Vingtièmes journées techniques du Comité Français d'Hydrogéologie
de l'Association Internationale des Hydrogéologues.
« Aquifères de socle : le point sur les concepts et les applications opérationnelles » La Roche-sur-Yon, juin 2015

The assessment of groundwater body status in hard rock regions

Gabion D. [(1)], Baran N., Bourgine B., Gourcy L., Gutierrez A., Lopez B., Mardhel V., Pinson. S, Stollsteiner P., Surdyk N., Thiéry D., Wuilleumier. A [(2)], GEOHYD [(3)]

(1) Agence de l'Eau Loire-Bretagne - Direction de l'Evaluation et de la Planification
(2) Bureau de Recherche Géologique et Minière (BRGM)
(3) Bureau d'étude GEOHYD
damien.gabion@eau-loire-bretagne.fr, p.nom@brgm.fr, p.nom@geo-hyd.com

The assesment of groundwater status was implemented following the national and European regulations based on the Water Framework Directive (Directive 2000/60/EC of 23/10/2000 establishing a framework for Community action in the field of water policy) and Directive 2006/118/EC of 12 December 2006 on the protection of groundwateragainst pollution and deterioration (Daughter to 2000/60/EC).

The Water Framework Directive sets goals and methods to achieve a good status for groundwater by 2015. The assessment of the status of groundwater bodies is based, among other criteria, on chemical standards which take into account the representativeness of the groundwater monitoring network, the assessment of trends to higher pollutant concentrations and the links between surface water and groundwater.
In this context, the Loire-Bretagne Water Agency relies on methodological approaches developed in partnership with BRGM and consultants to improve the assessment of groundwater bodies status in hard rock aquifers.

I. USE OF « WATERCOURSE » DATA IN THE ASSESMENT OF CHEMICAL STATUS OF GROUNDWATER BODIES IN HARD ROCK AQUIFERS (Bretagne).

In order to establish a coherent and complete assesment of the chemical status of groundwater, a monitoring program is established in accordance with Article R. 212-22 of the Environmental Code. The issues of the spatial representativeness of groundwater monitoring networks and of the methods enabling building a representative network are often discussed since the implementation of these networks.

Hard rock aquifers, due to their small size, can make difficult to choose a measurement station which is representative of the water body. In this context, GeoHyd realized (GEOHYD, 2009) on behalf of the Loire-Bretagne Water Agency, a study on the interrelation between the measurements observed in groundwater and surface water and the feasibility of integrating "watercourse measurement stations" in the analysis of the qualitative status of hard rock groundwater bodies.

A analysis of descriptive statistcs and a comparison of averages and classes of chemical status were made on the basis of nitrate levels observed in all of the rivers and underground water bodies for the year 2003, year of reference for long and severe low water levels. The results show that the comparative assessments made on the nitrate parameter does not allow to conclude a comprehensive synchronism between "surface water" and "groundwater". On one hand each water body can provide its own time of response to percolation/ infiltration phenomena and on the other hand a measurement station of the quality of surface water can not be representative of the groundwater body as a whole. However a local study can be conducted on each measurement station of the quality of surface water to find out which groundwater measurement station it is the closest. This requires studying chronical measurement over the medium - long term and throughout the hydrological cycle (high water / low water).

In the case of hardrock aquifers in Bretagne, a ranking of measurement stations of quality of underground water was performed according to an Agglomerative Hierarchical Clustering (AHC) on the basis of three parameters: the average of nitrates levels, the maximum average recorded on a panel of pesticides and maximum detection rate observed. Data were standardized to limit the effects of size. The Agglomerative Hierarchical Clustering has identified six classes of different measurement stations (Table 1) each with a particular type :

AHC Classes	Average of nitrates level	Average max phyto	Maximum detection rate (phyto)
1	Faible (-0,865)	Faible (-0,442)	-0,786
2	Forte (1,706)	Forte (3,352)	1,696
3	Significative (0,702)	Significative haute (1,887)	1,488
4	Forte (1,79)	Faible (-0,345)	-0,309
5	Moyenne (0,26)	Faible (-0,339)	-0,152
6	Significative (0,496)	Significative basse (-0,017)	1,285

