

COASTAL KARST AQUIFERS IN MEDITERRANEAN REGIONS. A VALUABLE GROUND WATER RESOURCE IN COMPLEX AQUIFERS.

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ABSTRACT

Karst aquifers afford important ground water resource from highly productive zones. A methodology developed by CNRS and BRGM based on hydrodynamical and hydrogeochemical data from the main outlet of the karst systems, consists of analysing their behaviour in order to survey or to exploit the resource. Concerning coastal karst aquifers, that approach must be adapted, because of their submarine springs and of the risk of point sea water intrusion. The knowledge of the submarine discharge and their monitoring are the key points of the strategy for exploring and exploiting the resource. That situation is particularly relevant in Mediterranean regions because of the important variations of sea level, responsible of a karst development deeply below the present sea level. A preliminary study of a spring discharging in the Thau lagoon (southern France) gave the bases of an adapted methodology.

Key Words: Mediterranean, coastal karst aquifer, methodology, monitoring, submarine spring

INTRODUCTION

In Mediterranean countries, the increase of population and of the water consumption requires investigations for exploiting in a most efficient way the known resource and for exploring new ones. In these regions, karst aquifers are one of the most interesting potential resource. Very common around the Mediterranean sea, carbonate rocks are of very high interest in the regional water economy, because they often afford the only exploitable resource. Their aquifer properties are particularly favourable because karst processes abundantly

enlarged the initial voids, creating very highly productive zones (karst conduits, large cavities in the phreatic zone). In many Mediterranean countries, large cities are only supplied from karst springs. However, karst aquifers present a set of characters which make them difficult to explore and to exploit particularly in Mediterranean coastal regions.

The purpose of the paper is to briefly remind the characteristics of karst aquifers, and how they constrain the investigation methods as well as the functioning under natural and exploitation conditions. Furthermore, the methodology for exploring, exploiting and protecting their ground water resource will be summarised. At last, the specificity of Mediterranean coastal karst will be presented in order to point out the methodological and technological problems. In a second paper, technological solutions facing these problems will be presented.

CHARACTERISTICS OF KARST AQUIFERS AND METHODOLOGICAL CONSEQUENCES

In a karst aquifer (fig. 1), a conduit network draining the aquifer develops in such a way as ground water flow paths are organised from the recharge area to the discharge point, i.e. the spring; this is the karst network which is a flow-driven heterogeneity. Karst aquifers are definitely characterised by the presence of conduits and large voids in which storage and flow are considerable. However these zones are rare and difficult, even impossible to be localised from the surface, by any method, geophysical as well as geological investigations. Despite that difficulty, the ground water resource is often easily exploitable from the springs which are the downstream end of the karst network.

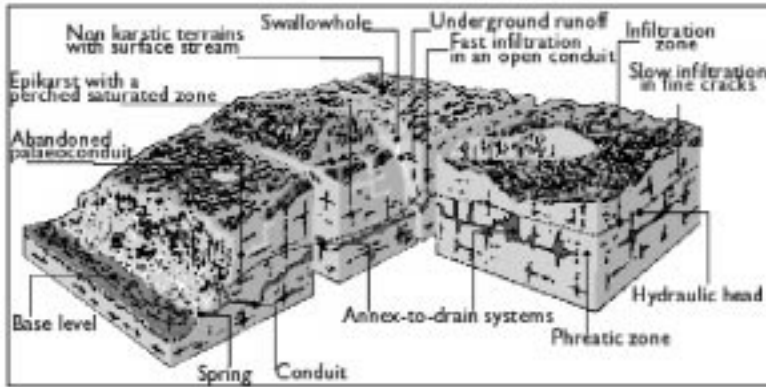


Figure 1. Synthetic representation of the karst aquifer (from Mangin, 1976, modified).

The main consequence is that the classical hydrogeological approach adapted to porous aquifers is inefficient in karst aquifers. Porous aquifers which can be considered as homogeneous at a regional level, may be explored from wells and bore holes and by geophysical techniques. Karst aquifers are characterised by a heterogeneity as high as bore holes are commonly unsuccessful; pumping tests cannot be interpreted by the way of classical models which are inappropriate and their results cannot even be extended to a part of the aquifer. Moreover, geophysical methods are frequently inefficient because of either the too low electrical resistivity of the medium or of the too small dimension of the voids compared to their depth below the ground surface. Consequently the investigation and exploitation methods must be adapted to karst specificity.

Therefore the flow-driven heterogeneity should only be approached by taking into account the whole karst network in its organisation and by its functioning. Consequently, the study of karst aquifers is based on a specific approach considering the karst system, i.e. the whole recharge area of a karst spring which determines and contains the karst network. On a practical point of view, the karst network must be the pinpoint for the exploitation of ground water, because it is the place of high transmissivity and of high flow rate potential.

Consequently for characterising and assessing the ground water resource in karst regions, the investigations obviously require important man and time resources, because it should be led at the system scale (commonly several tens of square km), for at least a hydrological year. In that goal, the spring is the main target for exploration as well as for exploitation.

