 55) Jurassic and Cretaceous limestones, marly limestones, crinoid limestones, bulbed limestones, quartzitic/silicitic limestones, and eventually sandy limestones, and calcareous sandstones/conglomerates (0.490 $L{\cdot}s^{-1}{\cdot}m^{-1}$; $5.24{\cdot}10^{-4}$ $m^{2}{\cdot}s^{-1}$; 30 pumping tests). All these are hard rocks of fissure and karst-

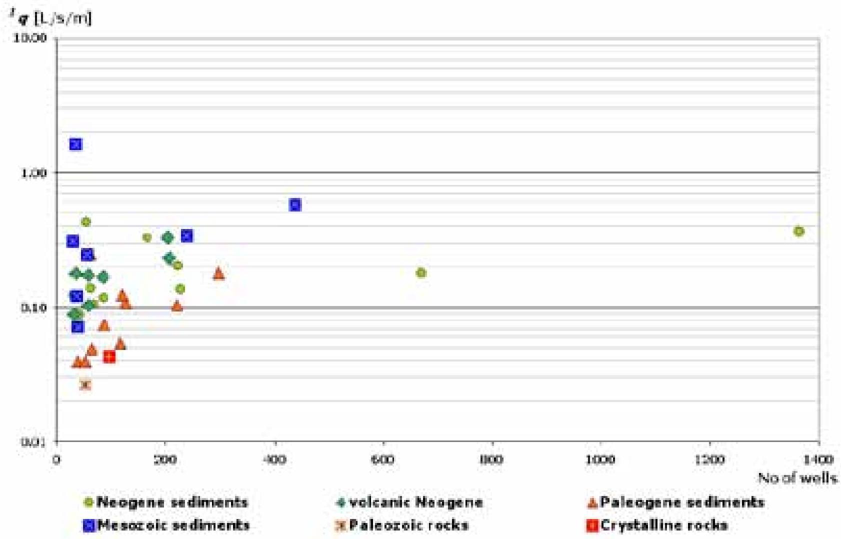

Figure 2: Comparison of mean regional values of the standard specific capacities ^{1}**q** *for aquifer types with ≥ 30 evaluated pumping tests on boreholes and wells.*

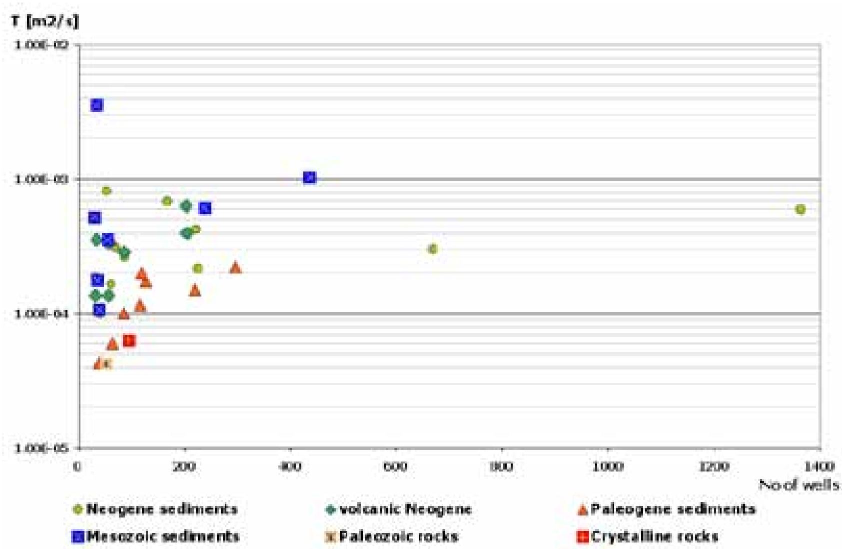

Figure 3: Comparison of mean regional transmissivity values for aquifer types with ≥ 30 evaluated pumping tests on boreholes and wells.

No.	description	origin and classification	group
1	mostly clays and claystones, variably with limited presence of silts, sands, gravels, diatomits, volcanic tuffs and coal clays with lignit	lake, lacustrin and fluvial sediments of Neogene age	Neogene sediments
2	clays, claystones, silts, sandy clays, sands, tuffits and diatomites with beds and layers of lignite, occasionally also gravels	lake, lacustrin and fluvial sediments of Neogene age	
3	clays, claystones and siltstones, variably with beds of sandstones, conglomerates, tuffs or limestones	shallow sea sediments and fluvial sediments of Neogene age	
4	clays, silts, sands and gravels	shallow sea sediments, lake and fluvial sediments of Neogene age	
5	clays, silts, sands, gravels, conglomerates and limestones	shallow sea sediments and fluvial sediments of Neogene age	
6	mostly clays, claystones and sands	shallow sea sediments and lake sediments of Neogene age	
7	mostly silts and sands	shallow sea sediments of Neogene age	
8	mostly sands and gravels or conglomerates	shallow sea and fluvial sediments of Neogene age	
9	claystones and sandstones with evaporites	shallow sea sediments of Neogene age	
10	claystones, siltstones and sandstones with beds of conglomerates and tuffs	shallow sea sediments of Neogene age	
11	mostly siltstones and sandstones, variably with beds of claystones and tuffs	shallow sea sediments of Neogene age	
12	mostly sandstones and conglomerates, to a lesser extent tuffs, tuffits, limestones	shallow sea sediments of Neogene age	
13	conglomerates and breccias, occasionally limestones, claystones, sandstones	shallow sea sediments of Neogene age	
14	limestones, variably with beds of claystones, sandstones or conglomerates	shallow sea sediments of Neogene age	
15	pyroclastic breccias, agglomerates and tuffs of basalts and basaltic andesites (including pyroklastic flow sediments)	volcanic Neogene rocks: basalts and basaltic andesites	volcanic Neogene
16	plutons and intrusions of granodiorite, diorite and dioritic porphyries	subvolcanic intrusions	
17	laccolithes, sills, dikes and volcanic necks of andesite porphyries and andesites, including beds of intrusive and tuffisite breccias	intravolcanic intrusions	
18	complexes of propylitised andesites and andesitic porphyries	metamorphic intravolcanic intrusions and volcanites	
19	protrusions, extrusive domes and short lava flows (dome flows) of andesites and their extrusive breccias	volcanic Neogene rocks: andesites	
20	lava flows of andesites and their mostly block lava breccias	volcanic Neogene rocks: andesites	
21	pyroclastic breccias, agglomerates and tuffs of andesites (including redeposited pyroclasts)	volcanic Neogene rocks: andesites	
22	tuffs of andesites (including ignimbrites and redeposited tuffs with admixture of epiclasts)	volcanic Neogene rocks: andesites	
23	hyaloclastic breccias and epiclastic volcanic breccias and conglomerates of andesites with rare beds of sandstones	volcanic Neogene rocks: andesites	
24	epiclastic volcanic and tuffitic sandstones of andesites, variably with admixture of small-grained breccias, conglomerates and redeposited tuffs	volcanic Neogene rocks: sediments of andesites	
25	epiclastic volcanic and tuffitic sandstones and siltstones of andesites	volcanic Neogene rocks: sediments of andesites	
26	tuffitic siltstones and claystones of andesites	volcanic Neogene rocks: sediments of andesites	
27	intrusions, laccoliths, sills and dikes of dacitic to rhyolitic porphyries and dacites to rhyolites, occasionally intrusive breccias	volcanic Neogene rocks: dacite to rhyolite intravolcanic intrusions	
28	tuffs of dacites to rhyolites (including ignimbrites and redeposited tuffs with admixture of epiclasts)	volcanic Neogene rocks: dacites to rhyolites	
29	hyaloclastic breccias and epiclastic volcanic breccias and conglomerates of dacites to rhyolites, variably with beds of sandstones and redeposited tuffs	volcanic Neogene rocks: dacites to rhyolites	
30	epiclastic volcanic sandstones and redeposited tuffs of dacites to rhyolites, variably with admixture of small-grained epiclasts	volcanic Neogene rocks: dacite to rhyolite volcanites/sediments	
31	calcareous siltstones and claystones, occasionally with coal intercalations	shallow sea sediments of the Buda Paleogene	Paleogene sediments
32	sands, marly and calcareous sands, decomposited sandstones and siltstones	shallow sea sediments of the Buda Paleogene	
33	gravels, decomposited conglomerates	shallow sea sediments of the Buda Paleogene	
34	claystones, calcareous claystones and marls and layers with overwhelming claystones/marlstones over sandstones, including menilite layers	morské sediments vnútrokarpatského paleogénu	
35	claystone flysch – flysch with prevailing claystones or marlstones	flysch sediments of Inner Carpathian Paleogene and Upper Cretaceous	
36	normal flysch – claystones/marls, siltstones and sandstones	flysch sediments of Inner Carpathian Paleogene and Upper Cretaceous	

No.	description	origin and classification	group
37	sandstone flysch – flysch with prevailing sandstones	flysch sediments of Inner Carpathian Paleogene and Upper Cretaceous	Paleogene sediments
38	conglomerate flysch – flysch with prevailing conglomerates	flysch sediments of Inner Carpathian Paleogene and Upper Cretaceous	
39	sandstones with thin intercalations of claystones	flysch sediments of Inner Carpathian Paleogene and Upper Cretaceous	
40	multicomponent conglomerates and breccias, variably with beds of sandstones	sea sediments and subaqueous slides of Inner Carpathian Paleogene	
41	calcareous breccias and conglomerates, sandy limestones, and limestones, variably with beds of sandstones, occasionally also marlstones	sea sediments of Inner Carpathian Paleogene and Upper Cretaceous	
42	claystones, calcareous claystones and marls and layers with dominantly prevailing claystones/marlstones over sandstones, including menilite layers	sediments of Flysch Belt and Clippen Belt	
43	claystone flysch – flysch with prevailing claystones, siltstones or marlstones	sediments of Flysch Belt and Clippen Belt	
44	normal flysch – claystones/marls, siltstones and sandstones (or feldspar sandstones)	sediments of Flysch Belt and Clippen Belt	
45	carbonate flysch – calcareous sandstones and marls	sediments of Flysch Belt and Clippen Belt	
46	sandstone flysch – flysch with prevailing sandstones (or feldspar sandstones)	sediments of Flysch Belt and Clippen Belt	
47	conglomerate flysch – flysch with prevailing conglomerates	sediments of Flysch Belt and Clippen Belt	
48	sandstones (feldspar sandstones), variably with thin intercalations of claystones	sediments of Flysch Belt and Clippen Belt	
49	limestones, sandy limestones, marly limestones, quartzitic limestones, occasionally dolomites or silicites/radiolarites	sediments of Flysch Belt and Clippen Belt	
50	claystones, shales, marls	Jurassic and Cretaceous sediments of Inner West Carpathians	Mesozoic sediments
51	claystones/shales and sandstones (also flysch), variably also beds of sandy limestones, conglomerates, silicites	Jurassic and Cretaceous sediments of Inner West Carpathians	
52	conglomerates, sandstones and shales/marls, occasionally also limestones	Jurassic and Cretaceous sediments of Inner West Carpathians	
53	shales/marls and limestones, silicitic limestones, bulbed limestones, quartzitic/radiolaritic limestones	Jurassic and Cretaceous sediments of Inner West Carpathians	
54	limestones, marly limestones and/or quartzitic/silicitic limestones with intercalations of silicites and/or shales/marlstones	Jurassic and Cretaceous sediments of Inner West Carpathians	
55	limestones, marly limestones, crinoid limestones, bulbed limestones, quartzitic/silicitic limestones, eventually sandy limestones, calcareous sandstones/conglomerates	Jurassic and Cretaceous sediments of Inner West Carpathians	
56	cellulated dolomites, dolomitic breccias, rauwacks	tectonically reduced carbonate rocks	
57	metamorphic limestones, carbonates	metamorphic sediments triasu	
58	limestones, quartzitic limestones, bulbed limestones, limestones with cherts	sediments of Middle and Upper Triassic	
59	sandstones, shales, variably beds or intercalations of limestones, dolomites, evaporites, metatuffs, silicites	sediments of Middle and Upper Triassic	
60	limestones	sediments of Middle and Upper Triassic	
61	limestones and dolomitic limestones, dolomites	sediments of Middle and Upper Triassic	
62	dolomites	sediments of Middle and Upper Triassic	
63	dolomites with intercalations of shales	sediments of Middle and Upper Triassic	
64	sandstones, variegated shales, marly shales, marls, marly limestones, limestones	Lower Triassic sediments	
65	shales, sandy shales with intercalations of sandstones	Lower Triassic sediments	
66	quartzites, quartzitic sandstones, sandstones	Lower Triassic sediments	
67	unsorted shales/phyllites, sandstones, feldspar sandstones, conglomerates, sporadically also intercalations of volcanic rocks	Late Paleozoic sediments	Paleozoic rocks
68	shales/phyllites, sandy shales, variably with sporadic intercalations of sandstones, conglomerates, dolomites or volcanic rocks	Late Paleozoic sediments	
69	sandstones, feldspar sandstones, sandy shales, shales/phyllites, occasionally intercalations of dolomites, conglomerates, and phosphatic sediments	Late Paleozoic sediments	
70	sandstones, feldspar sandstones, variably with intercalations of shales/phyllites, conglomerates, volcanic rocks	Late Paleozoic sediments	
71	metamorphic dolomites, magnesites, siderites	metamorphic sediments of Late Paleozoic	
72	acidic volcanite rocks of Late Paleozoic	volcanites of Late Paleozoic	
73	basic volcanite rocks of Late Paleozoic	volcanites of Late Paleozoic	

No.	description	origin and classification	group
74	amphibolites, amphibolite gneisses, gabbrodiorites, metabasalts and basic metavolcanites	Lower Paleozoic metamorphic volcanites	Paleozoic rocks
75	metarhyolites, acidic metavolcanites	Lower Paleozoic metamorphic volcanites	
76	phyllites, variably with beds and intercalations of metamorphic sandstones and feldspar sandstones, occasionally also metacarbonates and metavolcanites	Lower Paleozoic metamorphic sediments	
77	acidic and intermediary igneous rocks (granitoids) – granites, granodiorites, tonalites, pegmatites and aplits	Crystalline magmatic rocks	Crystalline rocks
78	metamorphic rocks of medium to higher degree – mostly slates, slate gneisses, paragneisses, metaquartzites	Crystalline metamorphic rocks	
79	high degree metamorphic rocks – orthogneisses, migmatitic gneisses, migmatites	Crystalline metamorphic rocks	

Table 1: The list and characteristics of the individual evaluated pre-Quaternary aquifer types (Malík et al. *2007), as derived from the digital geological map of Slovakia, in a scale of 1:50 000 (Káčer* et al. *2005)*

No.	n	min(¹q)	max(¹q)	M(¹q)	Md(¹q)	G(T)
1	222	0.011749	34.674	0.204	0.214	4.20E-04
2	670	0.354813	66.069	0.178	0.186	3.00E-04
3	87	0.001660	2.399	0.117	0.135	2.61E-04
4	1364	15.488166	1000.000	0.363	0.372	5.99E-04
5	63	26.915348	831.764	0.138	0.151	1.65E-04
6	227	0.034674	7.943	0.135	0.162	2.13E-04
7	16	0.000015	2.570	0.646	0.447	9.39E-04
8	167	0.017783	25.704	0.331	0.372	6.75E-04
9	41	0.016982	4.786	0.087	0.191	9.99E-05
10	32	0.060256	120.226	0.123	0.148	1.88E-04
11	70	0.000832	2.754	0.105	0.117	3.12E-04
12	9	0.001349	31.623	0.891	0.661	2.37E-03
13	54	0.020893	66.069	0.427	0.468	8.15E-04
14	27	0.000550	3.890	0.240	0.427	3.18E-04
15	8	0.000014	3.162	1.259	1.585	1.97E-03
16	3	0.000010	0.158	0.036	0.019	4.91E-05
17	6	0.000490	2.884	0.087	0.039	1.76E-04
18	3	0.000051	2.291	0.282	0.209	1.16E-03
19	58	0.000437	6.026	0.102	0.089	1.36E-04
20	85	0.010965	12.589	0.166	0.178	2.86E-04
21	57	0.016218	23.988	0.174	0.174	3.32E-04
22	32	0.001479	2.138	0.089	0.095	1.37E-04
23	206	0.001585	95.499	0.229	0.170	3.99E-04
24	203	0.001288	8.913	0.331	0.339	6.30E-04
25	34	0.036308	3.631	0.178	0.145	3.52E-04
26	21	0.001148	19.953	0.575	0.912	1.00E-03
27	5	0.000005	0.132	0.046	0.039	8.11E-05
28	15	0.002188	6.026	0.138	0.123	1.81E-04
29	3	0.000015	0.066	0.023	0.043	3.27E-05
30	4	0.000019	0.447	0.105	0.107	3.00E-04
31	116	2.454709	165.959	0.054	0.068	1.15E-04
32	16	0.000087	1.514	0.126	0.141	3.44E-04
33	3	0.000003	0.288	0.151	0.120	1.40E-04
34	127	0.012882	10.000	0.107	0.117	1.73E-04
35	7	0.000048	0.054	0.010	0.012	9.60E-06
36	220	0.013804	12.589	0.102	0.102	1.49E-04

fissure permeability types – porous aquifers of Neogene are found only in the fourth position. The most permeable Neogene aquifer type (No. 13) is built by shallow sea sediments of conglomerates and breccias, occasionally limestones, claystones, sandstones (0.468 $L{\cdot}s^{-1}{\cdot}m^{-1}$; $8.15{\cdot}10^{-4}$ $m^2{\cdot}s^{-1}$; 54 pumping tests). Phyllites, variably with beds and intercalations of metamorphic sandstones and feldspar sandstones, occasionally also metacarbonates and metavolcanites (No. 76), metamorphic sediments of Lower Paleozoic are found on the opposite side of permeability scale (0.023 $L{\cdot}s^{-1}{\cdot}m^{-1}$; $4.26{\cdot}10^{-5}$ $m^2{\cdot}s^{-1}$; 52 pumping tests).

The process of delineation of the leading lithological feature in the discussed aquifer types that would serve as the dominant aquifer lithological characteristic is difficult and not yet complete. The process is complex, as geologic description of lithological types does not necessarily reflect the quantitative representation of granulometric characteristics, required for better delineation of prevailingly psefitic, psamitic or pelitic types of aquifers. Keeping this in mind, 79 previously evaluated aquifer types are merged according to their stratigraphy (Neogene sediments/volcanic Neogene rocks/Paleogene sediments/Mesozoic sediments/Paleozoic rocks/Crystalline rocks; ***Figs. 2 and 3***) and treated in six basic groups. Still, such a division enabled us to find some similarities in the hydraulic behaviour of different aquifer groups, as well as to find some differences between them.