Table 1 - Barycentre and CAH classification

Spatialization the result of the AHC was then performed after a division of the territory by the method of Voronoi diagrams. The representativeness (%) of AHC classes could be defined for each polygons of groundwater body. Analysis of AHC classes and measurement stations of monitoring control network (RCS) was conducted in Bretagne for all hard rock water bodies according to the following guideline (Table 2) :

Analyse des classes CAH et des stations du réseau de contrôle de surveillance	
Yes	There is a RCS Station for the water body type
No RCS station but a water body measurement station	There is no RCS station but a surface water measurement station representative of the type of the water body
No RCS but a surface water body measurement station (no-representative)	There is no RCS station but a surface water measurement station non-representative of the type of the water body
No RCS	There is no RCS station for the type of the water body and the type is not reprensentative of the water body
No RCS, No surface measurement station	There is no RCS station nor surface water measurement station for a representative tye of the water body
Representativeness of CAH classification on the water body	
0%	**No type on the water body**
<25%	**Type not representative of the water body**
25% <v< 50%	**Type a little representative of the water body**
50% <v< 70%	**Type representative on average of the water body**
>75%	**Type representative of the water body**

Table 2 - Methodology of the analysis of monitoring control network (RCS) and AHC classification representative of hard rock groundwater bodies in Bretagne

For example, the analysis of AHC classes and measurement stations of RCS on the water body "Leon watershed FRGG001" (Table 3) shows that a river measurement station could be used to characterize a sector on which there is no RCS station for groundwater.

Groundwater Body Code	RCS station / AHC classe						area proportion of AHC classe					
	Classe 1	Classe 2	Classe 3	Classe 4	Classe 5	Classe 6	Classe 1	Classe 2	Classe 3	Classe 4	Classe 5	Classe 6
FRGG001	pas de RCS	pas de RCS mais station CE	Oui	Oui		Oui	0,07	0,47	0,08	0,27	0	0,11

Table 3 - Analysis of AHC classes and mesadurement stations (watershed LE LEON - FRGG001)

In Bretagne, on 24 hard rock groundwater bodies, 20 lack of measurement stations representative of the water body. The integration of measurement stations of "watercourse" quality would enable to fill the lack of representativeness of measurement stations of RCS for 14 groundwater water bodies.

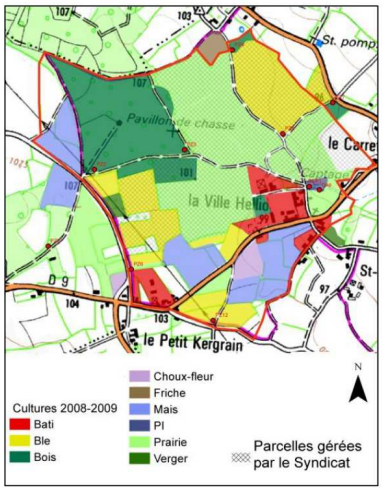
II. Simulation of the evolution of local nitrates concentrations

The inventory carried out in 2013 for the Loire-Bretagne basin indicates that 27% of groundwater bodies are at risk of not achieving good chemical status in 2021 mainly because of high levels of nitrates. In this context, BRGM and Loire-Bretagne Water Agency are working together to improve knowledge on groundwater contamination.

In certain areas where farming practices have been deeply modified, the related significative improvement in groundwater quality is not always noticeable in short periods. The existence of a stock of nitrates in the unsaturated area related to ancient practices is one of the main factors responsible for the inertia of the system. Thus, forecasting the future evolution of nitrates concentration from chronical concentrations themselves can be difficult (Baran et al, 2011).

At the watershed scale, global models incorporating agro-climatic data is a good alternative to deterministic models because their implementation is easier. The BICHE model (water chemical status ; Thiery, 1990), developed in BRGM, is an example of a global model to simulate water and nitrate flow of an aquifer at a watershed scale from chronical data on rain,ETP, agronomic data and calibration of the model (concentrations and flows or levels of aquifers).
The well capture zone of Hellio city (Plourhan , Côtes d'Armor Map 1) , representative area of a hard rock zone on the Loire-Bretagne basin, was subject to modelisation of nitrates concentrations in the aquifer (1985-2009).

