Annales de la Société Géologique de Belgique, T. 108 - 1985, pp. 43-47

HETEROGENEITY OF PERMEABILITY IN KARST AQUIFERS AND THEIR VULNERABILITY TO POLLUTION. EXAMPLE OF THREE SPRINGS IN THE CAUSSE COMTAL (AVEYRON, FRANCE)

by

Elisabeth Dominique DODGE [1]

(1 figure)

ABSTRACT.- Karst aquifers are vulnerable to pollution because of the rapid circulation of groundwater through very permeable channels.

Water quality depends therefore on the extent of development of the channels and the permeability of the blocks of rock between them.

These parameters can be deduced from an analysis of karst features and of the hydrodynamics and hydrochemistry of springs.

Within one particular karst region, the parameters may vary from basin to basin, as observed in the Causse Comtal (Aveyron, France). An understanding of these factors is a considerable asset in directing projects concerning the use of groundwater.

RESUME.- Hétérogénéité de la perméabilité des aquifères karstiques et leur vulnérabilité à la pollution. Exemple de trois sources dans le Causse Comtal (Aveyron, France).
Les aquifères karstiques doivent leur vulnérabilité à l'existence de conduits très perméables, siège de circulations rapides.

Ainsi, la qualité des eaux est conditionnée par le développement des conduits et par la perméabilité des blocs entre les conduits.

Ces paramètres peuvent être déduits de l'analyse de la karstification, de l'hydrodynamique et de l'hydrochimie des exutoires.

Ils peuvent varier d'un bassin à un autre au sein d'une même région, comme observé au Causse Comtal (Aveyron, France). Leur connaissance permet d'orienter favorablement des projets d'exploitation des eaux.

1.- INTRODUCTION

Hydrogeological research on karst aquifers began early in the twentieth century and was influenced by conflicting ideas in which the "underground river" theory was opposed to the "water table" theory.

Progress achieved today indicates that the specificity of karst hydrogeology is due to the coexistence and interaction of highly permeable channels and of the low-permeability blocks of rock around them. The initial theories have thus been reconciled and supplemented.

This concept of heterogeneity of permeability, called "double porosity" (Babushkin *et al.*, 1975; Burger, 1980), is very important in understanding the behaviour of pollution in karst terrain.

2.- DOUBLE POROSITY IN KARST AQUIFERS

Solution channels develop along partially open fractures, during the karstification process, through a gradual enlargement phenomenon. This leads to a small number of underground drainage trunks which, even in a highly karstified massif, only represent a small percentage of the total volume. The channels do not therefore contribute much to the water capacity. On the other hand, they have major effects on the hydrodynamics as they allow fast water circulation with velocities of 10^{-1} m/s (360 m/h) or more.

Between solution channels poorly karstified or unkarstified blocks of rock remain. In their fine fractures and interstices, water circulation is slow. Measurements by injection or by pumping tests, from boreholes in the blocks, indicate permeability ranging from 10^{-5} to 10^{-7} m/s (Kiraly, 1978).

1 *Laboratoires Associés de Géologie-Pétrologie-Géochronologie, Université Libre de Bruxelles, 50, av. F.D. Roosevelt, B 1050 Bruxelles (Belgique).*

Unlike the channels, the blocks themselves have high water capacities and contain most of the karst water reserves.

During low water conditions, water previously stored in the blocks by slow infiltration or during floods, is drained by the channels towards the discharge points.

On the contrary during flood conditions, if the discharge through the channel network is insufficient or inferior to the inflow, the channels act as feeders. Water pressure rises in them, injecting water into the fissures and interstices of the blocks and thus recharging them.

3.- FACTORS INFLUENCING WATER QUALITY IN THE CAUSSE COMTAL

Research carried out in the Causse Comtal (Dodge, 1982, 1983a and 1983b), especially analysis of karst features and of the hydrodynamics and hydrochemistry of springs, has made it possible to estimate the development of solution channels and the heterogeneity of permeability in different basins in this area. It is now possible therefore to predict pollution behaviour in the aquifer and its effect on water quality, in springs and in the water table, before catchment projects are launched.