In France, CNRS and BRGM research teams (Bakalowicz and Lachassagne, 1998) developed a general investigation methodology well adapted to the specificity of these resources, and an exploitation approach for managing and protecting the ground

water resource. That methodology is based on hydrodynamical and hydrogeochemical data from the main outlet of the karst systems; it consists of analysing the aquifer behaviour in order to survey or to exploit the resource. Many case studies showed that this approach is particularly convenient and efficient for karst aquifers, and that the classical hydrogeological approach of porous and fissured aquifers, based on geophysical exploration, boring of wells and pumping tests, does not response to the necessary sustainable exploitation of karst ground water resource.

That comprehensive methodology allows to identify and characterise the aquifer, to demonstrate and assess its exploitation condition, and to assess its vulnerability and propose management scenarios. By this step-by-step methodology, the recharge and discharge conditions are defined. The karst aquifer is characterised from its behaviour, at the aquifer level. The presence of a karst conduit network is identified, as well as its functioning or non-functioning. The importance of the storage in the phreatic zone is evaluated. The aquifer vulnerability is finally assessed.

COASTAL KARST AQUIFERS AND THE EVOLUTION OF KARST IN THE MEDITERRANEAN REGIONS

Coastal karst aquifers are subject to sea water intrusion, under natural conditions. They also may discharge partly into the sea or into coastal lagoons, at depth down to few tens meters. Sea intrusion as well as submarine springs are obviously related to changes in the karst base level, in connection to either tectonic subsidence or sea level rise. Changes in sea level are well documented during Quaternary times. They are related to glaciations which lowered the ocean level and to deglaciations; the maximum variation does not exceed 150 m.

However, in the Mediterranean basin, the magnitude of the variation was much larger than elsewhere: the Mediterranean sea lowered down to 1500 m, at the end of Miocene, 5.5 millions years ago. This was the Messinian crisis. The change in the base level was at the origin of an important entrenchment of the main valleys, which developed in rias and canyons, such as the Rhone canyon, about 800 m deep in Avignon area (Clauzon, 1982). Karst consequently developed deeply below the present sea level. Most of the known deep karst, for example in the Aix-en-Provence basin, at North of Marseille, or large brackish coastal springs, for example Fontestramar in France, Almyros of Heraklion in Crete island, should be related to the Messinian karst phase. Recent investigations by Arfib (2001) on Heraklion karst showed from the modelling of the spring functioning that the sea water intrudes into karst conduits most likely around 450 m below the present sea level. That depth of karst development is in good agreement with the geological structure and with the assumption of a deep karst development. That situation favours either the sea intrusion in the coastal aquifers, or the point discharge at submarine springs.

The effects of the Messinian sea level lowering are not yet fully assessed. The deepening of karst at that time had obviously much more important consequences on karst development than the later changes in sea level occurring during the glacial periods. During glacial times, and particularly during the Würm, the sea dropped only down to 120 m. Moreover the very cold climate on the European continent was not at all favourable to karst development, contrarily to what happens during the Messinian.

CONSEQUENCES ON AQUIFER CHARACTERISTICS AND FUNCTIONING

The very complex evolution of Mediterranean karsts has some important hydrogeological consequences on ground water resource:

- it exists deep karst features, which are flooded and work as huge storage structure in very wide aquifers;
- vertical conduits, which were created as karst inputs, act now as drains for these deep storage and as present day outputs;
- conduits existing below sea level may work as output of fresh water directly in the sea as well as input of sea water, depending on difference in water heads and water density between sea and fresh water;
- the phreatic zones may leak directly in the sea through open or clogged conduits or fractures.

METHODOLOGICAL CONSEQUENCES

Therefore the exploration methodology developed for karst aquifers is difficult to operate, because the output cannot be monitored. The springs are submarine, or if they exist at the coast, they work as overflow. Then the information from the monitoring of such springs is not reliable, particularly concerning the resource, the storage capacity and the functioning of the aquifer.

Moreover, the natural sea water intrusion makes difficult to extract the information related to the fresh water flow, particularly because sea level variations strongly influence the water head and discharge at the spring. Consequently, the functioning of coastal karst aquifers was never studied in details and is roughly approached. The recent work by Arfib (2001) of a coastal karst aquifer in Crete Island points out the difficulties, and also presents some new and very interesting results.

Consequently, the exploitation methodology is very problematical. Pumping for water supply from a submarine spring is presently unlikely. Moreover, pumping from inland wells is hazardous, even if the wells are located far from the coastline. Pumping commonly promotes the sea water intrusion through karst conduits, what produces a salinisation of the aquifer even if it is not overexploited. Such a situation requires moderate pumping rates and a monitoring of the ground water quality in a control well network (Mangin *et al.*, 1996).

THE EXAMPLE OF THE VISE SPRING AND THE THAU LAGOON SYSTEM

The knowledge of the submarine discharge and their monitoring are the key points of the strategy for exploring and exploiting the resource. In favourable hydrogeological conditions, or when submarine springs are the only known water resource, the exploitation of submarine springs should be attempted.