The modelisation integrates the analysis of land use, current and past agricultural practices and hydro parameter and was implemented in 3 main stages. The modeling was performed in 3 main stages : data collection, initialization / calibration and use of the model for predictive purposes . The time step used is monthly. The model was calibrated successfully as on the hydrodynamic aspects (level and flow of water) on the quality of water (Baran et al , 2013).



Map 1 - Ground o*ccupancy 2008-2009 on the well capture zone of Hellio city (arène argileuse du Briovérien) - BRGM/RP-60280-FR.*

The model showed a real interest in the simulation of scenarios. These help to alert the community about the likely trends in nitrate concentrations if no action is taken or help to show the impact of envisaged changes in farming practices on water quality (Figure 1).

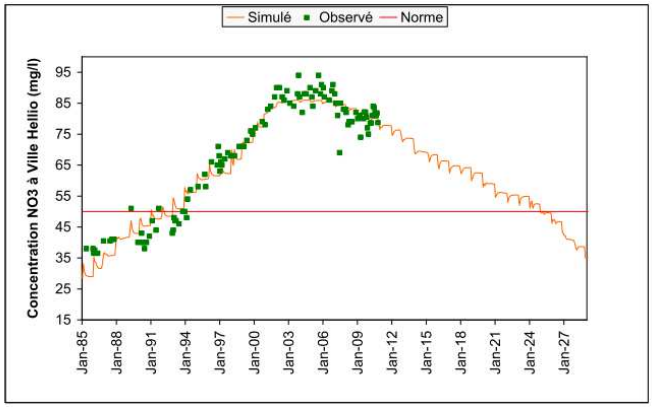


Figure 1 - *Comparison of nitrate concentrations measured and simulated from 1985 to 2027, according to the "continuity" scenario (repetition of past climate cycles and stabilization of current farming practices)*

III. Contribution of groundwater to streams of surface water bodies in Loire-Bretagne Basin : application to the HARDROCK regions

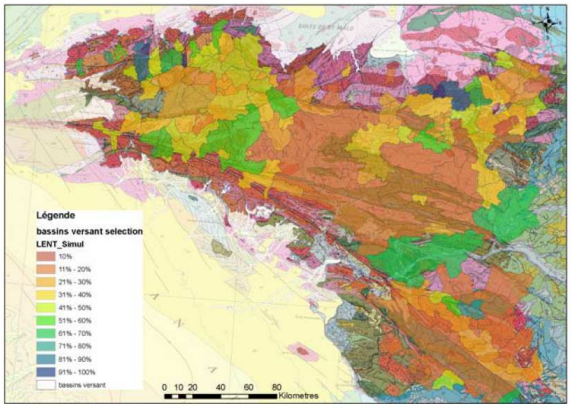
One of the objectives set by the "daughter Directive groundwater" and set out in Article 6 of the Decree of 17 December 2008 is to determine whether a transfer of groundwater pollutants to surface waters is likely to alter their chemical and/or ecological status and thus represent an obstacle to the environmental objectives of the WFD. To conduct this analysis, the Loire-Bretagne Water Agency builds on the work carried out by the BRGM on the assessment of the average contribution of groundwater to surface streams. The following items are taken from the poster "Contribution of groundwater to streams of surface water bodies in Loire-Bretagne Basin: application to hard rock area " directed by S. Pinson et al (2015) also presented in this conference.

The links between the two tanks that are on the one hand aquifers and on the other hand surface water are complex, time-shifted and complementary (karst, self-regulation and amplification of extreme events). Because of this complementarity, it appeared necessary to quantify the average contribution of groundwater to surface water, realising a pilot study, which is based on a combination of innovative methods (DPR : development and persistence of networks index, and modelisation GARDENIA / TEMPO) for the understanding of the mechanisms at the origin of groundwater and rivers relations.

This project was conducted in several stages: a qualitative approach with the definition of a typology, a quantitative approach adapted to the specific context of the watershed, a typological classification of watersheds and an assessment of groundwater behavior in their contribution to the flow and quality of rivers, with a test on the "nitrates" parameter.