The comparison of the resulting mean regional values of the standard specific capacities for these aquifers/aquitards (***Figs. 2 and 3***) shows lognormality of their statistical distribution as well as a relatively narrow range of mean values of individual datasets: nearly 95% of all mean values of these individual datasets were found in the interval of 0.03 to 1.0 $L \cdot s^{-1} \cdot m^{-1}$. According to this, mean transmissivity values of pre-Quaternary rocks are also distributed in a relatively narrow interval of one and a half orders of magnitude ($3.0 \cdot 10^{-5}$ to $1.0 \cdot 10^{-4}$ $m^2 \cdot s^{-1}$). An interesting feature was also found when comparing individual basic aquifer types groups (Neogene sediments, volcanic Neogene, Paleogene sediments, Mesozoic sediments, Crystalline and Paleozoic rocks) with ≥ 30 evaluated boreholes and wells. It was found that there is no major difference between Paleogene sediments, Neogene sediments, and volcanic Neogene aquifers (${}^1q$ in the range of 0.03 to 0.47 $L \cdot s^{-1} \cdot m^{-1}$; T from $4.2 \cdot 10^{-5}$ to $8.2 \cdot 10^{-4}$ $m^2 \cdot s^{-1}$). Mesozoic aquifers show slightly increased values (0.06 to 3.24 $L \cdot s^{-1} \cdot m^{-1}$; $1.1 \cdot 10^{-4}$ to $3.5 \cdot 10^{-3}$ $m^2 \cdot s^{-1}$, possibly due to karstification processes of some Triassic carbonates), and Crystalline and Paleozoic display slightly decreased values (0.02 to 0.04 $L \cdot s^{-1} \cdot m^{-1}$; $4.3 \cdot 10^{-5}$ to $6.3 \cdot 10^{-5}$ $m^2 \cdot s^{-1}$) for both standard specific capacity and interpreted transmissivity. An interesting feature was observed: with the growing population of evaluated boreholes, the mean regional values of all various pre-Quaternary rock types are asymptotically approaching a relatively narrow interval of mean transmissivity values, between $3 \cdot 10^{-5}$ – $1 \cdot 10^{-3}$ $m^2 \cdot s^{-1}$, as demonstrated in ***Fig. 3***.

Acknowledgements

The database of wells and hydrogeological boreholes was processed under the scope of the project "Research on groundwater vulnerability for sustainable management of groundwater use in the Bratislava self-governing region (BSK)" (ITMS code 26240220059), supported by the European Regional Development Fund and the Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic for the EU structural funds (ASFEU). The enormous effort in appropriate processing, sorting and evaluating data on 22,922 hydrogeological boreholes was made by Peter Bajtoš, Stanislav Olekšák, Soňa Cicmanová, František Bottlik, Erika Kováčová, Katarína Benková, Daniel Marcin, Juraj Michalko, Silvia Vojtková, Jana Miklasová-Macháčková, Ľubica Baranovičová, Mariana Sopková, Anna Tlučáková, Adriana Kamenická, Natália Bahnová-Kadlečíková, Alexandra Pažická, Katarína Tóthová and Miloš Gregor. The positive attitude of the aforementioned ERDF and the Agency, as well as all database builders, towards a thorough approach is gratefully acknowledged.

No.	n	min(¹q)	max(¹q)	M(¹q)	Md(¹q)	G(T)
37	13	0.000155	3.090	0.120	0.100	1.21E-04
38	4	0.000020	0.631	0.158	0.178	3.94E-04
39	120	0.004677	2.818	0.123	0.145	2.02E-04
40	17	0.001000	2.570	0.068	0.078	7.70E-05
41	60	0.054954	39.811	0.251	0.209	3.58E-04
42	39	0.006607	5.495	0.040	0.027	4.31E-05
43	86	1.288250	512.861	0.074	0.069	1.01E-04
44	65	0.013183	3.311	0.049	0.050	6.03E-05
45	52	0.001230	1.820	0.040	0.029	4.20E-05
46	296	0.091201	33.884	0.178	0.204	2.22E-04
47	3	0.000004	0.162	0.085	0.098	3.65E-04
48	4	0.000009	0.079	0.025	0.023	2.14E-05
49	13	0.000257	1.148	0.093	0.089	1.16E-04
50	3	0.000030	0.912	0.117	0.060	1.40E-04
51	21	0.000537	1.349	0.063	0.051	9.44E-05
52	12	0.000776	1.349	0.095	0.148	1.36E-04
53	16	0.013183	67.608	0.437	0.631	6.88E-04
54	55	0.602560	35.481	0.245	0.417	3.56E-04
55	30	0.053703	67.608	0.309	0.490	5.24E-04
56	6	0.000024	1.514	0.309	0.372	5.53E-04
57	5	0.000042	8.318	0.603	0.331	9.32E-04
58	34	0.002344	22.387	1.622	3.236	3.52E-03
59	20	0.000676	9.120	0.234	0.182	3.41E-04
60	238	4.466836	371.535	0.339	0.407	6.19E-04
61	3	0.000007	51.286	24.547	40.738	4.64E-02
62	438	0.057544	97.724	0.575	0.589	1.04E-03
63	23	0.000513	10.471	0.724	0.676	1.43E-03
64	39	0.000724	2.884	0.071	0.065	1.06E-04
65	19	0.002570	14.791	0.191	0.151	2.83E-04
66	36	0.002089	12.589	0.120	0.126	1.76E-04
67	20	0.000229	0.490	0.030	0.032	2.92E-05
68	6	0.001738	7.943	0.076	0.019	7.54E-05
69	14	0.000309	0.537	0.045	0.074	6.77E-05
70	7	0.000550	4.467	0.129	0.145	1.78E-04
71	4	0.000052	14.791	2.089	2.089	6.20E-03
72	5	0.001230	1.230	0.120	0.229	1.40E-04
73	3	0.000008	0.129	0.039	0.027	1.64E-04
74	5	0.000044	0.041	0.007	0.016	3.59E-06
75	8	0.000269	1.622	0.062	0.050	1.04E-04
76	52	0.015136	10.233	0.026	0.023	4.26E-05
77	95	0.007943	8.128	0.043	0.038	6.39E-05
78	18	0.000219	0.331	0.028	0.027	3.45E-05
79	11	0.001778	0.692	0.017	0.014	1.07E-05

Explanation of abbreviations: **n** *– number of interpreted hydraulic tests on hydrogeological boreholes and wells;* **min(¹q)** *– minimal value of the standard specific capacity* **¹q; max(¹q)** *– maximum value of the standard specific capacity* **¹q; M(¹q)** *– arithmetical average of the standard specific capacity* **¹q; Md(¹q)** *– median value of the standard specific capacity* **¹q; G(T)** *– geometrical mean of the transmissivity coefficient* **T**

Table 2: Basic statistical characteristics of the standard specific capacities **¹q** *(and derived values of the transmissivity coefficient* **T***) calculated for individual pre-Quaternary aquifers on the Slovak territory. The aquifer types are marked by the same numbers that correspond to their description in* **Table 1**.

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Integration of groundwater protection for human consumption in land use planning

C. Martínez-Navarrete, A. Jiménez-Madrid, S. Castaño, J.A. Luque and F. Carrasco*

The protection of water is one of the high-priority environmental objectives in the European policies. To protect drinking water it is very convenient to use a methodology that takes into account the risk of contamination. The need for planning tools is essential. To achieve this objective it is necessary to validate a management tool that integrates the protection of groundwater into planning, considering the economic assessment of different management scenarios. Preliminary results obtained in the intercommunity river basins of Spain indicate four possible zones in groundwater bodies. The zones to be established will be defined in different phases with an increasing degree of complexity. The results will be evaluated by a panel of experts.

La protection de l'eau est l'un des objectifs prioritaires de l'environnement dans les politiques européennes. En Espagne, pour protéger l'eau utilisée pour la consommation humaine est très pratique d'utiliser une méthodologie qui prend en compte le risque de contamination. Le besoin d'outils de planification est essentielle. Pour atteindre cet objectif, il est nécessaire de valider un outil de gestion qui intègre la protection des eaux souterraines dans la planification, compte tenu de l'évaluation économique des différents scénarios de gestion. Les résultats préliminaires obtenus dans les bassins hydrographiques intercommunautaires de l'Espagne envisagent quatre zones possibles dans les eaux souterraines. Celles-ci seront définies dans les différentes phases avec un degré croissant de complexité et les résultats seront évalués par un panel d'experts.

La protección del agua es uno de los objetivos ambientales prioritarios en las políticas europeas. En España, para proteger el agua empleada para consumo humano es muy conveniente utilizar una metodología que tenga en cuenta el riesgo de contaminación. La necesidad de herramientas de planificación es esencial. Para lograr este objetivo es necesario validar una herramienta de gestión que integre la protección del agua subterránea en la planificación, teniendo en cuenta la valoración económica de los diferentes escenarios de gestión. Los resultados preliminares obtenidos en las cuencas intercomunitarias de los ríos de España contemplan cuatro zonas posibles en las masas de agua subterránea. Éstas se definirán en diferentes fases con un grado creciente de complejidad y los resultados serán evaluados por un panel de expertos.

The protection of water is a priority environmental objective developed through the Water Framework Directive (WFD), Directive 2000/60/EC of the European Parliament and of the Council (European Union, 2000), and Directive 2006/118/EC of the European Parliament and of the Council (European Union, 2006), regarding the protection of groundwater against pollution and deterioration.

This legislation emphasises the importance of groundwater as a source of water supply to the population and the necessity for protecting this resource. This motivated its analysis within Working Group C, created in 2003 to facilitate the implementation of the WFD, which elaborated a guidance document (European Commission, 2007).

The need to make socioeconomic activities compatible with the safeguarding of groundwater quality and quantity has historically been addressed through land use planning. To achieve this, vulnerability cartography and wellhead protection areas have been established (Martínez-Navarrete *et al.*, 2009).

* Geological Survey of Spain (IGME), c.martinez@igme.es

Environmental Problem

In Article 6, the WFD requires that all water bodies used for the abstraction of water intended for human consumption be included in a register of protected areas, constituting the so-called Drinking Water Protected Areas (DWPAs). Because of these stringent requirements, in many states the majority of groundwater bodies must be considered under such protection, thus covering a large part of their territory.

It is important to mention that, although protected areas for drinking water must extend to the entire groundwater body in which they are located, this does not imply that measures to achieve the objectives of Article 7.2 must be applied to the full extent of the DWPAs. The requirements of Directive 98/83/EC for drinking water must be met at the point where the water is supplied to the consumer.

In some European countries, like Germany, the effective implementation of wellhead protection zones facilitates the protection of water for human consumption. In others, such as France, the protection provided by the wellhead protection zones is complemented with studies based on the evaluation of the risk of contamination.

Article 7.3 of the WFD requires that states ensure the necessary protection of DWPAs "in order to prevent deterioration of their quality to reduce the level of purification treatment required for the production of drinking water." To this end, states should take measures to protect water quality so that at the point of extraction, prior to purification treatments, no significant deterioration in water quality is produced that would require increasing the treatment. Each parameter deemed to be at risk should be individually controlled.

In practice, it is neither possible nor appropriate to apply the restrictive measures needed to accomplish their requirements in all the DWPAs in the same intensity. In order to overcome this, we consider the possibility of using "safeguard zones" where restrictions and control measures will be focused. The size of safeguard zones can be variable. There may be several in the same groundwater body or extending out from it, as may occur with karst media. It would also be necessary to conduct monitoring in these zones to demonstrate that there is a sustainable trend towards improvement over time.

The Spanish experience

Southern Europe is climatically characterised as a semi-arid region where wet periods and severe droughts occur cyclically. Therefore, the sustainable use of groundwater for human consumption is critical. In Spain, the percentage of groundwater that is used as the main source of water supply varies between 19% in settlements greater than 20,000 inhabitants and 70% in those with less than 20,000 inhabitants. To protect the drinking water supplied from the large number of groundwater bodies in Spain, a useful methodology should take into account the risk of contamination to identify areas that need particular safeguards.

The legal framework regarding the protection of groundwater in Spain is given in ***Table 1***, beginning from the most recent legislation.

In order to define safeguard zones in all groundwater bodies used for human consumption, a collaborative project has been carried out in Spain between the Ministry of the Environment and Rural and Marine Affairs and the Geologic Survey of Spain. Preliminary results are classified into four possible zones in groundwater bodies (***Fig. 1***): A) safeguard zone with heavy restrictions; B) safeguard zone of future prevention; C) safeguard zone not established (zone without restrictions); D) safeguard zone with moderate restrictions. The zones to be established are to be defined in different phases with an increasing degree of complexity and precision in the work required (***Fig. 1***).

In the first phase each groundwater body used for human consumption will be analysed in its whole extension, to identify which of the four proposed zones (A, B, C, D) can be distinguished according to the analysis of vulnerability pressures.

For the vulnerability analysis of groundwater bodies the COP method (Vías *et al.*, 2006) has been used for carbonate aquifers and the simplified DRASTIC index for intergranular porosity aquifers (DGOHCA and IGME, 2002; DGOHCA and CEDEX, 2002). The obtained vulnerability classes were sorted into two groups (***Table 2***). Existing pressures in each groundwater body were also evaluated. Finally, using GIS tools, the joint analysis of both factors was carried out by adding the scores given to the vulnerability and pressures and thus cataloguing the entire extension of the groundwater body as A, B, C or D.

Legislation	*Article number*	*Subject under legislation*
Law 11/2012 on urgent environment measures	*Article 1*	*Protected areas. Delimitation and linking to developing planning tools as well as the granting of licenses.*
Royal Decree (RD) 1514/2009 regulates the protection of groundwater against pollution and deterioration	*Article 4 and Annex III.C*	*Groundwater Chemical Status assessment in DWPAs.*
Order ARM/2656/2008 approves the hydrologic planning instruction	*Article 4*	*Protected areas.*
	Article 4.1.d	*Composition and extension of the groundwater abstraction protected area.*
	Article 4.2	*Future zones of abstraction for water supply.*
	Article 4.8	*Inclusion of wellhead protection areas for mineral and thermal waters in protected areas.*
	Article 6.1.4	*Environmental objectives for the protected areas.*
	Article 8	*Programme of measures of the competent authorities and their integration.*
Royal Decree (RD) 907/2007 approves the Hydrologic Planning Regulation	*Article 4*	*Content of the River Basin Management Plans with respect to protected areas.*
	Article 24	*What must be included in the register of protected areas.*
	Article 35	*Environmental objectives for protected areas.*
	Article 57	*Inclusion of wellhead protection areas of Articles 97 and 56 adapted from the Water Law text in the Hydrologic Plan.*
Law 62/2003 modifies the Water Law text and incorporates Directive 2000/60/EC (Article 129)	*Article 42*	*Content of River Basin Management Plans with respect to protected areas.*
	Article 99 bis	*Register of protected areas and groundwater protection.*
Royal Decree (RD) 1/2001 approves the unified text of the Water Law.	*Article 56.3*	*Wellhead protection areas of the aquifer, regulation of activities to protect against contamination risks.*
	Article 97	*Regulation of the prohibited polluting activities in the wellhead protection areas.*
Directive 2000/60/EC	*Article 4*	*Protected areas: environmental objectives, extensions and less stringent objectives.*
	Article 6	*Register of protected areas.*
	Article 7	*Avoiding deterioration in the quality of bodies of water to reduce the level of purification treatment. Possibility to establish "safeguard zones".*
	Article 11.3	*Programme of measures for safeguarding water quality.*
	Annex IV.1	*Register of protected areas.*
Royal Decree (RD) 849/1986 approves the Hydraulic Public Domain Regulation	*Article 173*	*Wellhead protection areas of drinking water abstraction points (quantity and quality).*

Table 1: Synthesis of the main provisions in the Spanish legislation for the protection of groundwater.

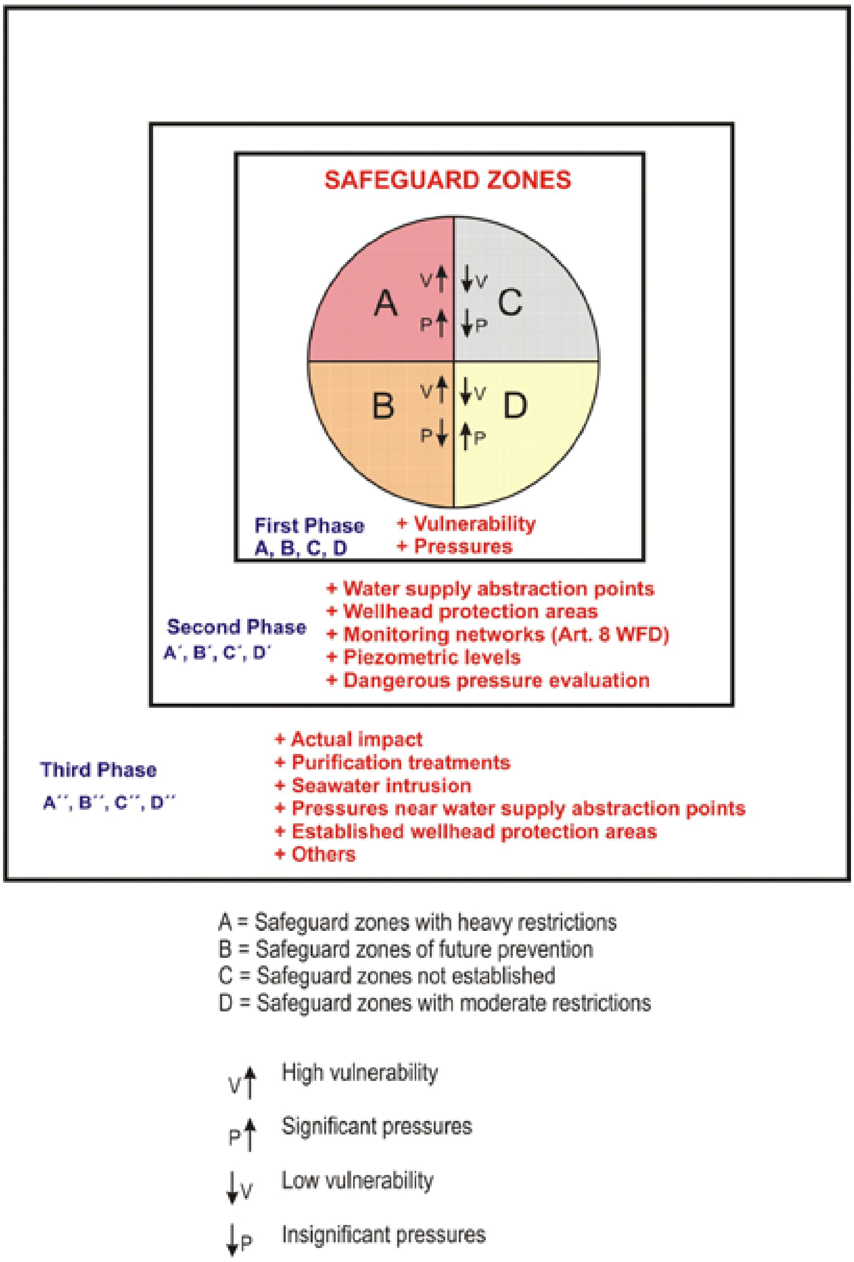

Figure 1: Safeguard zones in groundwater bodies used for the abstraction of water intended for human consumption, and phases in their assessment.