The three springs described in this paper illustrate various hydrogeological characteristics encountered.

1. GEOGRAPHICAL AND GEOLOGICAL SITUATION OF THE CAUSSE COMTAL

The Causse Comtal is part of the geological structure of the Détroit de Rodez, which is situated south-west of the Massif Central, between the Causses du Quercy and the Grands Causses, in the Aveyron Department.

The aquifers are located in three superimposed subhorizontal jurassic carbonate series which cover a total area of 265 km^2. The carbonate series are separated by impermeable clay formations.

The Upper and Lower Aquifer Series, each about a hundred meters in thickness, contain the major hydrogeological and karst features, among which, are those described hereunder.

The Lower Aquifer Series consists of a supratidal azoic dolomicritic formation overlaid by a limestone formation of oolitic and bioclastic grainstones.

The Upper Aquifer Series is formed by coarse grained diagenetic saccharoid dolomites also overlaid by oolitic and bioclastic limestones.

2. SALLES-LA-SOURCE SPRING

a) Introduction

The biggest spring in the Causse Comtal region is located at Salles-la-Source at the base of the Upper Aquifer dolomite formation. It drains a basin covering approximately 52 km^2, limited by two east-west oriented faults.

The Causse Comtal s.s. massif forms a slight syncline in which underground flow follows the 0.6 °/o westerly submergence, towards Salles-la-Source.

b) Karst phenomena

The Upper Aquifer limestone formation, which covers most of the Salles-la-Source basin, shows important surface karstification features. There are on an average, over ten dolines per square kilometer, and Kluftkarren lapiés have also been observed (Dodge, 1981, 1983a and 1983b).

Many caves are known and have been listed and described (Mugnier, 1962, 1976, 1979 and 1981). The main caverns are the Tindoul de la Vayssière, the Salles-la-Source Underground Delta, and the Aven de Vayssettes. These are respectively 2394 m, 1557 m and 416 m long.

The entrance to the Tindoul de la Vayssière, in the central part of the basin, is a large collapse doline. It leads to a major karst channel with an underground river, situated 65 m below the surface. Parts of the gallery are submerged even in the dry season, and the cave can become totaly flooded in wet conditions (Chouquet & Penez, 1983).

Five kilometers west of the Tindoul, several permanent and temporary springs are related to the Salles-la-Source Underground Delta, which is an interconnected horizontal cave network.

Dye experiments carried out from a sewage treatment plant discharge and from the underground river in the Aven de Vayssettes, both over 12 km from Salles, confirm the relationship between the eastern part of the massif, the Tindoul de la Vayssière and the springs at Salles (Dodge, 1983b). They also indicate very fast water flow in this direction : 57 m/h in October 1981 and over 180 m/h during flood conditions in August 1983. This implies that the karst channel network, part of which is observed at the Tindoul, is also well developed in other parts of the basin.

c) Hydrodynamic characteristics

The discharge at Salles-la-Source ranges from 35 l/s to over 10000 l/s. The hydrogram shows fast reaction to pluviometric impulses during floods, with high maximum discharge values. The ratio of annual maximum to minimum discharge values is between 150 and 300.

In the dry season a "base flow" of 1 to 1.5 $l/s.km^2$ is observed. This discharge is due to the draining of water stored in the blocks. The discharge slope is 0.025 ($days^{-1}$) on a semi-log daily hydrogram.

This discharge pattern is characteristic of a basin drained by a network of well enlarged solution channels and in which karstification is widespread. The blocks in such a case are relatively permeable.

Hydrodynamic analysis also shows that, for floods under 2 m^3/s, the recharge of the blocks depends mainly on slow vertical infiltration and not on injection phenomena from the channels.

d) Hydrochemical characteristics

Owing to the relative solubilities of calcite and dolomite and their solution rates, and the fact that the limestone formation lies above the dolomite formation in the aquifer, water hardness at Salles-la-Source is not a direct function of the time water remains in the aquifer.

