COMBINING OUTCROP RESERVOIR CONCEPTUAL MODELS AND SUBMARINE GROUNDWATER DISCHARGE MAPPING TO CHARACTERIZE COASTAL AQUIFERS: KARST AQUIFER VS. MATRIX AQUIFER

Arnaud Fournillon*, Bruno Arfib, Aurélie Tassy, Jean Borgomano
Laboratoire de Géologie des Systèmes et Résevoirs Carbonatés Case 67, Université de Provence
3 place Victor Hugo, 13003 MARSEILLE, FRANCE
Tel: +33-04-91-10-62-97, Fax: +33-04-91-10-85-23, E-mail: afournillon@gmail.com

ABSTRACT

This paper illustrates how to characterize coastal aquifers by combining conceptual reservoir models and measures of the Submarine Groundwater Discharge (SGD). The reservoir models are based on outcrops observations and thin-sections petrographic analysis. The SGD characterization is based on a survey of the sea surface salinity (SSS). Two neighbor aquifers have been chosen for the comparison: a karstic type aquifer and matrix type aquifer. The results point out that karstic aquifers have SGD only in a few concentrated points as expected. The results also show that the matrix type aquifer has both diffuse and slightly concentrated flow. The conclusions provided by the reservoir conceptual models and the SGD delineations are in good agreement.

INTRODUCTION

With the increase of the world population living near the shore, the management of coastal groundwaters has become a major challenge in hydrogeology. The SGD is a major component for the transfers between land and sea, especially for the transfers of nutrients and pollutants [1]. The SGD is a widespread phenomenon which can be either diffuse or concentrate [2].

The patterns of the SGD are multiple and they depend on numerous parameters, including geological factors. The aim of the paper is to characterize coastal aquifers by comparing measures of the SGD and outcrop-based conceptual reservoir models of the concerned aquifers. Two different aquifers, in the same climatic settings, have been chosen: a karst type aquifer and a matrix type aquifer

STUDIED AREA AND RESERVOIR MODELS

The studied area is part of the littoral zone of Provence (S.E. France, fig. 1). The two considered aquifers are cropping out about 5 km one from another and they are separated by impervious marls.

The first considered aquifer, which crops out in the Calanques area, is composed by 400 m of karstified urgonian limestones. Two important submarine springs, named Port-Miou spring and Bestouan spring, represent the outflow this aquifer. Their mean flow is about between $5m^3/s$ and $10\ m^3/s$ [3], coming from two pluri-kilometer long submerged karsts conduits. The matrix of this aquifer is very tight, between 0% - 1% of porosity. The observations on outcrops show numerous fractures and faults at different scale: from intra-bed scale to the whole outcrop. Most of the fractures are solution-enhanced, showing the development of small karsts. The thin-sections analysis points out that the only figured porosity is due to solution-enhanced micro-fractures. The resulting conceptual model is that the porosity of the aquifer is thought to be in the micro-fractures, and the permeability in the main karstic pipes. The link between these two scales, and between the stored water and the dynamic water, would be in the intermediate scale of fractures, i.e. centimeter- to decameter-scale.

The second considered aquifer, which crops out in the LaCiotat Bay area, is composed by 600 m of silty and sandy limestones. Water balance calculations indicate that this aquifer drains between 300L/s and 600L/s depending on its effective infiltration. However none inshore outlet is known. Founier and Borgomano [4] have measured petrophysical properties on 22 samples of this aquifer. The matrix porosity ranges between 2% and 24%. The outcrops observations show stratifications with beds alternating between clean rocks and decalcified rocks. The whole outcrop has also been weathered in some places, forming alluvial depressions. Some decameter-scale fractures and faults are also present. These fractures are often subject to oxidation processes and some solution processes. These two processes are due to the circulation of the freshwater in the discontinuities of the rocks. The conceptual reservoir model lead to the definition of several flow units: slow flow units present in permeable matrix and fast flow unit in the weathered zone and in the fractured zone. The stored water is mainly in the matrix. This aquifer is probably multi-layered with a succession of small aquifers in the decalcified rock beds and of small aquicludes in the clean rock beds. Then, the aquifer could potentially be partially confined.

SGD MAPPING

The SGD have been mapped by measuring the sea salinity surface with a Seabird SPE 19 salinity probe. This probe has been attached to a vessel that has cruised across the two studied areas. The accuracy of the salinity measures is 0.01 PSU. The values of salinity have then been interpolated by ordinary kriging. The resulting maps are presented fig. 1 and fig. 2.

The salinity measured in the Calanques area ranges between 19.35 PSU and 38.09 PSU. The map of the interpolated salinity (fig. 1) shows that the freshwater outflow is concentrated only in a few points. Each point of outflow is plume-shaped. Two main outlets are visible