In the Second Phase (see ***Fig. 1***) the zoning established in the previous phase will be modified according to the following factors: drinking water abstraction points; wellhead protection areas; monitoring of the network established to check compliance with Article 7.3; groundwater body piezometric levels and dangerous pressure evaluation.

The analysis of these criteria may modify the zones previously defined, increasing or reducing their size or even changing their previous classification, obtaining new A´, B´, C´, D´ zones. The work for the first and second phases has already been completed, defining zones A and D of the proposed methodology and integrating zones B and C into the same zone (the other part of the groundwater body).

The first results obtained in the intercommunity river basins of Spain (***Fig. 2*** and ***Table 3***) indicate that type A safeguard zones occupy 5% of the surface in all the basins except in the Guadalquivir and Segura basins, where they extend over more than 10% of the territory.

In the third phase the zoning established in the previous phase will be modified, if needed, in accordance with the following factors: analysis of current impact on drinking water quality; purification treatments; groundwater bodies with marine intrusion; evaluation of pressures near the abstraction points from detailed field studies and methodologies for defining wellhead protection areas.

While performing the official study, the necessity for modifying the applied methodology was recognised. Some research (e.g., Jiménez-Madrid *et al.*, 2012) has included additional activities (***Fig. 3***) that have been implemented in pilot areas. Such activities include identifying zones of contribution (ZOC) of abstraction points.

To complete the safeguard zoning process, the established protected areas should be integrated into the relevant policies affecting the territory. To do this, the

VULNERABILITY (V)		*PRESSURES (P)*	
Group	*Score*	*Group*	*Score*
COP: Range between 0-1 = HIGH	*2*	*Existence of pressures in the scope of the groundwater body*	*4*
COP: Range between 1-15 = LOW	*1*		
DRASTIC network: Range between 72-156 = HIGH	*2*	*Non-existence of pressures in the scope of the groundwater body*	*2*
DRASTIC network: Range between 16-72 = LOW	*1*		
- Zone A (V + P = 6): High vulnerability and significant pressures. Heavy restrictions *- Zone D (V + P = 5): Low vulnerability and significant pressures. Moderate restrictions* *- Zone B (V + P = 4): High vulnerability and insignificant pressures. Future restrictions* *- Zone C (V + P = 3): Low vulnerability and insignificant pressures. Without restrictions*			

Table 2: Criteria for the first phase in the definition of safeguard zones in Spain.

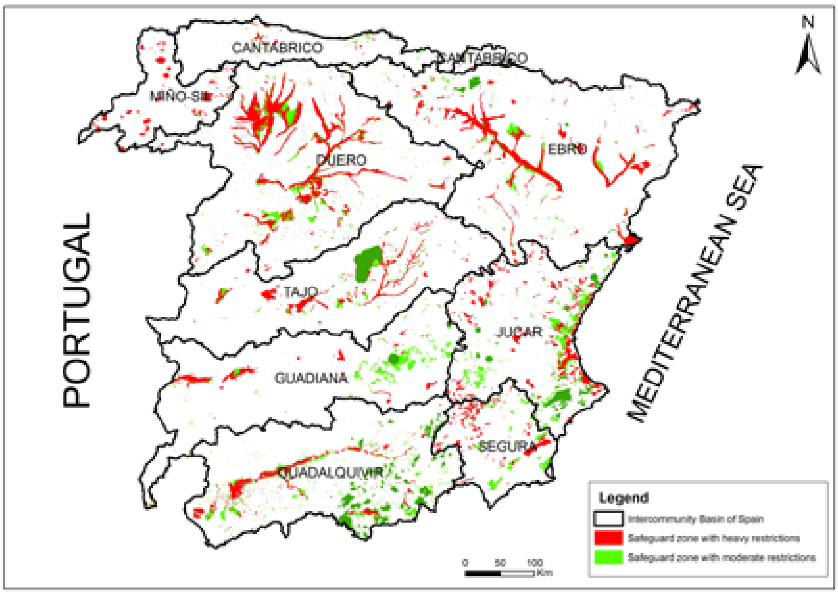

Figure 2: First results for intercommunity river basins of Spain.

RIVER BASIN	*% OCCUPATION*
DUERO	*5.75 %*
TAJO	*2.49 %*
MIÑO-SIL	*1.54 %*
SEGURA	*10.21 %*
JÚCAR	*5.21 %*
EBRO	*5.75 %*
GUADIANA	*2.49 %*
CANTÁBRICO	*1.54 %*
GUADALQUIVIR	*10.21 %*

Table 3: Percentage of occupation of the territory of the safeguard zone type A in Spanish intercommunity river basins.

establishment of the different safeguard zones has to be accompanied by a list of recommendations and restrictions to allow for adequate land use planning. For this measure to be effectively implemented, the development of cartography illustrating the permitted activities is also required.

Integration of safeguard zones in land use planning

The river basin management plans will include the register of protected areas, identify their specific objectives and coordinate and integrate the programme of basic and supplementary measures elaborated by the different authorities with competencies in water protection.

The Committee of Competent Authorities has been created in the intercommunity river basins in order to guarantee cooperation in the application of the different water protection measures, and does not affect the ownership of competences that correspond to the different public administration bodies. It consists of representatives of the river basin authorities, ministries, autonomous communities and local authorities within the river basin district. It is responsible for ensuring that each competent authority supplies the information needed for the elaboration of the river basin management plan.

The programme of measures will be the result of a participatory process of analysis of the different alternatives for meeting the objectives foreseen during the planning process. The river basin authority will have to monitor the effects on water bodies from the measures as a whole, with a view to guaranteeing their compatibility and finding the most suitable combination.

In the studies carried out in Spain, four types of safeguard zones with different protection levels are considered:

A. Heavy restrictions. Specific measures to reduce the source of contamination (chemical substances, microbiological and radiological contamination).
B. Future restrictions. Preventive measures.
C. Not safeguard zone – no restrictions. Codes of good agricultural practice applicable.
D. Moderate restrictions. Suitable preventive measures focused on the risks (pressures) identified.

The active cooperation among all actors involved is essential in the definition of the measures and restrictions that have to be taken. The implementation of the necessary measures involves the participation of autonomous communities and local authorities, but the general criteria and the objectives are set at a national level. To finish the process the administrations with competences in land use and city planning will have to take into account the definition and measures established for safeguard zones in the drawing up of the planning instruments, as well as in the granting of possible licences.

The need for planning tools is essential in countries such as Spain, where groundwater resources are scarce and should be shared

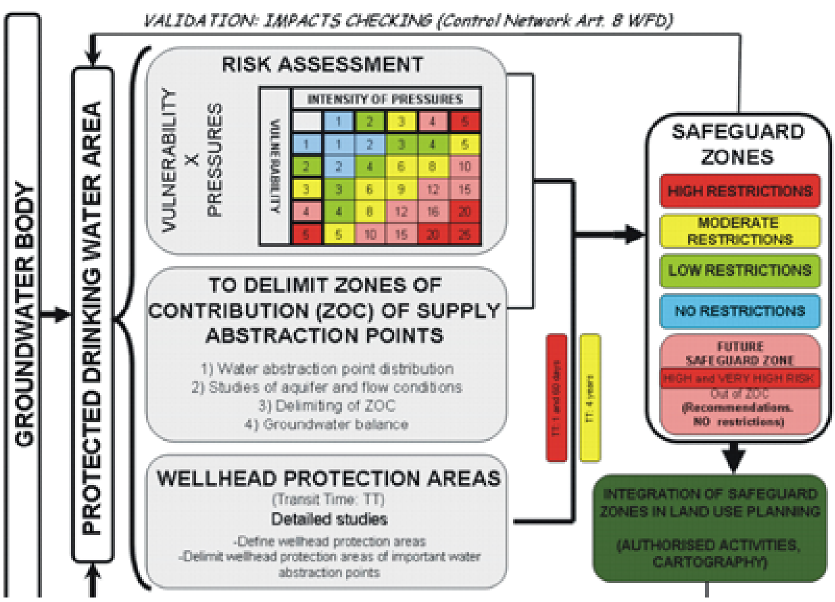

Figure 3: Methodological proposal to delineate safeguard zones, after Jiménez-Madrid et al.*, 2012.*

for different applications and where various administrative management bodies and users are involved. It is imperative, therefore, to achieve sustainable management of water resources that reconciles their protection for human consumption with other socio-economic activities.

To achieve this objective it is necessary to validate – in various media, with different pressures and socioeconomic circumstances – a management tool that integrates the protection of groundwater in the planning process, considering the economic assessment of different management scenarios.

The results of the application of this methodology require the validation of stakeholders, who are ultimately the parties affected by management decisions. The creation and simulation of "scenarios" are key to the implementation of this management tool. For this, the target objective is to be aware of the aquifer response to a situation or alternative (scenario) exploitation/use of groundwater, according to the existing conceptual model.

Initially it is considered necessary to examine the following aspect at the scale of groundwater bodies:

- analysis of the impact of different macroeconomic scenarios on the current status of the territory;
- modification of the situation and type of current pressures on the same economic framework;
- climate change impacts on extreme hydrological situations and land management;
- effect of changes in economic activities in groundwater bodies on ecosystems associated with groundwater;
- analysis of the uncertainty associated with numerical and non-numerical information obtained with geostatistical tools.

The results obtained by using the proposed tool for different scenarios will be evaluated by a panel of experts who value the need to consider other parameters or additional scenarios for the aims targeted. For this the role of organizations such as the European Federation of Geologists and other related associations is very important. The analysis of the results of different scenarios considered will enable us to define different criteria, parameters and thresholds for the optimal protection of groundwater bodies in an efficient manner and at the lowest cost, ensuring sustainable development.

The comparison of these criteria with the environmental legislation of the European Union and its transposition into national law will define the factors requiring redefinition or addition in future revisions of legislation. This meets the requirements of the Common Implementation Strategy of the European Environmental Directives.

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Characterisation of karst aquifers in Switzerland: the KARSYS approach

*Arnauld Malard and Pierre-Yves Jeannin**

Karst aquifers represent nearly 80% of Swiss groundwater reserves (nearly 120 km³) and at least 20% of groundwater resources. In spite of their significance, the location and quantification of these reserves have not been systematically documented. This is mainly due to the lack of a dedicated and pragmatic approach for characterising karst hydrogeological systems. As a documented overview of these aquifers does not exist, their management is far from being optimal and the study of related topics such as the protection of groundwater resources, the assessment of renewable energy or the prevention of natural hazards is not always satisfactory. To rectify this situation, the Swiss Institute for Speleology and Karst Studies (SISKA) has developed a pragmatic and systematic approach for the documentation of karst aquifers in the framework of the Swisskarst project. This approach is named KARSYS and thanks to additional supports from administrations and practitioners (federal offices, cantons, communities, companies, etc.) it is already being applied over large parts of the karst terrains in Switzerland. Such work will precisely characterise karst groundwater reserves and resources across the country. To complete such documentation, SISKA is developing appropriate modeling tools for karst hydrological systems. Information and results of the project are available at www.swisskarst.ch.

Les aquifères karstiques représentent 80% des réserves en eaux souterraines du territoire Suisse (environ 120 km³) et au moins 20% des ressources en eaux souterraines. Bien que les enjeux soient importants, ces réserves n'ont été que partiellement documentées à l'échelle du territoire. La raison principale étant qu'il manque à l'heure actuelle une approche systématique de caractérisation de ces systèmes hydrologiques. Ils souffrent d'un manque de connaissance qui rend difficile la gestion de ces eaux souterraines et l'étude des problématiques associées : protection de captage, évaluation des potentiels en énergie renouvelable (géothermie, hydroélectricité), prévention des risques naturels, etc.
Dans l'objectif de répondre à ces problématiques, l'Institut Suisse de Spéléologie et de Karstologie (ISSKA) a mis au point une approche systématique et pragmatique de documentation des aquifères karstiques dans le cadre du projet Swisskarst. Cette approche, appelée KARSYS, est appliquée sur une grande partie du territoire grâce au soutien complémentaire des administrations et du secteur privé (office fédéral, cantons, communes, compagnie, etc.). A terme le travail envisage de caractériser précisément les réserves en eau de ces aquifères et leurs ressources respectives. Afin de compléter cette documentation l'ISSKA développe, et teste en parallèle, des outils de simulation d'hydrogéologie karstique.
Davantage d'informations et de résultats sont disponibles en ligne à l'adresse www.swisskarst.ch.

Los acuíferos kársticos representan cerca del 80 % de las reservas de aguas subterráneas de Suiza (cerca de 120 km³) y, al menos, el 20 % de los recursos hídricos subterráneos. A pesar de su importancia, la localización y cuantificación de dichas reservas no han sido sistemáticamente documentadas debido principalmente a la falta de procedimientos pragmáticos y destinados a caracterizar los sistemas hidrogeológicos del karst. Como no existe una visión general documentada de estos acuíferos, su gestión está lejos de ser óptima y el estudio de aspectos relacionados, como la protección de los recursos hídricos subterráneos, el asesoramiento en energías renovables o la prevención de riesgos naturales, no es siempre satisfactoria. Para responder esta situación, el Instituto Suizo de la Espeleología y el Karst (ISSKA) ha desarrollado un método sistemático y pragmático para documentar los acuíferos kársticos en el marco del proyecto Swisskarst. El método, denominado KARSYS, ha sido aplicado en grandes partes de las áreas kársticas de Suiza gracias al apoyo adicional de administraciones y profesionales de la hidrogeología (gobierno federal, cantones, ayuntamientos, empresas, etc.). Así, el trabajo persigue caracterizar con precisión las reservas y recursos de aguas subterráneas en el conjunto del país. Para realizar dicha caracterización, el SISKA desarrolla herramientas adecuadas de modelización de los sistemas hidrogeológicos del karst.
La información y los resultados del proyecto están disponibles en la página web www.swisskarst.ch.

Karst aquifers: an unexpectedly significant groundwater reserve

Due to its high precipitation in an alpine context as well as the existence of numerous lakes, Switzerland is known as the water tower of Western Europe, feeding major rivers including the Rhine, the Rhône and the Danube. A recent synthesis from the Swiss Federal Office for the Environment (Sinreich *et al.*, 2012) estimated that national groundwater reserves are comparable to the amount of water storage in Swiss lakes (~150 km³). Karstified (or at least carbonate) formations represent the

* Swiss Institute for Speleology and Karst Studies (SISKA), CH-2301 La Chaux-de-Fonds, info@siska.ch

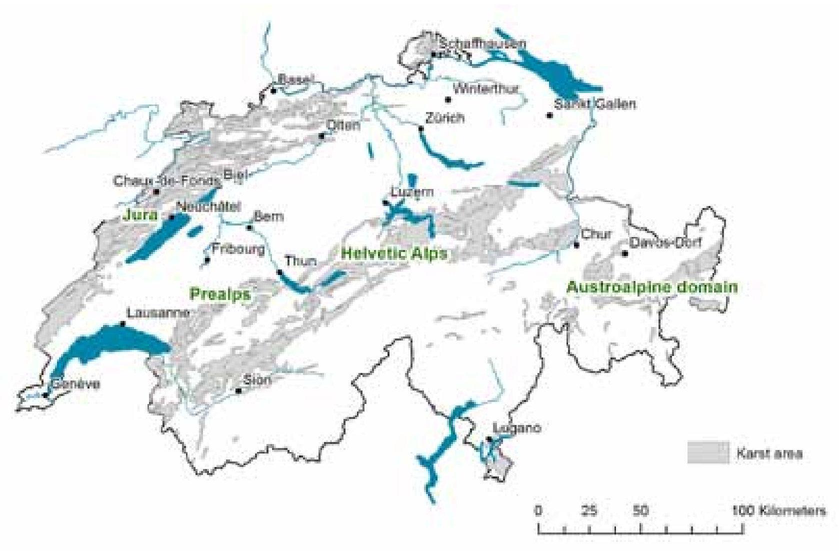

Figure 1: Distribution of karst areas in Switzerland.

most important aquifer type. Considering a depth until 1,000 m and assuming 2% of efficient rock porosity, it was established that karst groundwater represents nearly 120 km^3 or – in other words 80% – of Swiss groundwater reserves. Annual groundwater resources (recharge) were assessed at a minimum value of 3.8 km^3 per year, i.e., at least 20% of total groundwater recharge.

Karst outcrops cover nearly 20% of the Swiss territory (***Fig. 1***), mainly in the Jura, the Prealps and some parts of the Helvetic and Austroalpine domains. However, carbonate aquifers are present at depth, few dozen or few hundred meters below other sedimentary deposits in other parts of the Swiss territory (mainly the Swiss midlands). This means that karst aquifers extend over and could be exploited in much larger areas than indicated by the map in ***Fig. 1***. According to the Swiss Federal Office for Water and Geology, karst aquifers provide more than 18% of the drinking water, and several communities strictly depend on water extracted from these aquifers (Spreafico and Weingartner, 2005).

Swisskarst: a national project dedicated to karst aquifers

In the framework of the 61th National Research Program (*www.nrp61.ch*), which is supported by the Swiss National Science Foundation and dedicated to the sustainable management of water in Switzerland, SISKA offered to document all main karst aquifers by using (and improving) a pragmatic and systematic approach: KARSYS for KARst SYStem characterisation (Jeannin et al. 2012). Indeed, NRP61 requires that outputs and recommendations from research projects match engineering and applied issues. In addition, results must be intelligible to and accessible by administrators and practitioners – mainly water companies, energy providers and territorial managers that daily deal with karst environments and their resources.

The project – named "Swisskarst" – started in 2010 and has received further support from federal offices, cantons and communities. It turned out that the documentation resulting from the application of the KARSYS approach was very useful for a wide range of applications such as water supply, renewable energy or natural hazard assessment.

A pragmatic approach

By "pragmatic approach" we mean that the approach must be applicable with reasonable effort and that it must provide consistent results that are directly useful for the management of karst aquifers. Concerning the results, we considered that the approach should address the three following questions: (1) Where does the water emerging at a karst spring come from? (2) Which underground routes does it flow through? (3) What are the groundwater reserves and where are they located?