Nevertheless, the water chemistry fluctuations recorded during floods and the shape of the water hardness frequency histogram (Bakalowicz, 1979) indicate an advanced stage of karstification and largely agree with the results obtained by other methods and by direct observation (fig. 1).

e) Vulnerability to pollution

The hydrogeological characteristics of the Salles-la-Source basin renders the Salles spring water very vulnerable to pollutants which affect precise areas, such as dolines, karst water losses and avens. These sites are directly connected to underground channels where no filtration takes place. Dye experiments show rapid and concentrated expulsion. Pollution trapping followed by subsequent expulsion during floods, as described by Maire (1979), may also take place in the channels.

On the other hand, much of the spring's discharge comes from the blocks which to some extent dilute the pollution flowing in the channels.

During the dry season, the channels allow easy drainage and contamination is evacuated to discharge points. This has the advantage of preserving water quality in the blocks. Furthermore, the recharge mechanism in the blocks is such that water reserves are relatively well protected from contamination by pollution flowing in the channels. Catchment projects, by borehole pumping in the blocks, some distance from the main channels, could therefore be considered in the Salles-la-Source basin.

3. ROQUEMISSOU SPRING

a) Introduction

Part of the Causse Comtal s.s. massif situated east of Salles-la-Source basin is drained towards Roquemissou spring, on the right bank of the Aveyron river.

The basin covers approximately 5 km^2 and is mainly formed of coarse grained saccharoid Upper Aquifer dolomites.

At the present time, the spring supplies the commune of Montrozier with an annual 10000 m^3 of drinking water.

b) Karst phenomena

Surface karst features on Roquemissou basin consist of some dolines and a dry valley a few hundred meters long, leading to the spring. No caves are known in this area.

c) Hydrodynamic characteristics

The discharge at Roquemissou ranges from 24 l/s to approximately 1000 m^3/s; the ratio of annual maximum to minimum discharge values is below 42. This very low discharge variability at Roquemissou, contrasts with other karst springs in the Causse Comtal and indicates important damping of inflow impulses by the aquifer. Maximum discharges during floods are low and are followed by a very gradual decrease in discharge.

Due to the damping of impulses, the specific discharge modulus during the dry season is as high as 5 $l/s.km^2$ and the semi-log discharge slope is near 0.006 ($days^{-1}$).

These hydrodynamic characteristics imply relatively homogenous permeability, high specific yield, and no or only poorly developed solution channels in the basin.

d) Hydrochemical characteristics

The damping of impulse signals by the aquifer, attributed to reduced functional karstification is confirmed by the low range of hydrochemical variations for all analysed ions (Ca^{++}, Mg^{++}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{--}, Cl^{-}) during floods.

Water hardness varies between 25°f and 29°f only, and shows unimodal frequency distribution (fig. 1).

e) Vulnerability to pollution

The absence of major solution channels and of fast circulation in the aquifer means that any pollution tends to be diluted and eliminated gradually.

Furthermore, regular discharge rates and a high specific modulus in summer are interesting advantages to be considered in catchment projects.

On the other hand, the recharge mechanisms in this kind of aquifer, where pollution evacuation to discharge points is difficult, increase the risk of long-term contamination of the reserves.

4. BOZOULS SPRING

a) Introduction

The carbonate terrain of the Lower Aquifer forming the Causse de Bozouls, in the north-eastern part of