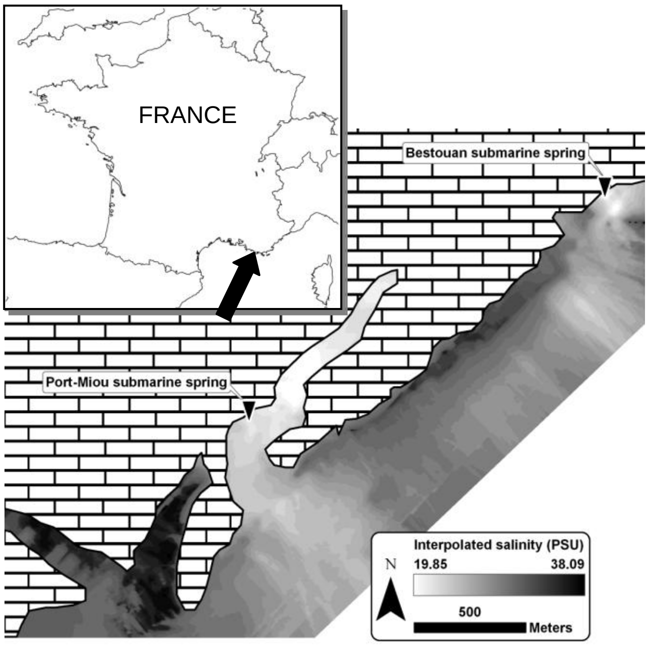

Fig 1 Location of the studied area and extract of the map of the interpolated salinity of the karstic aquifer (Calanques area).

which correspond in the two main submarine springs. Some smaller outlets appear also. Between each freshwater discharge zone the salinity remains very high, i.e. normal sea surface salinity.

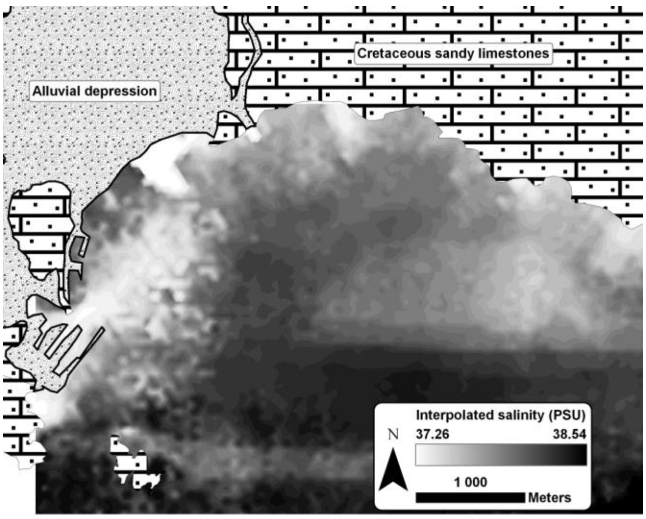

Fig 2 Extract of the map of the interpolated salinity of the matrix aquifer (LaCiotat Bay area).

The salinity measured in the LaCiotat Bay area ranges between 37.26 PSU and 38.54 PSU. The map of interpolated salinity (fig. 2) shows zones of weaker salinity just in front of weathered zones, alluvial depression, and in some places near to the coast. These places correspond to fractures and faults zones. Another underlined point is the relative low salinity remaining allover the LaCiotat Bay, between 37.6 PSU and 37.9 PSU, compared to the normal sea surface salinity, more than 38 PSU. This phenomenon is generally due to diffuse freshwater outflow [5].

CONCLUSION

In the Calanques area, the SGD mapping has pointed out that, as expected by the reservoir model, the groundwater flow is only concentrated in karstic features. The high salinity zone between each spring could be explained by a saline intrusion around the karst pipes [6].

In the LaCiotat Bay area, the SGD mapping has shown that alluvial depressions are the main groundwater vehicle. The relative low salinity all over the bay could be explained by the presence of small confined aquifers whose discharges are more offshore than those of alluvial depressions.

The combination of outcrop reservoir models and of SGD mapping has lead to a better understanding of two coastal aquifers. The information brings by the reservoir concepts and by the salinity survey are in good agreement and complementary. Indeed the hypothesis set by the reservoir model enlighten the analysis of salinity map. Such hydrogeological characterizations could be a useful tool for the implantation of wells for the water supply in coastal areas.

ACKNOWLEDGEMENTS

This paper is part of the KarstEAU project funded by the “Agence de l’Eau Rhône-Méditerranée-Corse”, the “Conseil Général du Var”, the “Conseil Général des Bouches-du-Rhône” and the “Région Provence Alpes Côte d’Azur”. Authors are very grateful to Eric Gilli for his implication during the salinity survey.

REFERENCES

[1] UNESCO : *Submarine groundwater discharge. Management implications, measurements and effects, Paris* (2004).
[2] W.C. Burnett, P.K. Aggarwal, A. Aureli, H. Bokuniewicz, J.E. Cable, M.A. Charette, E. Kontar, S. Krupa, K.M. Kulkarni, A. Loveless, W.S. Moore, J.A. Oberdorfer, J. Oliveira, N. Ozyurt, P. Povinec, A.M.G. Privitera, R. Rajar, R.T. Ramessur, J. Scholten, T. Stieglitz, M. Taniguchi & J.V. Turner: *J. of Total Env.*, **367** (2006), 498-543.
[3] B. Blavoux, E. Gilli & C. Rousset: *C. R. Geoscience*, **336** (2004) 523–533.
[4] F. Fournier & J. Borgomano: *Geophysics*, **74** (2009), E93-E109.
[5] M.J. Byrne & J.N. Gabaldon**:** *Hydrodynamic Characteristics and Salinity Patterns in Estero Bay, Lee County, Florida*, USGS/SIR (2007).
[6] A. Tassy, B. Arfib & E. Gilli: *Advances in research in karst media*, Springer, Berlin Heidelberg New-York (2010) in press.