Although numerous and various approaches do exist to characterise karst aquifers and their functioning, it appears that none of them really address these three questions. Moreover, most existing approaches require long-term monitoring, borehole investigations or costly chemical analyses. Furthermore, as results they often provide unverified hypotheses and not a concrete answer to our three questions. Unlike other standard approaches dedicated to porous or fissured media, KARSYS is based on a geological structural approach. It combines a three-dimensional model of the aquifer geometry and simple fundamental principles of karst hydraulics. As it is systematic, this approach is built around four basic steps (cf. ***Fig. 2***):

Step 1: data collection and identification of the karstified formations (aquifer) and their boundaries (aquicludes);

Step 2: construction of a 3D model focused on the aquifer geometry;

Step 3: implementation of hydrological features and modelling of the groundwa-

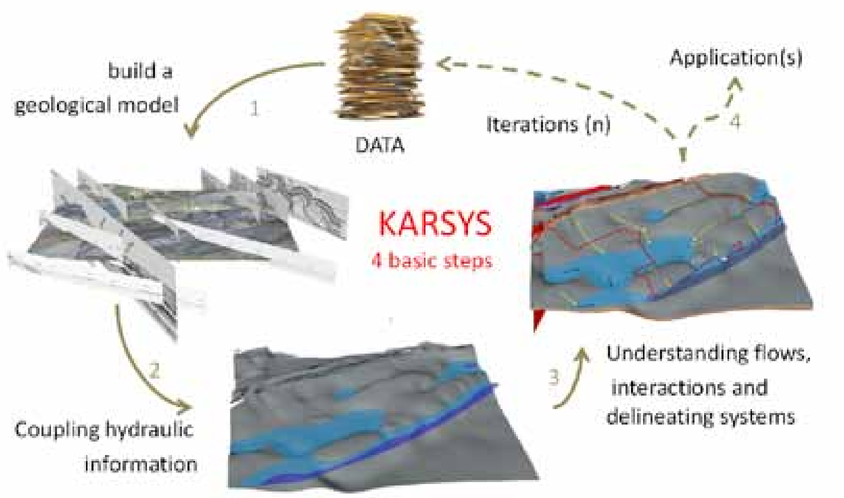

Figure 2: The four basic steps of the KARSYS approach. As the approach is iterative, the model may be made gradually more detailed until reaching the required precision at the desired scale.

ter table within the aquifer by assuming a low hydraulic gradient at low water stage. Unsaturated/saturated and confined/unconfined zones of the aquifer are then located;

Step 4: identification of the main drainage axes assuming the following principles: (i) a vertical flow through the unsaturated zone, (ii) a down-dip flow on top of the aquiclude, (iii) a pseudo-horizontal flow towards the spring(s) in the saturated zone. At that time the catchment area of the system can be delineated but final delineation depends on the system functioning at high water stage. Depending on applications, if the model does not provide the required precision, it may be made more accurate by new iterations.

KARSYS provides a concrete 3D image (conceptual model) of the studied karst aquifer and of the organisation of karst hydrological flow systems. The four steps can be iteratively repeated until the conceptual model reaches the desired reliability or precision (cf. ***Fig. 2***). Models can be validated by comparing all existing data, such as results of tracer experiments, hydrological budgets (minimum and average discharge rates of the springs), hydrographs, chemical or bacteriological measurements.

In a further step, the system's behaviour at the high water stage may be approached by implementing and interpreting data or features that are evidenced during high flow conditions (temporary springs, observation in caves, etc.). At that stage the water table may significantly rise and drainage axes may change, leading to water exchanges between adjacent systems and inducing a new delineation of the respective groundwater catchment areas.

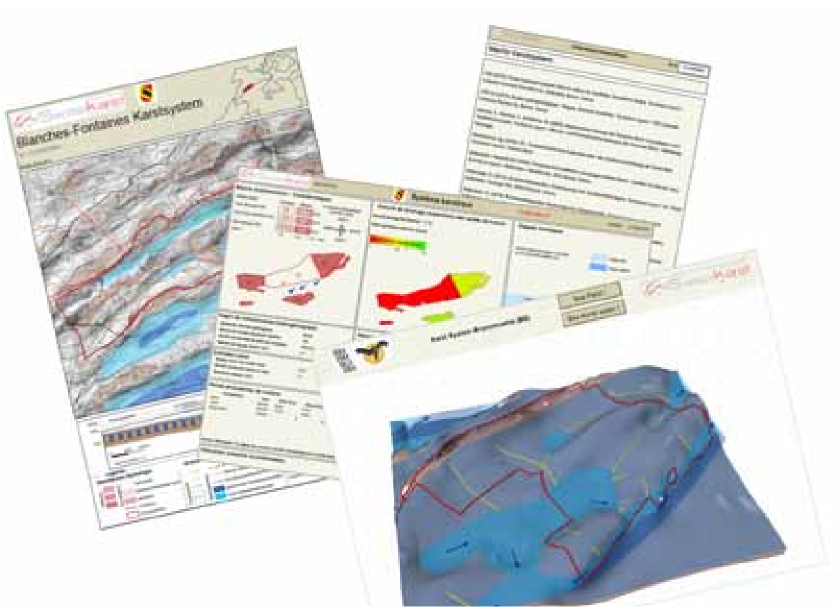

Figure 3: Standard outputs of the Swisskarst project: hydrogeological karst map, identity card, 3D pdf interactive model and a list of related literature (see also http://www.swisskarst.ch *> documentation > search by cantons or systems).*

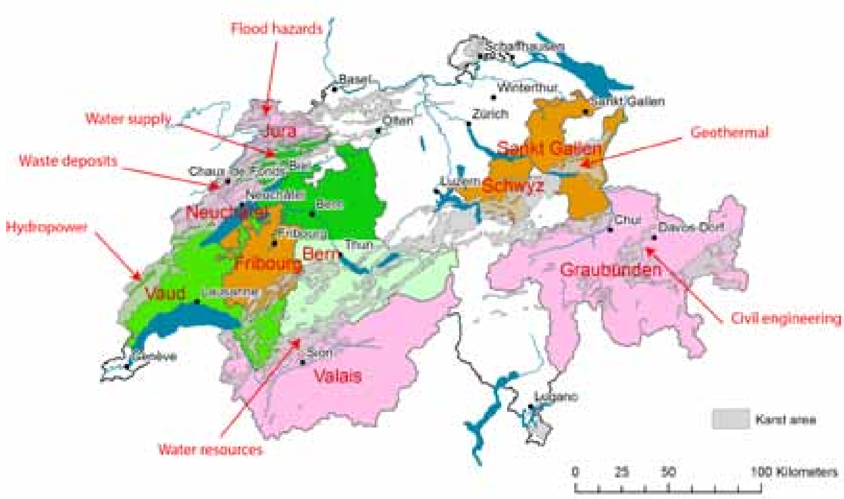

Figure 4: Progress of the Swisskarst project as of December 2012. Nine cantons are concerned with various interests: Valais and Bern for water supply, Jura for flood hazards, Vaud for hydropower assessment and Fribourg, Sankt Gallen, Schwyz, Neuchâtel, Graubünden for geothermal use, waste deposits and civil engineering.

A systematic and oriented documentation

Outputs of the NRP61 project are expected to be intelligible to the largest possible audience of practitioners. In this way maps and associated documents have been developed in a standardised and useful format for the documentation of karst hydrogeological systems (***Fig. 3***). They provide concrete information and comparable indicators. These "standard" documents are:

- A karst hydrogeological map, based on a standardised mapping process which displays the main characteristics of the system: permanent springs and temporary overflows, drainage axes, nature and extension of the groundwater table, catchment areas. Sub-catchments are distinguished according to areas feeding a single or several springs, and according to the nature of recharge processes: uncovered karst, semi-covered karst or non-karstic recharge areas;
- An "identity card" for each karst system which gathers its main characteristics: size of the catchment area, drainage density, lithological description of the aquifer, main springs (permanent and temporary) and their associated minimum, average and maximum discharges, etc.;
- An interactive and ready-to-use 3D model of the system which includes the same features as the map and offers predefined views focusing on particular aspects of the system. The model can be easily manipulated with a free pdf viewer and does not required expensive software or specialised equipment;
- A list of attachments (typically all types of literature: dissertation,

research report, journal article, geological or hydrogeological surveys, etc.) in relation to the system of interest. Materials, data and interpretation used for the establishment of the model are explicitly cited here.

As the KARSYS approach is systematic and iterative, most of these outputs are automatically processed and regularly updated with the integration of new data and/or the correction of previous ones. They provide a set of normalised and reproducible indicators which can be directly compared for all the documented systems. This supplies concrete values about karst water reserves and resources (groundwater content, system discharge rate, catchment specification, etc.). This also provides useful indications for the exploitation and management of karst groundwater, such as for geothermal or hydropower energy production or the prevention of natural hazards, or even for the assessment of civil engineering projects in karst environments.

A basis for a wide range of applications

The KARSYS approach has already been utilised for a large number of applications, according to various demands of water authorities and users. This contributes to the overall documentation of karst systems in Switzerland, and will hopefully lead to the complete coverage of the territory. ***Figure 4*** shows the coverage of the Swiss territory as of December 2012. The range of applications is presented below.

Assessing groundwater reserves and resources in karst media

Usually the objectives in this domain are: (i) the identification of major karst groundwater bodies, their volume, and their extension; and (ii) the identification of hydrological systems, i.e. the description of recharge areas feeding a group of springs. This includes the identification of diverging zones possibly feeding several groups of springs. This type of study was conducted in the Bernese Jura (= northern part of Bern canton) leading to the documentation of 17 major karst systems. Assessed karst groundwater reserves for this region reached 2.2 km^3 (Malard *et al.*, 2012). The catchment area of each system was delineated and compared to existing results of dye-tracer experiments for validation. A similar application is expected in Valais (VS) canton in 2013.

Assessment of hydropower energy potential of karst systems

Some karst systems offer a branching and vadose conduit network, and sometimes even a perched groundwater body. This may represent an interesting potential for electricity production with a significant discharge rate and elevation (Jeannin *et al.*, 2010). KARSYS was applied to 80 karst systems of Vaud (VD) canton (in total ~600 km^2 of karst terrain) and led to the selection of 39 promising sites. Based on KARSYS 3D models and according to various capture scenarios (perched spring, perched underground stream or perched phreatic groundwater body) the potential energy production was assessed for each site. The overall potential was estimated as up to 40 GWh/year. Seven sites were recognized as being of economic interest within the short/middle term. Two or three sites will probably be exploited in the near future. Fifteen other sites have been also recognized as manageable but would require more investigation, mainly because underground streams to be captured are only guessed at from KARSYS models; they have not been "speleologically" explored.

Evaluation of karst flood hazard

The recharge rate of karst systems is so high during storm events or snow-melt that headlosses in karst conduits become very significant during high water conditions and may produce water rising within the karst massif by tens or even hundreds of meters. Water may thus reach the land surface, inducing rare but intense overflow springs and flooding of lands. As karst systems are usually poorly documented, the prediction of such flood hazards remains difficult.

Application of the KARSYS approach (Vouillamoz *et al.*, 2013) for this purpose was conducted on the Beuchire-Creugenat karst system (Northern Jura Mountains), in a karst region which is sensitive to inundation. A 3D geological model depicting the aquifer basement was established and progressively enriched with hydraulic features (springs, overflow springs, estavelles, head measurements in caves, etc.). By following a series of simple principles of karst hydraulics it was possible to sketch the main (unknown) drainage axes in which water flows towards the permanent spring. The catchment area of the system was delineated and divided into sub-catchments, each presenting their own recharge characteristics. By using the available discharge data of the permanent spring and head measurements of an overflow spring, it was possible to determine thresholds in the functioning of the system and to assess the shape of the hydraulic gradient at the high water stage. Areas where water is likely to reach and flood the surface could thus be identified and mapped, considering various return periods (multiannual event, 30-year event, 300-year event). It was also possible to estimate maximum discharge rates of the potential outlets.

Supporting geothermal devices in karst

The dimensioning of geothermal heat pumps should be adjusted to the available heat and to their potential impact on the

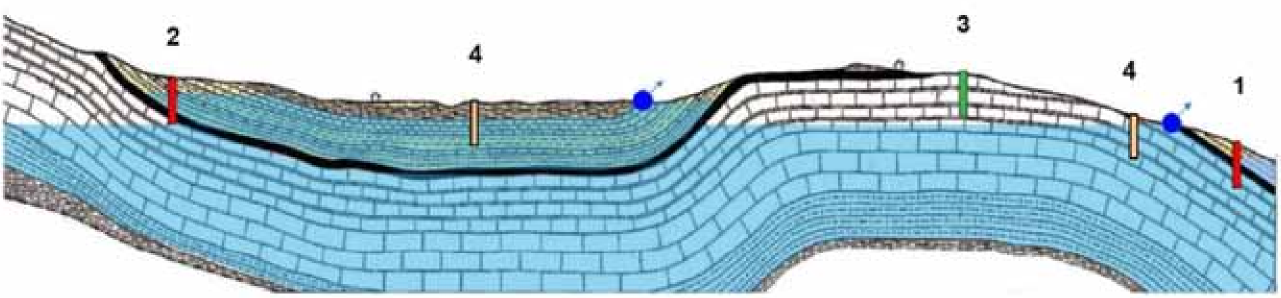

Figure 5: Various situations for geothermal heat pumps in a karst environment: Situations 1 and 2 are risky because they may produce connections between two aquifers. Situation 3 is not really problematic regarding impacts on groundwater, assuming that some basic rules are applied during drilling. Situation 4 should be assessed further.

aquifer. In many cantons of Switzerland such devices are forbidden in order to avoid any major impact on karst groundwater. However, this simple statement is problematic because on the one hand a geothermal heat pump may be very appropriate in some places, and on the other hand zones of karst, where probes are forbidden, cannot be easily delineated without a sufficient knowledge of karst systems. For instance Situations 1 or 2 in ***Fig. 5*** are located outside areas of outcropping karst and would possibly not be forbidden, although they are probably the least appropriate situations. Similarly, Situation 3 might be forbidden, although it does not directly impact the karst aquifer.

Several cantons have to face a large number of demands for geothermal heat pumps. In this context two of them: Saint-Gall (SG) and Fribourg (FR) decided to apply KARSYS in order to obtain an overview of karst aquifers and systems in their territories. KARSYS models will be then used for the formulation of practical recommendations or guidelines. This will probably also be expanded to other regions in the future.

Other applications based on KARSYS are still being developed. They concern the assessment of construction projects in karst (e.g. tunnels), as well as water pollution issues, or the management of waste deposits. In fact any activity in a karst region can benefit from a better knowledge and documentation of karst groundwater systems.

Conclusion

Since the Swisskarst project started, ongoing improvements have been made to the KARSYS approach following three main objectives:

i. to address the three standard questions in karst hydrogeology: Where does water come from? Through which flow routes? Where are the water storage zones?
ii. to develop a systematic, pragmatic, comparable and reproducible approach;
iii. to provide concrete and usable outputs.

The KARSYS documentation provides a standard and comparable support system which can be adapted to these various needs. Progress has been made in addressing the needs of practitioners concerned with water management, such as those dealing with water supply, renewable energies (hydroelectricity, geothermal probes), natural hazards and various types of construction. The standardisation of the generated indicators and information, as well as the automation of outputs from GIS tools, offers the opportunity to regularly update maps and identity cards of the concerned systems. KARSYS documentation is progressively extending over the Swiss territory and will probably cover the whole country within the next five years. An assessment of the expected evolution of the karst hydrological regime and water quality according to climate changes could thus be attempted. Collaborations abroad have also made it possible to apply this approach in Slovenia and Spain, showing the wide applicability of the approach.

Further information, progress reports and results are available at the *www.swisskarst.ch* website (optimized website with Firefox).

Acknowledgments

The development of KARSYS was made possible thanks to the support of the Swiss National Science Foundation and several water authorities (federal, cantons and communities); we wish to thank all of them.

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Global warming in the Alps: vulnerability and climatic dependency of alpine springs in Regione Valle d'Aosta (Italy) and Canton Valais (Switzerland)

Pierre Christe, Gianpiero Amanzio, Enrico Suozzi, Eline Mignot, Pascal Ornstein*

*Mountain springs of mid- to high altitudes are particularly sensitive to climatic variations, as documented by spatio-temporal discharge measurements. Recent models predict significant modifications of the hydrological regime for the Alps within the next 100 years. Anticipating global warming effects, Action 3 of Project STRADA –"Strategies for adaptation to climate change for the management of natural hazards in the border region – Operational Program under the European Territorial Cooperation border, Italy/Switzerland 2007/2013" (*www.progettostrada.net*) aims at better understanding short- and long-term mountain spring behaviour related to hydrogeological settings. Based on the interaction mechanisms between surface and groundwater, the physico-chemical parameters of springs are correlated with climatic events and used to determine general aquifer behavior. Particular attention is given to the role of snow melting in discharge basins. The resulting characterisation of monitored springs provides an objective solution to adequately surveying alpine hydrogeological systems. Furthermore, the approach supports the efforts of authorities in developing efficient strategies for sustainable groundwater resources management.*

*Les sources de montagne en moyenne et haute altitudes sont particulièrement vulnérables aux changements climatiques, comme l'indiquent les mesures spatio-temporelles de débit. Des modèles récents prévoient, pour les Alpes, des modifications significatives du régime hydrologique, pour les cent prochaines années. En prévision des effets liés au changement climatique global, l'Activité N° 3 du Projet " STRADA" – "Stratégies d'adaptation au changement climatique pour la gestion des risques naturels dans la région frontalière – Programme opérationnel de la Coopération Européenne Territoriale frontalière, Italie/Suisse 2007/2013" (*www.progettostrada.net*) -, a comme objectif une meilleure compréhension, à court et moyen termes, du comportement des sources de montagne au sein des contextes hydrogéologiques. Basés sur les mécanismes d'interaction entre les eaux de surface et souterraines, les paramètres physico-chimiques des sources sont corrélés avec les événements climatiques et utilisés pour déterminer le comportement général de l'aquifère. Le rôle de la fonte des neiges au niveau du bassin d'alimentation fait l'objet d'une attention particulière. Les résultats spécifiques propres au suivi des sources de montagne représentent une solution objective à l'étude appropriée des systèmes hydrogéologiques alpins. De plus, cette démarche soutient les efforts consentis par les autorités dans le cadre du développement de stratégies efficaces .pour la gestion durable des ressources en eau souterraine.*

*Los manantiales de montaña de altitudes medias o altas son especialmente sensibles a las variaciones climáticas tal y como demuestran las medidas de descarga espacio-temporales. Modelos recientes predicen modificaciones significativas del régimen hidrológico en los próximos 100 años en los Alpes. Para anticiparse a los efectos del calentamientos global, la Acción 3 del proyecto STRADA "Estrategias para la adaptación al cambio climático de la gestión de los riesgos geológicos en las regiones de frontera. Programa operacional en la frontera de Cooperación Territorial de Europa entre Italia y Suiza 2007/2013" (*www.progettostrada.net*), tiene como objetivo, entender mejor el comportamiento a corto y largo plazo de los manantiales en sus entornos hidrogeológicos. En base a los mecanismos de interacción entre las aguas superficiales y subterráneas, se correlacionan los parámetros hidroquímicos con los eventos climáticos y se emplean para determinar el comportamiento general del acuífero. Se pone especial atención en el papel de la fusión de la nieve en las cuencas de descarga. La caracterización resultante de los manantiales monitorizados, proporciona una solución objetiva para el estudio adecuado de los sistemas hidrogeológicos alpinos. Además este enfoque apoya los esfuerzos de las autoridades en el desarrollo de estrategias eficaces para la gestión sostenible de los recursos de aguas subterráneas.*

The Alps are considered the "water castle of Europe" and influence surface and groundwater patterns in neighbouring countries. The complex tectonic evolution of the Alps and the resulting rock structural relationships control the storage and flow capabilities of groundwater resources. The understanding of hydrogeological systems, based on both geological interpretation and hydrogeological evidence, is therefore a prerequisite to optimising future exploitation strategies.

One major issue for the 21st century is the management of the water resources on both local and regional scales. This research focusses on the possibility to accurately determine the degree of vulnerability and resistance against climatic changes of mountain springs used for drinking water distribution.