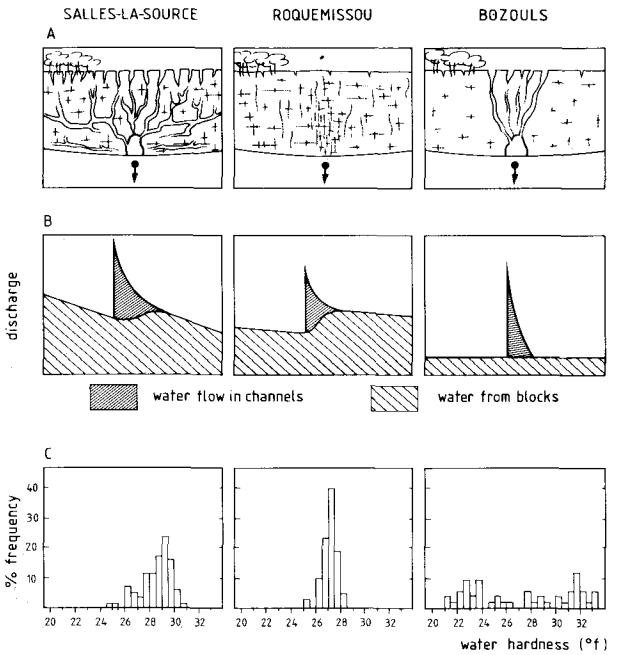

Figure 1

Comparison of hydrogeological characteristics in three basins of the Causse Comtal: Salles-la-Source, Roquemissou and Bozouls.

A. Illustration of aquifer structure and permeability.

B. Schematic semi-log hydrograms showing influence of blocks and channels.

C. Water hardness frequency histrograms (based on 91, 45 and 50 samples analysed in 1981).

Figure 1

Comparaison des caractéristiques hydrogéologiques de trois bassins du Causse-Comtal: Salles-la-Source, Roquemissou et Bozouls.

A. Illustration de la structure de la perméabilité de l'aquifère.

B. Hydrogrammes semi-logarithmiques schématiques montrant les influences respectives des blocs et des chenaux.

C. Histogrammes de fréquence de la dureté des eaux (basés respectivement sur 91, 45 et 50 échantillons analysés en 1981).

the study area, slope towards the south west with a 3 o/o dip.

Ten square kilometers of the Causse de Bozouls is drained in this direction towards Bozouls spring, located in the dolomicritic formation, near the base of aquifer.

b) Karst phenomena

Surface karst features on Bozouls basin consist of rare dolines and a one kilometer long dry valley leading to the spring.

A hundred and fifty meters from the spring, and hydrogeologically related to it, is the Grotte de l'Espoir on the right bank of the Dourdou river.

The cave is over two kilometers long and occupies a geological position similar to that of the Bozouls spring. In many places the cave leads to underground lakes and streams (Mugnier & Pelissier, 1976).

c) Hydrodynamic characteristics

The discharge at Bozouls ranges from 10 l/s to about 5000 l/s. Hydrodynamic reactions are rapid and well-marked during floods and are followed by a rapid decline in discharge. The ratio of annual maximum to minimum discharge values is high, between 100 and 550 (fig. 1). Fast circulation in solution channels is therefore indicated as at Salles-la-Source.

The specific discharge modulus, of 0.6 to 1 $l/s.km^2$, is inferior to that of Salles-la-Source. At Bozouls, the semi-log discharge slope is also very low : 0.001 ($days^{-1}$).

Limited but rather constant discharge during the summer suggests that the specific yield of the blocks is low.

Permeability in the Bozouls aquifer therefore appears even more heterogeneous than that of Salles-la-Source, with a strongly marked contrast between the channels and the blocks.

d) Hydrochemical characteristics

Calcium and magnesium contents in the water at Bozouls are directly correlated and vary inversely to the spring discharge. The rapid hydrochemical fluctuations during floods are responsible for water hardness values ranging from 21°f to 34°f (fig. 1).

These results confirm the hypothesis of a marked permeability contrast between blocks (low permeability and highly mineralized water) and channels (well-developed, with fast flow of water with low mineral content through the aquifer).

e) Vulnerability to pollution

Our results show that the Bozouls basin is drained by a network of functional solution channels. Consequently, any pollution entering this network will result in rapid and concentrated pollution at the spring, especially as the blocks offer little possibility of dilution.

Furthermore, the poor permeability of the blocks limits their value in water catchment projects.