A preliminary study of a karst spring discharging into the Thau lagoon (southern France) gave the bases of an adapted methodology. The Thau karst system extends over 225 km² in the Jurassic limestones and the associated sediment formations. The system is recharged through direct infiltration, point infiltration into swallow holes and possible leakage of overlaying aquifers. It discharges at several permanent springs, some of them being brackish during low stage, at an overflow spring which is the main outflow during floods, and at a submarine spring at the bottom of a 30 m depth depression in the Thau coastal lagoon (Doerfliger *et al.*, 2001). Leakage of that aquifer is assumed to discharge into the deep Jurassic regional aquifer which feeds the Balaruc thermal springs (Aquilina *et al.*, 2002).

The management of the lagoon, mainly for tourism and shell and fish farming, is quite difficult because of the multiple uses of continental and marine waters. A hydrologic balance was attempted in quantity and quality, in order to improve the water quality and the fresh water flux to the lagoon. However some problems remain, such as toxic algal blooms, which have an effect on the shell quality and then endangered the economy of the region. The actual contribution of the ground water to the water budget and quality of the system was not known precisely, so that the problems were assigned to the unknown submarine spring.

Therefore the regional administration asked for the study of the ground water flux from the submarine spring. The imposed condition was not to modify the natural outflow conditions. The outflow was captured from a small fracture lateral to the main spring at 30 m below the lagoon surface and a 200 m long pipe (30 mm in diameter) drove the water on the shoreline, in a monitoring device, for measuring the water head, the electrical conductivity and the temperature. Because the measured water head is not the real one (the whole outflow is not captured), it is partly influenced by the lagoon level variation. Therefore the lagoon level is also monitored. The real aquifer water head time series may be extracted from the two monitored series; it is only a relative information, the real water head and the discharge remaining unknown.

Consequently, the fresh water plume above the submarine spring was surveyed during low stage of the aquifer, for its temperature and electrical conductivity, from a boat. The aim was to estimate the submarine ground water discharge. Rough estimates by divers and fishermen suggested flow rates in the range 0.5-1.0 m³/s, i.e. more than the nearest permanent spring of the system.

The instant flow rate was estimated by comparing the observed plume to modelled plumes for different flow rates values, between 0.1 and 1.0 m³/s, from the temperature data. The comparison indicates that the real flow rate was lower than 0.1 m³/s. That value was in good agreement with some other data, such as the hydrologic balance of the system.

However any calibration curve relating the flow rate to the relative water head could not be elaborated, because the survey of the plume requires 3 days, with

permanent flow regime and excellent climatic conditions. Consequently, the discharge of the submarine spring remains unknown.

CONCLUSION

The knowledge of coastal and submarine karst spring functioning is of absolute necessity for a sustainable use of ground water resources in their quantity and quality. Their functioning cannot be approached by monitoring the water level in coastal bore holes or the discharge of coastal springs. The submarine springs must be monitored not only for their water head variations, but also for their discharge. A specific methodology must be developed for this purpose.

REFERENCES

- Aquilina, L.; Ladouche, B.; Doerfliger, N.; Seidel, J. L.; Bakalowicz, M.; Dupuy, C.; Le Strat, P.; 2002. *Origin, evolution and residence time of saline thermal fluids (Balaruc springs, southern France): implications for fluid transfer across the continental shelf*. Chemical Geology, (1-2): 1-21.
- Arfib, B. 2001. *Étude des circulations d'eaux souterraines en aquifère karstique côtier: observations et modélisation de la source saumâtre Almyros d'Héraklion, Crète (Grèce)*. Doctorat Thesis, Paris VI - Pierre et Marie Curie, Paris, 343 pp.
- Bakalowicz, M. and Lachassagne, P. 1998. *De nouvelles révolutions techniques pour la mise en valeur des aquifères discontinus : aquifères de socle et aquifères karstiques*. Conférence Internationale " Eau et développement durable ", Paris.
- Clauzon, G. 1982. *Le canyon messinien du Rhône: une preuve décisive du "dessicated-deep model" (Hsü, Cita et Ryan, 1973)*. Bull. Soc. Géol. France, 24 (7): 597-610.
- Doerfliger, N.; Ladouche, B.; Bakalowicz, M.; Pinault, J.L. and Chemin, P. 2001. *Étude du pourtour est de l'étang de Thau, phase II. Synthèse générale (Volume 4)*. Report BRGM RP-50789-FR, BRGM.
- Mangin, A. 1975. *Contribution à l'étude hydrodynamique des aquifères karstiques*. Ann. Spéléol., 29 (3): 283-332; 29 (4): 495-601; 30 (1): 21-124.
- Mangin, A.; Knithakis, M.; Bakalowicz, M.; Papadopoulos, C. and D'Hulst, D. 1996. *Hydrogéologie des aquifères carbonatés de la région d'Agios Nikolaos (Crète, Grèce)*. Report IGME (Greece) & CNRS (France), Rethymnon (Crete, Greece) & Moulis (Ariège, France).