In addition to the quantitative monitoring of springs' regime, the difficulty of protecting groundwater quality in the long term is highlighted. With increasing land use and development, human activities can represent a threat to rational and sound practice in sustainable water resource management that has to be properly evaluated.

* Canton du Valais, Service de la Protection de l'environnement - SPE, Pierre.CHRISTE@admin.vs.ch

Figure 1: Map of the project area between Regione Valle d'Aosta, Italy, and Canton Valais, Switzerland. Five Swiss and eight Italian springs in various hydrogeological settings were investigated for the spatio-temporal analysis of spring behaviour in mountain areas. Monitored parameters are: discharge [l/s], temperature [°C], and electrical conductivity [µS/cm]. Detailed analysis in three catchment basins (one in Switzerland and two in Italy) has been conducted for studying the effect of snow cover on spring discharge.

Evidence of global warming

Models have been developed in recent years to predict global warming effects on water resources (see FOEN, 2012). Data are often incomplete and uncertainties affect most predictions. Nevertheless, direct observations permit us to confirm significant changes already. For example, glacial retreat is occurring nowadays in every major orogen, with the fastest rates observed in the Hindu Kush-Himalayan region (ICIMOD, 2011). In Switzerland, it is estimated that 60-80% of existing glaciers will be lost before the end of the 21st century (FOEN, 2012).

It is however uncertain how quickly such tendencies will impact on human activities in the near future. There is an evident need to address an analysis from an integrated point of view today and to base predictions on field observation data. In this context, monitoring of natural systems is particularly important in the development of adequate strategies and action plans. With robust indicators derived from direct evidence of water resources, the risk of making improper political decisions with respect to observed water use-conflicts is lowered.

Policy in Switzerland and Italy

In Switzerland, about 80% of all drinking water is supplied by groundwater. In Italy, this proportion is estimated to be 85%. Groundwater has accordingly to be considered a resource of public interest. In both countries, public authorities are by law responsible for ensuring adequate protection standards to maintain clean groundwater resources for future generations.

In Switzerland, the obligation to protect water from both a quantitative and qualitative perspective was introduced in the 1990s with federal policies for water protection (LEaux, 1991 & OEaux, 1998). To ensure resource protection, the compilation of water protection maps is a legal obligation to help regularise land-use practice according to different protection sectors, zones and areas. The cartographical delimitation of land organisation measures depends directly on the geological and morphological conditions. Although groundwater flow conditions are quite easily determined in relatively homogeneous settings (i.e. loose rock or low to medium fractured aquifers), it is more difficult to precisely determine groundwater behaviour in heterogeneous media such as highly fractured or karst aquifers. The increasing structural underground complexity is directly expressed by the size (e.g. land surface coverage) of protection sectors, zones and areas. Such considerations are particularly relevant for spring and catchment protection zones, as they result in severe land use regulation and private property restrictions.

In Italy Regulation n° 152/2006 art. 94, integrated into Regulation n° 5/2012, describes the spring protection areas delimitation for groundwater intended for human consumption. The regulation distinguishes three different protection areas defined to preserve water quality. Spring protection areas are subdivided into three zones (Civita, 2008):

1. Immediate protection zone (ZTA) that includes the immediate area surrounding the spring or its drains. This zone must be adequately protected and must be used only for catchment works.
2. Inner protection zone (ZR) that includes a portion of the area surrounding the immediate protection zone. Activities forbidden in this area are described in the Italian law.
3. Outer protection zone (ZP) that overlaps the whole alimentation area of the spring.

In the Aosta Valley, Italian law is applied and regulated by rules L.r. 11/98 and Delibera del Consiglio Regionale n. 792/XI del 28/07/1999. The boundary of the protection areas is carried out following the Civita method, according to the final degree of vulnerability evaluated for the springs (Civita, 2005).

In both countries, policies for groundwater protection and management have the potential to introduce conflict between land use practice and water protection needs in the alimentation basins of springs. Typically observed conflicts in Canton Valais and Regione Valle d'Aosta concern mountain agriculture, remote inhabited zones, infrastructure of hydroelectric production plants, and the development of ski resorts.

The development of adaptative ground-

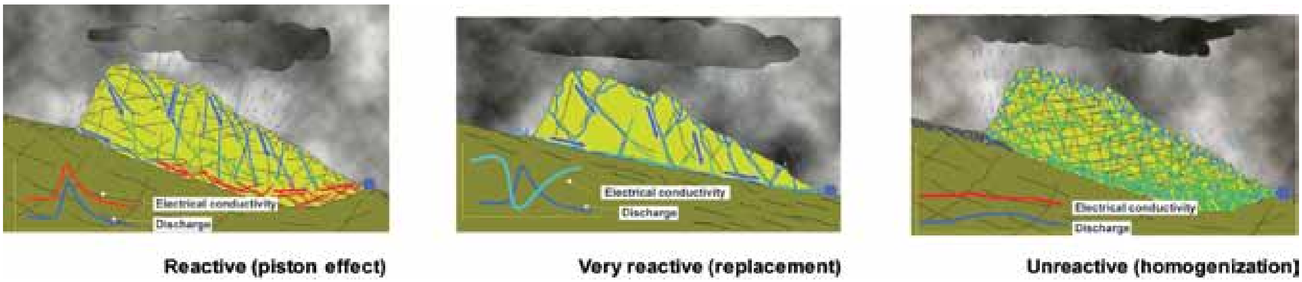

Figure 2: Generic models of aquifer behaviour, illustrating groundwater and spring reactivity to climatic events (adapted from Galleani et al. *2011). **A) Reactive:** spring discharge is a direct function of the climatic event, with a positive correlation between discharge and electrical conductivity (piston effect, e.g. medium risk of water pollution). **B) Very reactive:** Immediate spring reaction to the climatic event, producing an inverse relationship between discharge and electrical conductivity (replacement, e.g. high risk of water pollution). **C) Unreactive:** The spring discharge remains relatively insensitive to climatic events and the physico-chemical groundwater signature remains unaffected (homogenisation, e.g. low risk of water pollution).*

water protection strategies to climatic change and increasing land-use practices requires therefore an integrated understanding of hydrogeological systems and sustainable regulation possibilities on the administrative/political level.

Research and monitoring network

Project STRADA (*www.progettostrada.net*) is a research program consisting of six actions addressing the impact of climate change on territory planning and management. Action 3 focuses on mountain springs, based on EU-directive 2000/60/CE. It is conducted in partnership between the Regione Valle d'Aosta of Italy and Canton Valais in Switzerland, and it is subdivided into the two following sub-actions:

1. ACTION 3.1: Characterisation and temporal evolution of the snow cover in mountain areas in relation to its potential contribution to spring discharge (e.g. Snow Water Equivalent, Jonas et al. 2009).
2. ACTION 3.2: Characterisation of mountain springs in different hydrogeological settings based on physico-chemical observations and evidence from meteorological data stations.

Figure 1 shows the monitoring network that has been implemented in this regard since 2010 in the transborder territory between Italy (Regione Valle d'Aosta) and Switzerland (Canton Valais).

Direct and indirect acquisition methods for the meteorological, hydrogeological, geological and morphological observations

	PARAMETERS	ACQUISITION METHOD	DATA INTERPRETATION
HYDROGEOLOGICAL DATA (SPRINGS)	Discharge [l/s]	Automatic measurements (3 parameters-probes) with data transmission	Vulnerability methods (i.e. VESPA index, Galleani et al., 2011) & Cross correlation analysis (Fiorillo and Doglioni, 2010 ; Kresic and Stevanovic, 2010)
	Temperature [°C]		
	Electrical conductivity [µS/cm]		
	Bacteriology	Ponctual groundwater analysis (Laboratory)	
METEOROLOGICAL DATA	Snow	Automatic weather station with data transmission (STRADA)	SWE model (Jonas et al. 2009)
		Ground penetrating radar GPR in catchment basin	
		Ponctual manual measurements (avalanche probe)	
		Field measurements of snow and density	
	Relative humidity of air	Automatic weather station with data transmission (STRADA) + Swiss & Italian meteorological database	GEOtop model (ARPA, Valle d'Aosta)
	Solar radiation		
	Wind direction and speed		
	Rain		
	Air temperature		
GEOLOGICAL DATA	Lithology	Geological Atlas & Bibliography + Field observations + Geological investigations (geophysics)	Conceptual modelling
	Tectonics & Structures		
MORPHOLOGICAL DATA	Altitude	Swiss & Italian land-survey imagery	Geomorphometric analysis from DTM with GIS
	Slope		
	Drainage network		
	Concavity / convexity		
	Rugosity		
	Exposure		

Table 1: Direct and indirect acquisition methods used to conduct Actions 3.1 and 3.2 of Project STRADA. A compilation of hydrogeological, meteorological, geological and morphological data is performed to improve the understanding of mountain springs with regard to climatic changes.

SPRINGS		GEOLOGICAL SETTING	AQUIFER TYPE	REGIME	OBSERVATION PERIOD
CANTON VALAIS, SWITZERLAND	LA LÉ 1550 m.a.s.l.	Morenic + alluvial deposits	Porous / Heterogeneous	Snow melt	2008 - 2013
	LE BROCARD 620 m.a.s.l.	Bedrock : gneiss	Fissured	Snow melt	1981 - 2013
	LA VOUETTE 730 m.a.s.l.	Sandstone (Permo-Carbonifer)	Fissured	Snow melt	2010 - 2013
	LE PIERRIER DE VISSE 1605 m.a.s.l.	Limestone + Scree	Karst	Snow melt - Rainfall	2010 - 2013
	BRUNNENSTUBE 1 1460 m.a.s.l.	Bedrock : granite Quaternary deposit: morenic	Fissured / Porous	Snow melt - Rainfall	2011 - 2013
VALLE D'AOSTA, ITALY	ALPE PERROT 1280 m.a.s.l.	Bedrock: serpentinites – metabasalts Quaternary deposit: morenic - slope material	Porous	Snow melt - Rainfall	2010 – 2012
	CHESEROD BASSA 1100 m.a.s.l.	Bedrock: Calc-schist Quaternary deposit: morenic	Porous	Snow melt	2010 – 2012
	ENTREBIN 1000 m.a.s.l.	Bedrock: Calc-schist Quaternary deposit: morenic	Porous	Snow melt	2010 – 2012
	MASCOGNAZ1 1850 m.a.s.l.	Bedrock: metabasalts Quaternary deposit: morenic	Porous	Snow melt - Rainfall	2010 – 2012
	MASCOGNAZ2 1860 m.a.s.l.	Bedrock: metabasalts Quaternary deposit: morenic	Porous	Snow melt - Rainfall	2010 – 2012
	PIANET 1270 m.a.s.l.	Bedrock: Calc-schist – gneiss minuti	Porous	Snow melt - Rainfall	2010 – 2012
	PROMIOD 1650 m.a.s.l.	Bedrock: metabasalts Quaternary deposit: morenic	Porous	Snow melt - Rainfall	2010 – 2012
	VALMERIANA2 1700 m.a.s.l.	Bedrock: serpentinites – metabasalts Quaternary deposit: morenic - slope material	Porous	Snow melt - Rainfall	2010 – 2012

Table 2: Mountain springs studied within the framework of Action 3.2 of Project STRADA. See **Figure 1** *for geographical locations.*

have been implemented, as illustrated in ***Table 1***.

Based on the hydrogeological data, a physico-chemical characterisation of springs has been performed according to different approaches reflecting the Swiss and Italian experiences, strategies and policies. Spring vulnerability is accordingly estimated based on either a quantitative- or a qualitative-oriented perspective.

For quantitative aspects, the discharge reactivity of springs to climatic events in alimentation basins is considered. Generally, effects of particular climatic events are evaluated directly from hydrogrammes. For the Italian springs, a cross-correlation function has moreover been implemented to determine a time lag (in days) between rainfall (or snow melting) peaks and their effect on spring discharge (Fiorillo and Doglioni, 2010; Kresic and Stevanovic, 2010).

For qualitative aspects, the risk of spring water pollution is estimated either directly (field evidence and sample analysis) or indirectly, assuming three generic models of aquifer behaviors depicted in ***Figure 2***. An index for vulnerability (to pollution) can consequently be proposed following the VESPA method of Galleani *et al.* (2011).

Spring characterisation

Table 2 summarises the different Swiss and Italian mountain springs monitored during Action 3.2 of Project STRADA. For each spring, general indications about geology, aquifer structure and overall regime are given. Data acquisition is restricted to the duration of the project (2010-2013). When available, older chronicles have been taken into account and used for interpretation.

Springs in ***Table 2*** have been characterised in terms of their vulnerability, with a particular focus on the quantitative and qualitative perspectives described in the previous section. Results are presented in ***Table 3***.

Table 3 demonstrates that the quantitative and qualitative characterisation perspectives can be very consistent with each other. However, a lack of consistency is observed for several springs. This is particularly true for sensitive aquifers (heterogeneous or karst aquifers), probably due to the fact that the determination of the "quantitative vulnerability" is derived mostly from a relatively short observation period (≤ 3 years). Spring behaviour is accordingly either under- or over-estimated.

At this stage of the research, it has been shown that each characterisation method provides important information that is in some way complementary. From only monitoring of springs, however, the possibility to derive robust predictive models for the optimisation of spring protection and use is still incomplete and needs further development.

Comparison with climatic data

Between 2010 and 2013, a set of high-quality data was collected in the framework of Action 3.2 of the STRADA project and is currently used for:

1. developing monitoring techniques and strategies for mountain springs that are representative of various hydrogeological environments in order to achieve a better understanding of aquifers currently or potentially used for domestic needs.
2. adopting common and standardised criteria for the characterisation, survey and protection of groundwater resources in mountainous areas with regard to the structural and morphological complexity of mountain environments.
3. determining specific indices of vulnerability and resistance against climatic changes for springs that rely on an integrated cross-correlation analysis of parameters indicative of the spring hydrological regime and its mid- to long-term evolution.

Action 3.1 of Project STRADA allowed us to focus specifically on the mechanisms which regulate snow-water interaction. To derive short- and long-term management strategies for springs, it is now necessary to evaluate how the hydrogeological interpretation can be improved through a

	SPRING	AQUIFER BEHAVIOUR	VULNERABILITY OF SPRINGS: DISCHARGE REACTIVITY TO CLIMATIC EVENTS	VULNERABILITY OF SPRINGS: RISK OF SPRINGWATER CONTAMINATION	
		Estimated from field observations		Estimated from field observations and sample analysis	VESPA (vulnerability index V)
CANTON VALAIS (CH)	La Lé	Replacement and homogenisation			5.470
	Dilogne	Replacement			1.780
	Baltschieder	Replacement			5.140
	Brocard	Homogenisation			0.016
	Vouette	Homogenisation and replacement			0.002
			Cross correlation analysis Rainfall - Discharge (time lag in days)	Estimated from field observations	VESPA (vulnerability index V)
VALLE D'AOSTA (I)	Alpe Perrot	Homogenisation	0		0.032
	Cheserod bassa	Piston effect - homogenisation	>100		0.009
	Entrebin	Replacement	28		3.030
	Mascognaz1	Replacement	0		1.650
	Mascognaz2	Undefined	0		-
	Pianet	Replacement	1		12.060
	Promiod	Piston effect	5		1.390
	Valmeriana2	Replacement	0		0.260

DISCHARGE REACTIVITY TO CLIMATIC EVENTS		RISK OF SPRINGWATER CONTAMINATION			
	Field observations			VESPA (vulnerability index V)	
Very high	$T < 1$	Very high	Karst	Very high	$V > 10$
High	$1 < T \leq 10$	High	Very heterogeneous fissure aquifers	High	$1 < V \leq 10$
Medium	$10 < T \leq 50$	Medium	Low thickness of unsatured zone with medium permeability	Medium	$0.1 < V \leq 1$
Low	$T > 50$	Low	Important thickness of unsatured zone with low permeability	Low	$V \leq 0.1$

Table 3: Mountain spring characterisation results obtained during Action 3.2 of Project STRADA. Aquifer behaviour correspond to the models of **Figure 2**. *To optimise in practice effective spring protection measures, vulnerability is evaluated according to a quantitative (reaction to climatic events) or qualitative (contamination by meteoric water) perspective. The vulnerability (to pollution) index V is calculated following the VESPA method of Galleani* et al. *(2011).*

process-oriented integration of meteorological and geological/morphological data, as performed for the snow modelling. In this sense, the following approaches are considered:

1. Analysis of seasonal water inputs, such as the onset of the snow melting process in spring alimentation basins. For example, springs showing a maximum annual discharge rate directly related to the available volume of snowmelt can accordingly be characterised as "unresistant/very sensitive to climatic change".
2. Improved determination of springs' alimentation basin geometry based on combined hydrogeological and morphological constraints ("3D conceptual models"). Accordingly, relevant alimentation basins with a high contribution of meteoric water in both territories must be identified.
3. Integration of long-term observations on springs and climate evolution whenever available. As a matter of fact, those data allow us to draw inferences on the dimensions of mountain aquifer systems, which in turn provide better assessment of their future evolution.
4. Further research on the development of specific indexes for the sustainable use of groundwater resources (e.g. a spring drought resistance index).

Perspectives

Investigating the effects of global warming on spring behavior in mountainous areas requires the possibility to access hydrogeological, meteorological and geo(morpho)logical data. To do so, coordination between public services and research centers is a prerequisite, allowing the introduction of particular standards for the constitution of databases.

It is therefore of prime importance for authorities to support efforts in the development of modern information systems able to provide quick access to relevant and integrated information. In the framework of Action 3 of Project STRADA, a global management system for spring monitoring and vulnerability determination has already been proposed. It demonstrates that groundwater protection would clearly benefit from a risk reduction and a probabilistic approach, based on the temporal evolution of spring discharge measurements. To develop sustainable protection and management strategies for springs, the possibility to confront the hydrogeological evidence with different climatic scenarios and a predictive model of land use practice has to be considered.

Guidelines for good practice should accordingly implement not only scientific but also societal and political considerations. In particular it is recommended to focus on:

- modernization of existing policies to cover new requirements in terms of land-use practices, resource use, and ground property restrictions,
- education of third parties and development of controlling organs,
- coordination of authorities responsible for different water sectors for rational budgeting of water resource monitoring.

In terms of sustainable development, the three following axes should be addressed for groundwater resource management in mountain areas:

- ***Water monitoring strategies***: observation must integrate springs, water tables, precipitation (rain/snow) and glaciers. To ensure spring protection in mountainous areas, a primary requirement is to secure catchment works.
- ***Water use strategies***: before considering water shortage in function of climate change, optimisation of water distribution networks has to be considered (drinking water, irrigation, and hydro-electrical purposes). Technical improvements offer an interesting rationalisation of current practices to avoid water waste.
- ***Strategies for protection against water***: ensuring access to an integrated hydrogeological database, as expected from Action 3 of Project STRADA, the adoption of measures for the mitigation of natural hazards in mountain areas can be greatly facilitated.