4.- CONCLUSIONS

Research by direct observation of karst features coupled with analysis of spring hydrodynamics and hydrochemistry show that hydrogeological characteristics may vary greatly from one basin to another, even within one lithological formation.

Although all karst aquifers tend to be vulnerable to pollution and therefore require careful protection, some basins are quantitatively and qualitatively more suitable for groundwater use than others.

Projects can be directed on the basis of knowledge of the relative permeabilities of channels and blocks and of possible interactions between them in different hydrodynamic conditions.

In the Causse Comtal area, results indicate that the features of the Roquemissou basin render it suitable for the direct use of spring water. In the Salles-la-Source basin, on the other hand, basin projects should be directed towards pumping in the blocks. Finally, the features of the Bozouls basin are such that groundwater projects should be avoided there.

BIBLIOGRAPHY

BABUSHKIN, V.D. *et al.,* 1975. Regime of subterranean water flows in karst regions. *In :* Hydrology of karstic terrains, I.A.H., Int. Union of Geol. Sc., series B, 3 : 69-77.

BAKALOWICZ, M., 1979. Contribution de la géochimie des eaux à la connaissance des aquifères karstiques et de la karstification. Doct. thesis, Univ. P. and M. Curie, Paris VI, 269 p.

BURGER, A., 1980. Effets hydrodynamiques et hydrochimiques de la double porosité dans les aquifères karstiques du Jura Central. Vol. Hommage à L. Calembert, Ed. C. Thone, Liège : 33-41.

CHOUQUET, J.C. & PENEZ, P., 1983. Explorations des siphonistes Spéléo Ragaï - 1982 - Tindoul de la Vayssière, Spelunca, July-September, 1983, 11 : 7.

DODGE, E.D., 1981. Quelques observations sur la géologie, l'hydrogéologie et la karstification du Causse Comtal. Grands Causses, Ann. 6e and 7e congress : 59-77.

DODGE, E.D., 1982. Mise en évidence par traçage des conséquences d'une éventuelle pollution des eaux souterraines sur le Causse Comtal. Actes du 3e colloque d'Hydrologie en Pays Calcaire, Ann. Sc. de l'Univ. de Besançon, Géologie, Mém. 1 : 89-96.

DODGE, E.D., 1983a. Répartition quantitative des phénomènes karstiques superficiels et souterrains en fonction de la lithologie sur le Causse Comtal. Karstologia, 1, 1983 : 25-32.

DODGE, E.D., 1983b. Hydrogéologie des aquifères karstiques du Causse Comtal (Aveyron, France). Doct. thesis, Faculté des Sciences, Univ. Libre de Bruxelles, 621 p.

KIRALY, L., 1978. La notion d'unité hydrogéologique, essai de définition. Bull. Centre d'Hydrogéol., Neuchâtel, 2 : 83-216.

MAIRE, R., 1979. Comportement du karst vis-à-vis des substances polluantes. Colloque franco-belge de Karstologie Appliquée, Ann. Soc. géol. Belgique, 102 : 101-108.

MUGNIER, C., 1962. Essai sur l'hydrologie et la paléohydrologie du Causse Comtal (Aveyron). Ann. de Spéléo., 17 : 509-537.

MUGNIER, C., 1976. Premier supplément à l'inventaire spéléologique du Causse Comtal et de ses satellites (Aveyron). Ann. 1°, 2° and 3° congress, Grands Causses : 211-258.

MUGNIER, C., 1979. Deuxième et troisième suppléments à l'inventaire spéléologique du Causse Comtal et de ses satellites (Aveyron). Ann. 4° and 5° congress, Grands Causses : 319-336 et 337-371.

MUGNIER, C., 1981. Quatrième supplément à l'inventaire spéléologique du Causse Comtal et de ses satellites (Aveyron). Ann. 6° and 7° congress, Grands Causses : 221-240.

MUGNIER, C. & PELISSIER, J.L. and R., 1976. La Grotte-résurgence de l'Espoir et son bassin d'alimentation (Bozouls, Aveyron). Spelunca, 4 : 165-168.