Acknowledgements

This project is financed by EU and Swiss fundings (*Project INTERREG, 2007 - 2013 / STRADA Action 3*) and is realised with close collaboration between

- Switzerland: Service de la Protection de l'environnement du Canton du Valais (SPE), Alpgeo Hydrogéologues conseils, and Centre de Recherche sur l'environnement alpin (CREALP), and
- Italy: Dipartimento difesa del suolo e risorse idriche and ARPA Regione Valle d'Aosta, and Dipartimento di Ingegneria dell' Ambiente, del Territorio e delle Infrastrutture (DIATI), Politecnico di Torino.

The authors would like to thank Hakeline Villavicencio and Jérôme Tavernier from Centre Hydrogéologique de Neuchâtel (CHYN) for their important contributions to the data compilation and analysis; and Dr D. Bertolo, Dr L. Pitet, Dr L. P. Lodi, Prof. M. De Maio, Dr G. Bianchetti, and Dr U. Morra di Cella for the fruitful collaboration during the last three years. Suggestions from an anonymous reviewer were highly appreciated.

The final report of Project STRADA is expected in June 2013.

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Ground Water Asset Management: Rehabilitation techniques - Use of a combination chemical for borehole rehabilitation

*Mike Deed**

Mineral contamination, particularly iron oxide encrustations and iron bacteria, can seriously affect the performance of wells and boreholes. Iron is one of the most common elements found in nature, accounting for at least 5% of the earth's crust, and most groundwater contains a certain concentration of dissolved iron. Possible reasons for iron bacteria infection include presence of bacteria before a bore is drilled, introduction of bacteria via contaminated water used during the drilling process or changes in the chemistry of the groundwater which provides an environment in which bacteria can become established. Whether caused by bacterial activity or through chemical reactions, these residues will eventually affect nearly everyone who sources water from aquifers.

Iron bacteria derive the energy they need by oxidising the soluble ferrous iron (Fe^{2+}) present in the groundwater to an insoluble ferric form (Fe^{3+}). The resultant biofilm is commonly found as a slimy or gelatinous deposit and over time these deposits develop into solid encrustations that become difficult to remove. Symptoms of biofouling including reduction in the capacity of the bore, deterioration of water quality, motor burn out of the submersible pump, and encrustation on the pump, column, bore casing, screens and reticulation systems (***Fig. 1***). Over time the contamination can become so serious that a well has to be decommissioned.

There are a range of mechanical, hydromechanical and chemical techniques commercially available to remove incrustations and control iron bacteria. Research has shown that chemical rehabilitation can amount to 40-60% of the total gain reached during a combined chemical and hydro- or mechanical rehabilitation (Houben, 2001).

* Managing Director of Geoquip Water Solutions, www.geoquipwatersolutions.com

Professional well field management has now started to focus on controlling mineral and bacterial contamination by implementing ongoing maintenance programmes that monitor operational parameters. It has been acknowledged that the expense of installing new boreholes, as well as the licensing, logistical and sustainability considerations, makes a preventative and proactive approach rather than a reactive one the best way forward, impacting beneficially on both the bottom line and in terms of the environment.

Geoquip Water Solutions, in partnership with Aquabiotics Industrial and Laval Underground Systems, has been developing a borehole maintenance programme for the last ten years and their programme, which incorporates the BoreSaver range of treatments, has achieved some notable successes. The goal of the BoreSaver borehole maintenance programme is to return borehole production to as close to the original drilled capacity as possible and to help maintain a continual, problem-free water supply.

The programme includes a downhole camera survey, a bespoke software program that analyses the survey and the available water quality data, a purpose-built rehabilitation rig and BoreSaver, a range of approved borehole rehabilitation treatments that are now used in more than fourteen countries worldwide.

The BoreSaver flagship product is Ultra C, specifically developed for the treatment of iron oxide and iron bacteria contamination. The active ingredients are oxalic acid dehydrate and copper sulphate penta hydrate, and research has shown that the key component of BoreSaver is one of the most effective at dissolving iron contamination (Houben, 2003).

BoreSaver Ultra C dissolves and/or loosens deposits by processes of reduction and complex formation in mildly acidic conditions, and the iron III (insoluble) is converted to iron II (soluble iron). Byproducts of the process are carbon dioxide and water. Residual components of BoreSaver Ultra C are readily biodegraded during the flushing process to harmless inorganic ions and compounds, which occur in the biosphere in abundance.

Figure 1: Iron oxide on pump removed from Lodi recharge well.

BoreSaver Ultra C has been tested and approved in both the UK and the US. In the UK, Ultra C, Liquid Enhancer and IKL Pro (for calcium carbonate) have been approved by the Secretary of State under Regulation 31 of the Water Supply (Water Quality) Regulations 1989 for use in potable water applications. In the USA, BoreSaver Ultra C has been tested and certified by NSF International, the Public Health & Safety Organisation in America, under ANSI/NSF Standard 60 for use in potable water supplies.

BoreSaver's low environmental impact makes it an attractive solution for organisations intent on maintaining their responsibilities to the wider public. Two new BoreSaver treatments are being launched in 2013: EZ-Eco, a non DG (dangerous goods) product and Multi-Kleen, a gen-

Figure 2: Lodi: Down-the-well shot before treatment showing the extent of the contamination.

Figure 3: Lodi: Down-the-well shot after treatment: bridge slot steel screen. Slots can now be clearly seen (image on left-hand side is a pipe).

eral purpose treatment. Both completely remove a range of contaminants including calcium carbonate, manganese oxide and iron oxide and are still fully biodegradable. Geoquip Water Solutions and Aquabiotics Industrial have worked closely with and achieved considerable success in using the BoreSaver maintenance programme in geothermal applications and the mining sector, both of which rely heavily on a large supply of water.

Use in geothermal systems

Geothermal systems are one of the most efficient heating and cooling systems available – a geothermal heat pump unit produces 3-5 times more heat than the energy it consumes, making it 300 to 500% more efficient than using electric resistance heat and 20 to 30% more efficient than typical boiler/tower systems. It is estimated that installing a geothermal system can achieve cost savings of up to 70% and up to a 50% reduction in carbon dioxide emissions, if correctly designed.

Geothermal systems fall broadly into open loop and closed loop categories. Open loop systems abstract groundwater from one or more sources and heat is either extracted or added by the primary refrigerant loop, while the water is then returned to a separate well or body of water. For an open loop system to work effectively it needs a large supply of clean water and one of the biggest problems is mineral and bacterial concentrations in the groundwater source.

The bacteria and associated residues can build up inside the heat exchanger, clog both the abstraction and recharge wells, and increase the friction losses in the flow section of the system. Ultimately this reduces output, wastes energy, increases operating costs and ultimately compromises the original reason for opting for geothermal energy.

The consequences of a clogged system can be quite severe. In 2008 in the town of Lodi, Italy, a geothermal plant was installed to service an air conditioning system for the District Council offices. The system was designed with an overall thermal power of 0.6 MW, achieved by one heat pump with plate heat exchangers, a 42 m deep abstraction well, a 29 m deep recharge well and 100 m of pipework. The system ran into immediate problems as blockages in the recharge well were causing flooding in adjacent areas and the system had to be switched off for rehabilitation. A second screen was installed and the system was cleaned with hydrochloric acid, obtaining poor results. The system was used the following year but the blockages remained and the flooding continued.

In October 2009 groundwater and ground source energy specialist ESI was consulted to find a solution, as iron bacteria growth was suspected. A video inspection of the system by Millars Products, Italian rehabilitation specialists, showed that both wells were completely clogged with iron bacteria and iron oxide residues (***Fig. 2***). The slots in the screens in the recharge well were completely sealed, preventing the discharge of purged water into the ground. BoreSaver Ultra C Pro was used to treat the system and a post-treatment video inspection revealed that the screen slots were virtually clear of contamination (***Fig. 3***) and the system worked efficiently through the summer without subsequent borehole clogging.

Towards the end of 2010 however, levels in the recharge well were once more increasing (***Fig. 4***) and it was evident that on-going maintenance needed to be implemented to control the contamination of iron bacteria. Millars Products returned in May 2011 to carry out maintenance and using BoreSaver returned the system to full operational use (***Fig. 5***). A regular maintenance programme is now part of the Lodi geothermal management plan. The Lodi case study demonstrates the importance of having an effective monitoring and maintenance programme when using a geothermal system.

Figure 4: Groundwater level measurements, Lodi well, 2010.

Figure 5: Groundwater level measurements, Lodi well, 2011.

Use in mines

Mines that extract minerals or metals also rely heavily on groundwater to operate, using it in all steps of the mining process, including equipment cooling, dust control, dredging and waste separation. If water yields decrease or dry up, work stoppages or mine shutdowns occur and there are also environmental considerations, as toxic waste and mine effluents can be mobilised by water, causing regulatory, legal and reputational risks for companies. Iron oxide and iron bacteria contamination is an operational issue for mining companies, as clogging can lead to reduction of the yield and bore capacity, which in turn affects production.

The Tiwest Mine at Cooljarloo in Australia produces more than 700,000 metric tons of heavy mineral concentrate every year using a dredging operation and dry mining techniques. The minesite has 24 wells in two separate fields (North and South) and utilises water in a diversity of processes and techniques, ranging from watering rehabilitation areas through dust control to dredging used in the mining process.

In 2008 iron bacteria contamination had started to become a serious problem at Cooljarloo (***Figs. 6 and 7***). Breakdowns had increased, groundwater yields were consistently below target and cost overruns were a serious problem. However, the need for continual flow meant limiting bore and pump maintenance to a breakdown-only basis.

Kevin Wintergreene from Water Bore Redevelopers (WBR) was invited to develop a new well management strategy and WBR recommended a phased rehabilitation treatment and ongoing maintenance programme using the BoreSaver treatments and a purpose-built cable tool rig.

The wells were monitored weekly for drawdown and flow and these measurements, together with the comprehensive historical records, were used to target the worst performing wells and implement an ongoing light rehabilitation programme, on a planned rotation. As the crisis events stopped and flows increased, monitoring moved to every 3 or 4 weeks and this has continued for the last four years.

To consider the effects of the maintenance programme, a comparison of the well field performance between 2008 and 2011 has been completed and the benefits have proved to be substantial. In 2008, a week before the rehabilitation programme started and with all available wells in operation, the yield in the South field was down by 27,919 m^3 (an extraction variation of 46 L/s). Three years on, in 2011, and with half the wells only running part time, 14,279 m^3 more water per week was being extracted. By running 6 of the 12 wells part time, it became a simple process to balance water flows to allow for maintenance without slipping below production targets. As well as reducing maintenance costs, operational costs, particularly power consumption, have been substantially reduced. The pumps are no longer clogged with iron bacteria, can run at peak efficiency and, importantly, breakdown incidents have been reduced to a minimum

The outcome in the north well field was identical to the south – higher water yield at a lower cost and reduced down time. With water production 10,765 m^3 higher than in 2008, Tiwest is now able to run 3 of the wells on a part-time basis, allowing for an ongoing maintenance programme to be implemented without any effect on operational levels.

Figure 6: Evidence of iron oxide contamination, Tiwest Mine.

Figure 7: Iron oxide contamination, Tiwest Mine.

Use in water supply boreholes

Another organisation that has been using BoreSaver for the last five years is Yuasa Batteries, world leaders in valve regulated lead acid battery design and manufacturing. Their plant in Ebbw Vale, South Wales produces over 500,000 batteries a year. The plant employs around 350 people and Yuasa use their boreholes to supply drinking water for the staff and dionised water in their batteries as well as for the plant's showers and fire mains.

Two boreholes supply the water for the plant, 75 m and 90 m deep respectively, which were drilled ten years ago. The plant is in a heavy ironstone area and in 2007 iron oxide contamination was starting to cause operational problems and a significant reduction in the flow capacity of the wells, down from 32 m^3 per hour to 15 m^3 per hour. Geoquip recommended treating the system with BoreSaver Ultra C to remove the build-up of deposits on the screens and pumps and regular use of BoreSaver Liquid to control the iron bacteria contamination. Yuasa have been carrying out an annual maintenance programme for the last five years and use BoreSaver Liquid every fortnight to maintain the system. The capacity is back up to 32 m^3 per hour with a corresponding reduction in operational problems.

Whilst BoreSaver has played a crucial part in the rehabilitation processes in these case studies, there is no doubt that the implementation of an effective monitoring and maintenance programme is equally crucial. For organisations where there is a need for continual flow to maintain operations, limiting bore and pump maintenance to a breakdown-only basis often has huge financial implications. Regular, proactive maintenance can increase or restore specific capacity and it is now becoming common to build in such a programme at the design stage rather than waiting until operations commence and a problem occurs.

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The water-energy nexus: a growing environmental threat

Florence Bullough

Water stress and scarcity is one of the most urgent cross-cutting challenges facing the world today and is intrinsically linked with the need for energy. Extraction and processing of fuel for electricity supply and transport requires water. Water is used to process fuels, for cooling in power plants and for irrigation in the case of biofuels. Energy is required for pumping, transportation and the purification of water, for desalination, and for wastewater. In the context of rapid global environmental change and a growing population seeking to improve its living conditions, this is a fundamental global challenge.

Les contraintes concernant l'eau et sa raréfaction constituent l'un des défis les plus visibles et les plus urgents auquel le monde doit faire face aujourd'hui, et sont intrinsèquement liées au besoin d'énergie. L'extraction et le traitement du fuel, pour la fourniture d'énergie et les transports, nécessitent de l'eau. L'eau est utilisée dans le traitement des carburants, pour le refroidissement des centrales nucléaires et pour l'irrigation dans le cas de carburants d'origine biologique. De l'énergie est nécessaire pour pomper, transporter et purifier l'eau, pour sa désalinisation et pour les eaux usées. Dans le contexte d'un changement environnemental rapide et global et d'une population croissante cherchant à améliorer ses conditions de vie, il s'agit d'un défi global et fondamental.

La escasez y la tensión hídrica es uno de los retos de la coordinación transversal a los que se enfrenta hoy el mundo y está unida intrínsecamente a la necesidad de energía. La extracción y el tratamiento de combustible para el suministro de electricidad requieren agua. El agua se utiliza para el tratamiento de los combustibles, para el enfriamiento de las plantas de generación y para el riego en el caso de los biocombustibles. Hace falta energía para el bombeo, el transporte y la purificación del agua, para la desalinización y para las aguas residuales. En el contexto de un cambio global rápido y de una población en aumento que busca mejorar sus condiciones de vida, este es un reto global fundamental.

The scarcity of freshwater and drinking water is among the most important cross-cutting challenges in the world today. The issue of water security is intrinsically linked to energy security. Energy production consumes large amounts of water, mainly due to cooling in power plants, and water production requires energy for treatment, pumping and transport. Both are of significant concern in terms of future provision and sustainability. The interconnectedness, as this paper will show, is such that water and energy cannot be addressed as separate entities. This interdependence is termed the 'water-energy nexus', an approach which allows a more holistic, non-reductive assessment of energy and water security issues. Water scarcity is intensifying due to excessive withdrawal, whilst concern for energy provision is sparked by diminishing fossil fuel reserves and the built-in problem of CO_2 emissions and climate change.

Globally, over the last 50 years, the amount of water withdrawals has tripled while the amount of reliable supply has remained constant (Lee *et al.*, 2012) (See ***Fig. 1*** for the distribution of baseline water stress.) This has resulted in depletion of long term water reservoirs and aquifers, most acutely in emerging economies with high population growth such as China, India and areas in the Middle East.

* Policy Assistant, The Geological Society, Burlington House, London, florence.bullough@geolsoc.org.uk

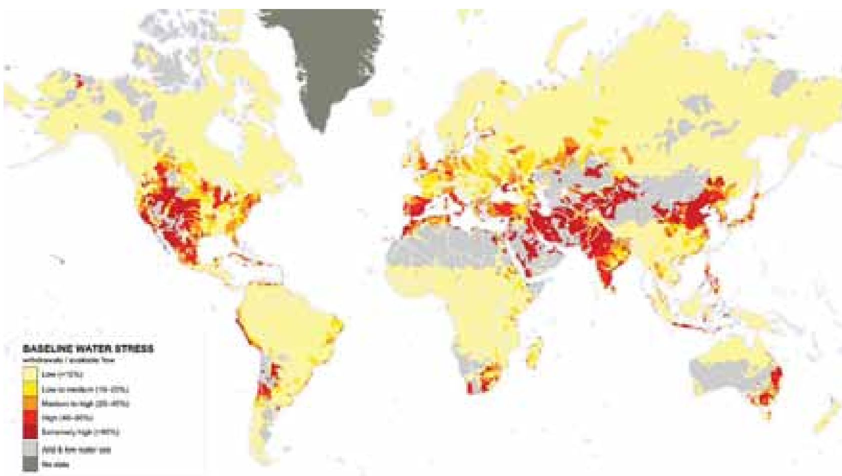

Figure 1: World map of baseline water stress – a measurement of total annual water withdrawals expressed as a percent of the total annual available flow (from Gassert et al.*, 2013).*

The dynamics of the water-energy connection are often misstated, because of confusion over the definition of consumption and withdrawal. ***Consumption*** refers to water that either disappears or is diverted from its source for irrigation or drinking water; this source may or may not be replenished but if so it could potentially take decades, centuries or longer. ***Withdrawal*** is when water is uptaken for a given use, but is then returned to its source, potentially at a lower quality (Glassman *et al.*, 2011).

Water stress and environmental change will increase the strain on energy production in drier areas, while energy shortages will place limitations on water purification and distribution. For this reason, policy frameworks and regulations, devised for the future of water and energy provision,

Energy type	*Water consumed (m³/MWh)*
Wind	*0.001*
Gas	*1*
Coal	*2*
Nuclear	*2.5*
Oil/Petrol	*4*
Hydropower	*68*
Biofuel, 1st gen. (corn, US)	*184*
Biofuel, 1st gen. (sugar, Brazil)	*293*

Table 1: Comparative water consumption values by energy type (WssTP, 2011).

will require consideration of the interdependence of water and energy.

Energy is limited by water

The energy sector relies heavily on the use and availability of water for many of its core processes. Resource exploitation, the transport of fuels, energy transformation and power plants account for around 35% of water use globally (Lee *et al.*, 2012). Thermoelectric power plants use significant amounts of water and account for the majority of water use by the energy sector. In the USA in 2007, thermoelectric power generation – primarily comprising coal, natural gas and nuclear energy –generated 91% of the total electricity and the associated cooling systems account for 40% of USA freshwater withdrawals (King *et al.*, 2008). This water demand has been exacerbated by the shift from open loop cooling systems to closed loop cooling. Open loop cooling systems have high withdrawals and low consumption, which is preferable but results in the discharge of water at a higher temperature, causing thermal pollution of waterways. For this reason closed loop cooling was adopted, which has low withdrawals but high consumption due to evaporation during re-circulation of the water (King *et al.*, 2008).

Of the different types of power plants, gas-fired plants consume the least water per unit of energy produced, whereas coal-powered plants consume roughly twice as much water, and nuclear plants two to three times as much (WssTP, 2011). By contrast, wind and solar photovoltaic energy consume minimal water and are the most water-efficient forms of electricity production. Comparative water consumption by energy source can be seen in ***Table 1***.

Claims that certain fuels and technologies reduce CO_2 emissions can be misleading, as the consideration of water consumption is often omitted. For example, unconventional fracked gas is often presented as a preferable source of energy over coal due to its reduced associated CO_2 emissions, but the extraction of fracked gas consumes seven times more water than natural gas (Glassman *et al.*, 2011). Additionally, carbon capture and storage (CCS) technology has the capacity to remove CO_2 from the system but is also estimated to need 30-100% more water when added to a coal-fired power plant (Glassman *et al.*, 2011). Looking at carbon intensity alone may set a trajectory to a scenario where electricity production is constrained by water scarcity, while global demand for electricity increases.

The current trend in diversification of energy sources into non-conventional, often lower quality fuels will require increasingly water intensive practices. Extraction of oil from oil sands requires up to 20 times more water than conventional drilling, while biofuels can consume thousands of times more water than conventional fossil fuels due to the need for irrigation (Glassman *et al.*, 2011).

Water limited by Energy

The counterpart to the need for water for energy production is the need for energy in order to produce and deliver water for drinking and other domestic, agricultural and industrial use. Domestic water heating accounts for 3.6% of total USA energy consumption (King *et al.*, 2008). Supply and conveyance of water is also energy-intensive and is estimated to use over 3% of USA total electricity. Energy is required at every step of the supply chain, from pumping ground water (530 kWh M^{-1} for 120 m depth), to surface water treatment (the average plant uses 370 kWh M^{-1}) and transport and home heating (King *et al.*, 2008). Water treatment will require even more energy with the addition of treatment technologies and purification measures. This was evidenced in a recent draft EC directive reviewing the priority substance list under the Water Framework Directive (WFD). Water companies in the UK report increases of over 60% in electricity usage since 1990 due to advanced water treatment and increased connection rates, and conservative estimates predict increases of a further 60-100% over 15 years in order to meet the myriad relevant EU directives (WssTP, 2011). While this increased energy use may contribute to a reduction in water pollution levels, it will lead to higher CO_2 buildup in the atmosphere, thus simply displacing the pollution problem.

Desalination

One of the most problematic developments in the competition for water and energy is the growth of desalination. It is used in areas suffering from water scarcity, but with viable energy sources to power the energy-intensive purification process. In areas such as the Middle East, the Mediterranean and western states of the USA, governments have increased their investment in desalination technology in order to secure a more stable water supply. However, the high-energy requirements, steep operational costs, wastewater disposal issues and large CO_2 emissions often make this an unsustainable solution (Lee *et al.*, 2012) (See ***Fig. 2*** for details on desalination technology and its use in Europe).

Desalination is often made economical through access to cheap, local energy sources and an abundant water source. This usually precludes the adoption of desalination in many land-locked countries, as operational costs increase with distance from the water source (Lee *et al.*, 2012). However, increased water stress is leading to calls for more ambitious projects such as the planned Red Sea–Dead Sea project to build a desalination plant and a 180 km pipeline through Israel, Palestine and Jordan.

The high energy demands of desalination exacerbate water–energy dependence and lead to increased CO_2 emissions. Desalination can use 10-12 times as much energy as standard drinking water treatment, and is expensive and unsustainable (King *et al.*, 2008). These undesirable effects have led to widespread opposition to desalination in areas such as Carlsbad, California (USA) and Chennai (India). Utilising renewable energy resources, coupled with the use of saline or wastewater for cooling at the power plants, could make the process more sustainable.

The Impact of Water Scarcity

Freshwater scarcity is a growing issue and by 2030, demand is set to outstrip supply by 40% (Lee *et al.*, 2013). This is due in part to economic and population growth, but also the rise of aspirational lifestyles, which creates demand for more water-intensive products. This increase in demand will put additional pressure on water-stressed regions, as well as intensifying current trans-boundary water conflicts. The issue of water shortages often intersects geographically with fragile or weak governments and institutions that may lack the capacity to put in place measures to address water security (Lee *et al.*, 2012). In 2004, 29% of India's groundwater reserves resided in blocks that were rated semi-critical to overexploited (Lee *et al.*, 2012). About 60% of India's existing and planned power plants are located in water-stressed areas and there are plans to build a further 59 GW of capacity, around 80% of which will be in areas of water stress and scarcity (see ***Fig. 3***). The geography of water scarcity often coincides with emerging economies, the growth of which may be impeded by water scarcity, and this tension could potentially lead to instability.

Desalination Technology and Usage in the EU

Water with a Total Dissolved Solids value exceeding 1,000 mg/L is considered to be saline. Desalination is commonly carried out by one of two methods.

1. Phase change thermal processes
   - o Water is heated until evaporation occurs, and the salt is left behind while the vapour condenses to fresh water.
2. Membrane processes.
   - o Water is passed through a relatively permeable membrane which induces two zones, one of freshwater and one of saline water. The main separation principle lies in the size of the ions and molecules in the water i.e. salts are bigger than water molecules.

Spain has been using desalination technology since 1964 and Europe has a growing share in global desalination capacity. Desalination in Europe now accounts for 10% of global capacity with countries such as Greece, Italy, and Spain accounting for the majority. Desalination is becoming increasingly used during freshwater scarcity in dry periods and Spain's production has doubled in the last decade.

Bajo Almanzora Desalination Plant in Almeria, Spain-Treats 60,000m3 a day and can serve 15% of the population of Almeria province.

Figure 2: Desalination technology and usage in the EU.

Pressure on water provision, impact on soil quality and aquifer depletion are likely to have damaging effects on food crops and irrigation. Food production will have to compete with other industries for water, which may create economic conflict. There is also concern that some countries will resort to large-scale river redirection projects similar to those seen in China. These affect ecosystems, and also result in significant re-settlement, which in itself has impacts on water supply. The effects can also be felt in other countries downstream, increasing cross-boundary tensions.

Climate change impacts

Environmental change presents a challenge to business-as-usual assumptions about future energy and water provision. Predicted major heat waves and droughts will add pressure to both water and energy security. Climate change is set to affect areas around the world in unprecedented ways; Africa, Asia, Oceania and Latin America are all expected to experience significant water shortages by 2030. In southern Europe, temperatures are likely to rise, and drought will become more common in a region already vulnerable to water stress (Gassert *et al.*, 2013). This is true particularly in Spain, a country that derived 14.3% of its electricity production from hydropower in 2010,

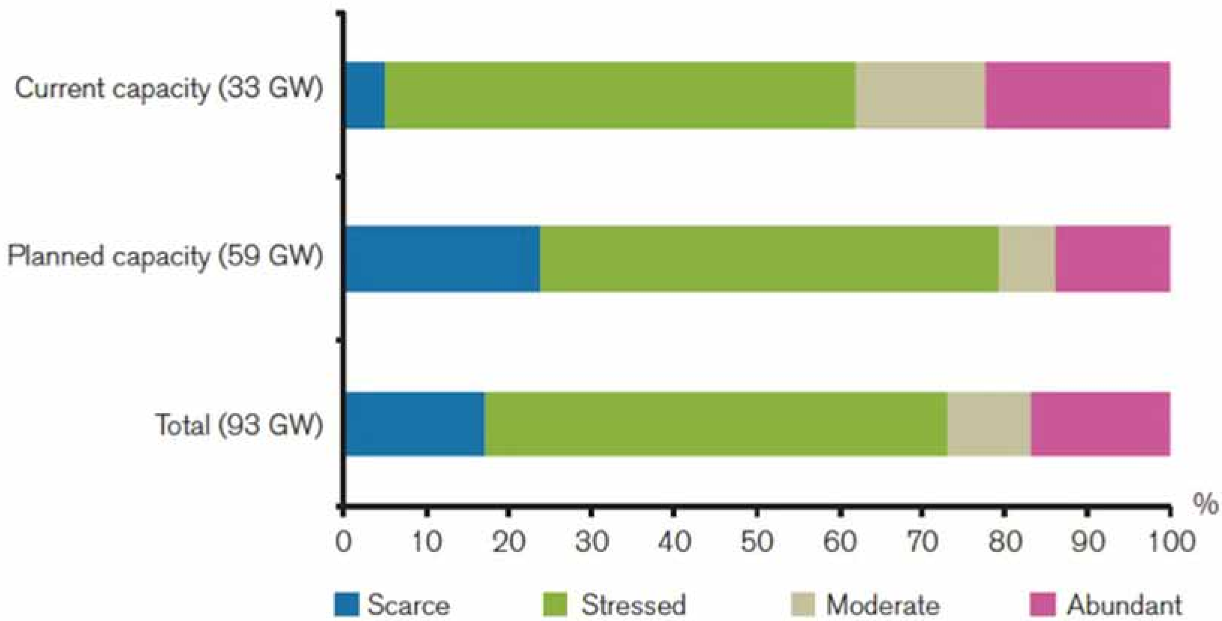

Figure 3: Location of power plants in India with regards to level of water stress (Lee et al.*, 2012).*

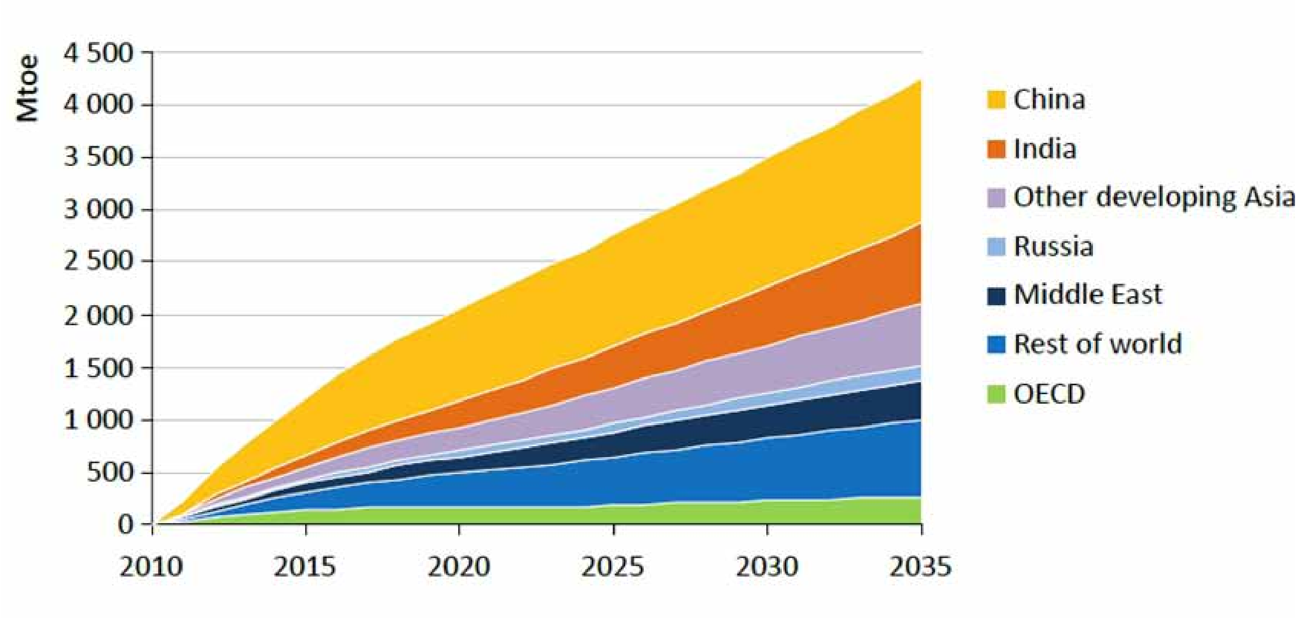

Figure 4: Growth in primary energy demand (in Mtoe) (IEA World Energy Outlook, 2011).

where hydroelectric plants have been under considerable stress in the last 20 years due to long running issues with drought (Perez y Perez *et al.*, 2009; Trading Economics, 2013). As well as hydropower, this is likely to affect tourism and crop productivity, which are both crucial to the economy of the Mediterranean region.

Power cuts caused by extreme weather events, which are expected to become more frequent, will affect areas that rely heavily on energy-intensive ground water extraction for drinking water. In India, for instance, more than 60% of water for irrigation and over 85% of its drinking water comes from pumped groundwater (Lee *et al.*, 2012). Environmental change resulting from our past and current activities will only be exacerbated by increasing energy usage, which, as seen in ***Fig. 4***, is set to increase globally by 67% from 2009 to 2030 if the status quo is maintained (IEA World Energy Outlook, 2011).

Climate change will function as a threat multiplier to the issues outlined above and the wider supply chain as extreme events compromise production and resource infrastructure. Water and energy are set to become increasingly interdependent, and by 2050 water consumption to generate electricity is forecast to more than double (Lee *et al.*, 2012).

What can be done?

Climate change is now considered an issue of national security in many countries, threatening both people and the environment within and across state boundaries. For this reason, climate change mitigation and adaptation must be managed at a new strategic level, beyond that of national law making. A more holistic approach to management of environmental change, water and energy security will also be required. The conflict between more water-intensive energy production and the water needs of a growing population, seeking a better quality of life, will exacerbate an already stressed water-energy nexus. Addressing this challenge will require strategic planning of water and energy security over much longer timescales than previously.

Planning

Incorporation of the water-energy nexus approach into planning and regulation will allow the linked issues identified above to be addressed more effectively. A major challenge will be to adapt the current siting and energy and water delivery systems of cities based on the climate of the last century or so. This will require a paradigm shift to adapt to a rapidly changing climate. Water availability has become a critical determinant for planning and investment in major infrastructure projects such as such as power plants and large-scale residential developments. These must be sited with consideration for water withdrawal, consumption and local power accessibility. Planning should take into account the full effects of the water-energy nexus and future unpredictability in climate, particularly as the lifetime of such developments is several decades or more.

Countries should move away from a single source of energy and water, building adaptability into their energy and water profile to reduce risk. Smaller scale, distributed energy systems may also be more resilient than centralised systems, although these are often difficult to fund. Operating costs and energy and water consumption, not just capital costs, need to be built into the planning phase. Water planning should be based on the catchment-based approach to water use and conservation espoused by the WFD, and discussion between stakeholders should be encouraged.

Regulatory Changes

Another important tool to address these issues is regulation. Current regulatory frameworks such as the European Climate and Energy Package and the WFD need to be developed in light of the water-energy nexus model. The EU is committed to a 20-30% reduction in CO_2 emissions by 2020 compared to levels in 1990, with reductions of up to 50% by 2030 and 80% by 2050 under negotiation. In contrast, the WFD requires additional treatment measures and this will need additional energy, exacerbating tensions between water and energy demand (WssTP, 2011).

There are many policy instruments that can be used to regulate the role of water and energy management, such as water pricing and charges on carbon emissions to provide incentives for sustainable behaviour. The development of CCS technology could reduce the carbon footprint of power plants, but water consumption implications should be taken into consideration. Adoption of disincentives for certain types of land-use change and stricter building and engineering regulations could also be introduced to increase resilience against extreme weather.

The growing geopolitical issues of water location and scarcity will need to be managed through adaptable water sharing agreements, since many of the world's largest and most important river basins – such as the Mekong River, which passes through south-east Asia – cut across many borders. Co-management strategies such as shared water level and quality information will become important so that the water systems can be managed effectively. Governments must also improve their resilience to extreme weather conditions individually and collectively.

A greater focus on recycling energy- and water-intensive commodities would also alleviate water stresses when taken together with other measures. Education about recycling and water and energy conservation programmes could produce benefits, but also require investment and careful management. Conservation or pollution prevention is often more economical than a high-tech approach: generating energy with clean water is very expensive, for instance, whereas the re-use of sea water, wastewater and low quality water for power plant cooling can reduce the overall water footprint of a power plant.

This broad set of issues can only be effectively ameliorated through a holistic approach. A broad analytic framework is needed to evaluate the water-energy relationship, and this must be balanced with local policy contexts and different regulatory measures to ensure that water and energy are sustainably managed in the 21st century.

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Mentoring for geoscientists in Germany

*Tamara Fahry-Seelig**

Mentoring is based on Greek mythology, where Mentor appeared as a character in Homer's epic poem the Odyssey as a friend of the hero Odysseus and guardian of his son. Since then "mentor" has meant a fatherly friend and advisor. The idea of mentoring as an informal network comes from the USA, where it has been practised since the 1970s.

For more than nine years the German Professional Association of Geoscientists (BDG) has offered a mentoring programme to its members. "Our aim", says Dr. Ulrike Mattig, President of BDG, "is to support young geoscientists while starting their career in geoscientific profession as well as during reorientation or reentrance, e.g., after a family break."

Over a fixed period of 12 months the mentorees will get advice and receive targeted support from experienced professionals, according to their individual goals. Examples include:

- feedback and support during the job application process
- building up a network, transfer of contacts
- development of a career strategy
- introduction to informal knowledge and business networks
- shadowing (participation in the professional life of the mentor).

During that time, the mentors pass on their own experience to the mentorees.

Asked for their motivation for participating in the mentoring programme, the mentorees answered as illustrated in Fig. 1.

The cooperation starts with a workshop in which opportunities and risks of mentoring are discussed and aims are defined. For the duration of their cooperation, mentorees and mentors are accompanied by the Berlin branch of the BDG, which coordinates the program. It is supported by the Project Steering Group (PSG) in which all fields of geoscience activities are represented. Both groups recruit potential mentors from among their members.

The commitment of all mentors is voluntary and therefore participation in the programme is free of charge. But mentors also draw benefits from the relationship: the survey results of the last series have shown that the majority of them enjoy sharing their own experiences and thereby helping their mentorees. In addition, the curiosity of young people and their enthusiasm for geoscience are important reasons in deciding to act as a mentor.

The BDG cooperates with other geoscience societies in Germany to establish as large a network as possible. Cooperation partners are: the Engineering Technical Association for Contaminated Land Management and Land Recycling (ITVA), the Association for Geoecology Germany (VGöD), the Association Soil (BVB) and the Association for Applied Geography (DvaG).

More information can be found on the BDG homepage *www.geoberuf.de*.

Here are the opinions and experiences of two of our mentorees:

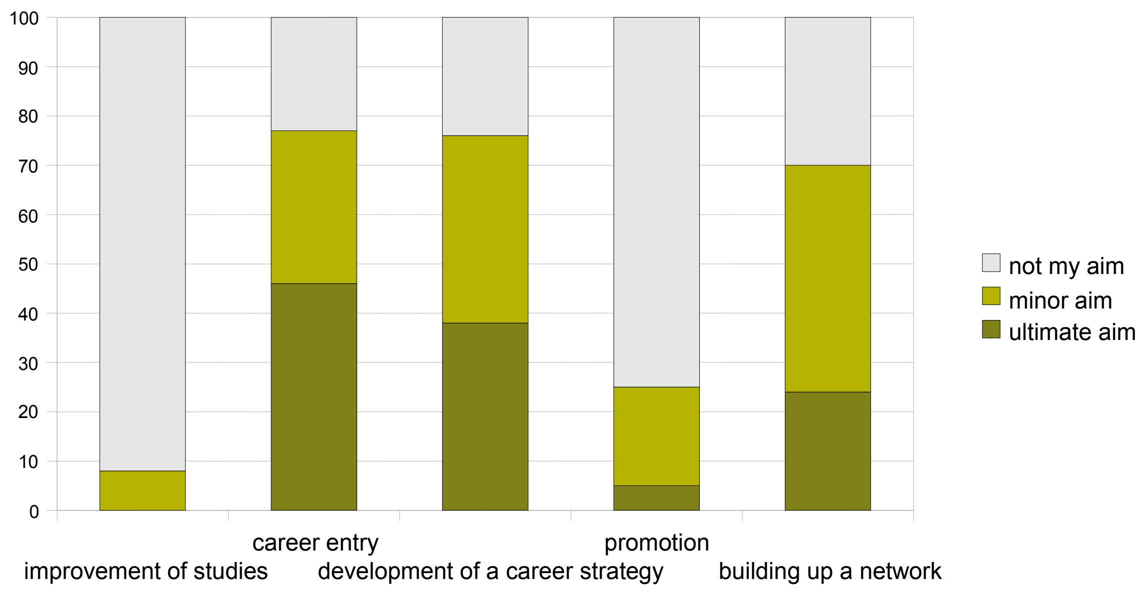


Figure 1: Aims of mentorees for programme participation.

* German Professional Association of Geoscientists (BDG), fahry-seelig@geoberuf.de

Ulrich Knies

Wants to develop a career strategy.

How have you experienced the programme on a personal level?

I had a relaxed meeting with my mentor, which helped me in putting my academic skills into the perspective of the needs of the "real" business world. It has shown me that the path to senior positions isn't always straight and encouraged me to follow opportunities outside my PhD topics.

Has participation had any effects on your professional development? If so, what kind?

Not really, but some advice on salaries and work contract conditions was super helpful, especially considering that this is usually something not talked about with people in senior positions.

Do you consider that the BDG's mentoring programme could be applied in other European countries? Could it become a tool for encouraging mobility in Europe?

Sure, why not.

Johannes Grossmann

Young graduate, application phase.

How have you experienced the programme on a personal level?

From the first moment, the mentoring relationship began on a highly professional level. Most of the conversations with my mentor concentrate on sharing personal experiences, general information on working as a geologist, and providing valuable advice concerning career planning. Personal matters that go beyond that have never been a strong subject in our talks.

Figure 2: Mentoree group of the 12th edition of the programme.

In my point of view, an open-minded attitude on the part of both of the mentoring partners is an essential pre-condition for this project.

Has participation had any effects on your professional development? If so, what kind?

Professors at universities try to catch their students for their own field of research. As a student, the conversations with my mentor helped me to obtain a broader point of view towards the different careers of geologists, especially outside of universities and pure research. I began to concentrate my professional interests on more applied fields of research and away from research subjects at my own university. Consequently, I spent an additional internship during my Master's program in a company and for my thesis I work in cooperation with an external (applied) research institute.

Do you consider that the BDG´s mentoring programme could be applied in other European countries?

I am sure that the concept of the BDG´s mentoring programme is also applicable in other European countries. Young geoscientists always have to think about their careers. Furthermore, many universities only introduce their students into the world of research. BDG´s big mentoring pool, with most mentors having an economic background, offers the opportunity for an introduction into other career fields beyond pure research.

News corner:
*Compiled by Isabel Fernández Fuentes and Anita Stein**

European Minerals Day

This initiative by the European minerals sector and related organisations gives the opportunity to the European-wide public to explore the world of minerals and discover more about an industry that affects every aspect of our lives.

This biannual event welcomed more than 30,000 visitors in over 100 sites in 17 European countries during its first edition in 2007. European Minerals Day 2009 engaged children and adults at more than 160 sites in 27 countries. In the 2011 edition, more than 180 sites in 21 European countries and 11 in the rest of the world took part - good for more than 200 events.

Minerals play an essential role in our lives, with 70% of EU manufacturing production depending on mined substances. The construction, chemicals, automotive, aerospace and machinery sectors, which provide a total added value of € 1324 billion and 30 million jobs, all depend on access to raw materials.

This year, the European Commission has chosen European Minerals Day as a key channel for promoting the European Innovation Partnership Initiative, creating synergies among all raw material stakeholders to illustrate the role of raw materials throughout the whole value chain with special focus on innovation and resource efficiency.

Biodiversity remains one of the recurring themes, considering that quarries may host a variety of rare plant and animal species, and many companies are therefore proud to guide visitors through rehabilitated areas. This and many more activities aim at raising awareness of this sustainable sector. Entertaining side activities such as fossil hunting, animations for children, jeep safaris, workshops etc. make European Minerals Day an unforgettable experience for people of all ages.

In addition to the events organised from 24 to 26 May, a wide range of sectors and organisations joined forces from 6 to 8 May to illustrate the role of mineral raw materials for innovation and resource efficiency throughout the whole life cycle. The exhibition tells our story, and leads you through the life cycle of a mineral product: from extraction (covering biodiversity and sustainable mining practices), to processing, usage (applications in downstream sectors), to transformation and recycling. The exhibition received active support from the European Commission, several Members of European Parliament, Member States, unions, NGOs, and industry. EFG is one of the supporting organisations of this initiative.

More information: *www.mineralsday.eu*

New IUGS Task Group on Global Geoscience Professionalism

The starting point for this Task Group was the idea that, in general, the majority of those who define themselves as professional geoscientists work in industrial/applied sectors, but professionalism is just as important in the academic and teaching arenas, which tend to fall outside the purview of professional registration and oversight. Raising the profile of professionalism and gaining acceptance of its importance amongst the academic and research communities is vital if their work is to truly serve society. It is rapidly becoming accepted that excellence in practical and professional skills go hand-in-hand with excellence in scientific research.

To ensure that the international geoscience community is engaged in this transformation of its profession and to enable IUGS to secure itself as the logical home of the professional dimension of the Earth Sciences over time, a new IUGS Task Group entitled the Professional Affairs Task Group was formed in 2012.

The sponsors of this new Task Group are:

- European Federation of Geologists (EFG)
- Geoscientists Canada
- American Institute of Professional Geologists (AIPG)
- Australian Institute of Geoscientists (AIG)
- South African Council for Natural Scientific Professions (SACNSP)
- El Colegio de Geólogos de Bolivia (College of Geologists of Bolivia).

The EFG office in Brussels has agreed to serve as the initial secretariat for the Task Group, and the office of Geoscientists Canada in Vancouver has agreed to be responsible for setting up and maintaining the website.

Some of the first actions are to broaden the geographical basis of the group and to increase its communication. In this sense, a website is currently being established which will go live soon.

In early 2013, EFG President Ruth Allington presented the Task Group at two occasions:

- the IUGS meeting in Paris, France, 19 February 2013.
- the EGU 2013 meeting, Vienna, Austria, 7-12 April 2013.

* EFG Office, info.efg@eurogeologists.eu

PERC

About PERC

The Pan-European Reserves & Resources Reporting Committee, PERC, is the European equivalent of the Australasian JORC, SAMREC in South Africa and similar reserves reporting standard bodies in the USA, Canada, Russia, and Chile, and along with them is a constituent member of the Committee for Mineral Reserves International Reporting Standards (CRIRSCO - *www.crirsco.com*). Representation on PERC covers major and minor mining sectors, industrial minerals, aggregates, coal, the investment and financial community and the professional accreditation organisations, including the Institute of Materials, Minerals, and Mining (IOM3), the European Federation of Geologists, the Geological Society of London, and the Institute of Geologists of Ireland.

The PERC reporting standard is recognised by ESMA (the European Securities and Markets Authority), together with other CRIRSCO-aligned standards, for use in reporting mineral reserves, mineral resources, and exploration results on markets within the European Union, and is also accepted for reporting on stock exchanges in Canada. Because of the close similarity of all the CRIRSCO-aligned reporting standards, including the same classification system and the same set of standard definitions, it is also very simple to translate reports from one standard to another.

NGO constitution and AGM

Since December 2011, a caretaker crew of PERC officials composed of Paul Gribble (acting Secretary), Ruth Allington (acting Treasurer) and Stephen Henley (acting Chairman), and a few others have been preparing for the reconstitution of PERC in a new formal structure and the relocation of the organisation to Brussels.

Over the past year, with advice and assistance from EFG, a set of statutes for PERC has been developed to register as a 'not for profit' organisation ('asbl') in Brussels. The director of the Royal Belgian Institute of Natural Sciences (RBINS), Mrs. Pisani, accepted the registration of PERC asbl within the facilities agreed to EFG . The director of the Belgian Geological Society, Michiel Dusar, was very supportive in this issue. The newly created organization acquired its legal personality on 7 March 2013.

Hosted by EFG and the Royal Belgian Institute of Natural Sciences, PERC held its first annual general meeting (AGM) since the reconstitution of the organization on 15 March 2013.

The meeting was subdivided into two sessions, a closed morning session, attended only by PERC members, and an open afternoon session which was attended by stakeholders from minerals associations and representatives from the European Commission. During the closed session the new PERC reporting standard was approved and is now available online at *www.perc.org*. Furthermore, the officers for the next two-year term have been elected:

CHAIRPERSON: Eddie Bailey (GSL)
DEPUTY CHAIRPERSON: Steve Henley (IOM3)
SECRETARY: Carlos Almeida (EFG)
TREASURER: Ruth Allington (EFG)

EGU

The annual meeting of the European Geosciences Union (EGU) - General Assembly is among the important conferences for Earth scientists employed by universities and research institutes. It is organized in Vienna, in April, by the Copernicus Office. The 2013 EGU meeting attracted a total of 11,167 scientists from 95 countries, of which 28% were students. In total 4,684 oral talks and 8,207 posters were presented.

After the success of the session "Geodiversity and Geoheritage in University Education and Research" held at the EGU 2012 meeting in collaboration with the EFG Panel of Experts (PE) on Geological Heritage, a similar session was proposed in 2013. This time the University of Lausanne has taken the lead, and the PE on Geological Heritage was one of the co-organisers. The session was convened by Emmanuel Reynard (University of Lausanne), Hanneke van den Ancker (Coordinator of the EFG PE on Geological Heritage), José Brilha, and Erik Cammeraat The proposed session theme was be roughly similar to that of the EGU-2012 meeting: how to improve geoheritage and geodiversity teaching and studies in universities and research institutes, and their importance for sustainable land management.

More information: *http://www.egu2013.eu/*

EAGE/EFG Photo Contest 2013

In 2013, the European Association of Geoscientists and Engineers (EAGE) and the European Federation of Geologists (EFG) are for the first time jointly organising a photo contest. The theme of this year's contest is 'Geoscientists at work'. All EAGE and EFG members were invited to submit photos that portray some aspect of the theme by, for example, depicting geological features of the earth relevant to geoscientific work, geoscientific activities (such as field geophysics, mapping or modeling) or the geoscientist's roles in particular sectors (such as oil and gas, natural hazards, water resources, construction or mining and minerals). The deadline for submitting entries was 1 April 2013. From 5 April to 10 May, all members of EAGE and EFG related societies then had the opportunity to cast their votes for the best 12 pictures on the contest website *www.houseofgeosciences.org*.

These 12 best photographs:

- will be awarded with a beautiful 2014 calendar that includes their photograph(s)
- will be displayed at the 75th EAGE Conference & Exhibition incorporating SPE EUROPEC 2013 (10-13 June 2013, London)
- will be displayed at the EFG Hydrogeology Workshop (22-23 November 2013, Brussels)
- will be displayed at the EFG Council Meeting (23-24 November 2013, Brussels)

During the exhibitions, starting with the 75th EAGE Conference & Exhibition incorporating EUROPEC on 10-13 June in London, UK, delegates have the chance to cast their vote on-site. The three most popular photographs will be announced in the November issue of First Break (winners will be contacted earlier).

Book review:
Peligros naturales
*Isabel Manuela Fernández Fuentes**

Peligros Naturales (Natural Hazards)
by Rosa María Mateos

Published by: Instituto Geológico y Minero de España and Catarata. Catalogo oficial de publicaciones oficiales www.060.ES. Colección Planeta Tierra
Year of publication: 2013
ISBN: (IGME) 978-84-7840-854-2
(Catarata) 978-84-8319-792-9
How to order: http://libros.igme.es/product_info.php?products_id=78 or http://www.catarata.org/libro/mostrar/id/825
Price: 14€

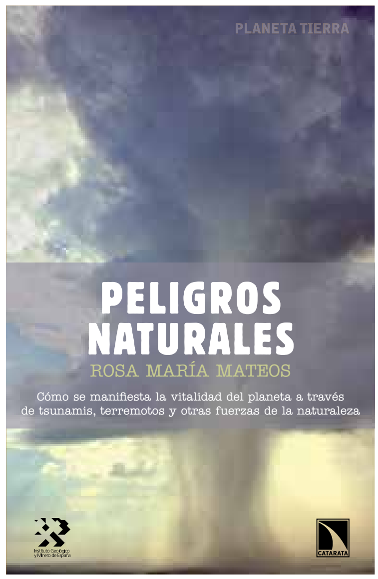
This book is an example of diffusing Earth Sciences to society. Focusing on natural hazards, Geology is coupled in a reader-friendly way with other disciplines as History, Art or Geography. The readers thereby assimilate and understand how relevant events in our society have parts of their origin in the very dynamics of our Earth.

The book not only explains how and why natural hazard events occur, and which causes what effects – as traditional geology literature – but in addition there are pedagogical examples on how this has influenced our history and culture. The author invites us to travel around the globe and through time: recent natural hazard events, such as the Indian Ocean tsunami in 2004, the earthquakes in Haiti in 2010 and Japan in 2011, or the El Hierro submarine eruption in 2012, are coupled with historical dives into past centuries. It makes us understand the geological origin of these phenomena, and relates this to our landscape and its social impact, through examples and anecdotes that sometimes provoke laughter from the reader.

The focus of this book on natural hazards is about how the vitality of the planet Earth is manifested through tsunamis, earthquakes, and other forces of nature. Through four chapters the author discusses plate tectonics and its relation to geological events or natural disasters.

The epilogue reflects on how to live with geological risks today, and the influences of increased vulnerability. As the population increases, there is a tendency to place cities in areas with higher geological risk, and thereby increase the risk of natural disasters. The book shows the origin of these natural hazards and invites the reader to learn to live with them, through minimisation of damage. The author invites all parties – scientists, authorities, emergency services and the general population – to get involved in the process of natural hazard prevention and in efforts to harmonise the work in the society.

Hopefully this book will be translated



into many languages to be available for a larger European public.

Rosa María Mateos has a PhD in Geology. She has worked as scientific officer in the Geological and Mining Institute of Spain. Her field of expertise covers geological risks, specifically those related to slope movements. She is passionate about science communication. She has published a children's book on "The Curiosities of the Geology" and has frequently collaborated with the media on science communication.

Submission of articles to European Geologist magazine

Notes for contributors

The Editorial Board of the European Geologist magazine welcomes article proposals in line with the specific topic agreed on by the EFG Council. The call for articles is published twice a year in December and June along with the publication of the previous issue.
The European Geologist magazine publishes feature articles covering all branches of geosciences. EGM furthermore publishes book reviews, interviews carried out with geoscientists for the section 'Professional profiles' and news relevant to the geological profession. The articles are peer reviewed and also reviewed by a native English speaker.
All articles for publication in the magazine should be submitted electronically to the EFG Office at info.efg@eurogeologists according to the following deadlines:

- Deadlines for submitting article proposals (title and content in a few sentences) to the EFG Office (info.efg@eurogeologists) are respectively 15 July and 15 January. The proposals are then evaluated by the Editorial Board and notification is given shortly to successful contributors.
- Deadlines for receipt of full articles are 15 March and 15 September.

Formal requirements

Layout

- Title followed by the author(s) name(s), place of work and email address,
- Abstract in English, French and Spanish,
- Main text without figures,
- Acknowledgements (optional),
- References.

Abstract

- Translation of the abstracts to French and Spanish can be provided by EFG.
- The abstract should summarize the essential information provided by the article in not more than 120 words.
- It should be intelligible without reference to the article and should include information on scope and objectives of the work described, methodology, results obtained and conclusions.

Main text

- The main text should be no longer than 2500 words, provided in doc or docx format.
- Figures should be referred in the text in italic.
- Citation of references in the main text should be as follows: 'Vidas and Cooper (2009) calculated…' or 'Possible reservoirs include depleted oil and gas fields… (Holloway et al., 2005)'. When reference is made to a work by three or more authors, the first ame followed by 'et al.' should be used.
- Please limit the use of footnotes and number them in the text via superscripts. Instead of using footnotes, it is preferable to suggest further reading.

Figure captions

- Figure captions should be sent in a separate doc or docx file.

References

- References should be listed alphabetically at the end of the manuscript and must be laid out in the following manner:
- Journal articles: Author surname, initial(s). Date of publication. Title of article. Journal name, Volume number. First page - last page.
- Books: Author surname, initial(s). Date of publication. Title. Place of publication.
- Measurements and units
- Measurements and units: Geoscientists use Système International (SI) units. If the measurement (for example, if it was taken in 1850) was not in SI, please convert it (in parentheses). If the industry standard is not SI, exceptions are permitted.

Illustrations

- Figures should be submitted as separate files in JPEG or TIFF format with at least 300dpi.
- Authors are invited to suggest optimum positions for figures and tables even though lay-out considerations may require some changes.

Correspondence

All correspondence regarding publication should be addressed to:
EFG Office
Rue Jenner 13, B-1000 Brussels, Belgium.
E-mail: *info.efg@eurogeologists.eu*

Note

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15 Euro per issue

Contact

EFG Office
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E-mail: *info.efg@eurogeologists.eu*

Advertisements

EFG broadly disseminates geology-related information among geologists, geoscientific organizations and the private sector which is an important employer for our professional members, but also to the general public.

Our different communication tools are the:

- EFG website, *www.eurogeologists.eu*
- GeoNews, a monthly newsletter with information relevant to the geosciences community.
- European Geologist Magazine, EFG's biannual magazine. Since 2010, the European Geologist Magazine is published online and distributed electronically. Some copies are printed for our members associations and the EFG Office which distributes them to the EU Institutions and companies.

By means of these tools, EFG reaches approximately 50,000 European geologists as well as the international geology community.

With a view to improving the collaboration with companies, EFG proposes different advertisement options. For the individual prices of these different advertisement options please refer to the table.

Prices for advertisements

EGM	**One Insertion**	**Two Insertions**
Full page (colour)	820 Euro	1320 Euro
Half page (colour)	420 Euro	670 Euro
Quarter page (colour)	220 Euro	350 Euro
Full page (black and white)	420 Euro	670 Euro
Half page (black and white)	220 Euro	350 Euro
Quarter page (black and white)	120 Euro	200 Euro
Business card size	90 Euro	150 Euro
Preferential location	25% plus	
Price for special pages:		
Outside back cover (colour)	1200 Euro	1900 Euro
Second page (colour)	1000 Euro	1600 Euro
Second last page (colour)	1000 Euro	1600 Euro
Geonews	**Annual Price**	
Ad and regular newsfeed	1300 Euro	
EFG Homepage		
Ad and regular newsfeed	1300 Euro	
University ad		
Ad for training opportunities in the job area of the homepage	500 Euro	
Annual package		
Business card size ad in the EGM, GeoNews and homepage.	2500 Euro	