The qualitative approach has lead to a classification of watersheds, according to 10 major types, with differentiation of the Armorican Massif (three areas), a clear distinction between the behavior of Armorican Massif and the Massif Central and a better understanding of transition regions between the sediment and the hard rock area. For the quantitative part, watersheds spread over the hard rock area have been modeled using the TEMPO software and GARDENIA BRGM. This approach was used to estimate a percentage of "simulated slow" which is the average contribution of groundwater to the river flow. These data from modeling were then crossed with qualitative data to look for correlations. For the hard rock area, a relationship between the QMNA5 (value of the monthly minimum flow with the probability 1/5), average speed and simulated flows were highlighted.

This relationship enabled tocalculate the average percentage contribution of groundwater to river flows on all non-modeled watersheds, but with a measurement station, and thus enabled to cover a large part of the hard rock area belonging to the Loire-Bretagne Basin.



Map 2 – Average contribution of groundwater to stream flows - Armorican Massif - BRGMRP/57608

IV. TRENDS ASSESMENT of pollutant concentrations in groundwater

One of the environmental objectives of the framework directive (WFD) is the reversal of any upward trend, both significant and on the long run, of the concentration of any pollutant in groundwater resulting from the impact of human activity (uptrends). Member States must implement the necessary measures to meet this objective, specific to groundwater.

The decree of December 17th 2008 clarified the Article R. 212-21-1 of the Environment Code and completed the transposition of the WFD and its daughter directive on groundwater. It stipulates that these identification exercises should be performed at least every six years (Article 8) and for water bodies on which an upward trend is highlighted, the starting point of setting of projects to reverse a significant and long term upward trend must be defined (Article 9).

BRGM developed as part of an agreement between ONEMA - BRGM, a statistical tool of trend identification tool, programmed under the HYPE software (B Lopez, 2011). This tool characterises time series, identifies development trends of contaminants in groundwater and can handle one or more quality chronic.

Several modules enable to extract the main features of chronics (mean, standard deviation, quantization frequency, etc.) and to apply statistical tests of trend and break on chronic.

Information sheets "evolution trend of nitrate concentrations in groundwater for water bodies" are proposed (Figure 2) and include a map with the result of the Mann- Kendall statistical test at the points of the water body (color code according to the slope), the result of the WFD “widespread” method, the Regional Kendall statistical test on the scale of the groundwater body and a confidence index of the assesment (probability of error in the definition of the slope).

For example, the water body from the Leon watershed (FRGG001) includes 15 "quality" points with an evolution trend of nitrate concentration gowing down. Furthermore, the Regional Kendall statistical test identifies an overall downward trend of 2.39 mg / L of nitrate per year and that there is a 19% chance of having, for the same point of the water body, lower nitrate contents between two analyzes.

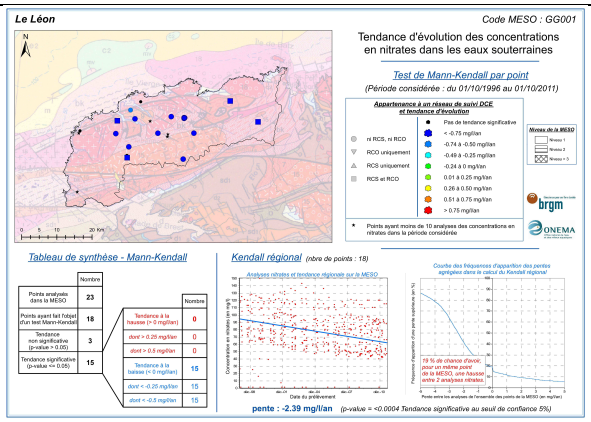


Figure 2 - Information sheet «evolution trend of nitrate concentrations» for Leon watershed

Références :

BARAN N., GOURCY L., LOPEZ B., BOURGINE B., MARDHEL V. (2009)- Transfert des nitrates vers les eaux souterraines à l'échelle du bassin Loire-Bretagne – Phase 1: temps de transfert, tendances et typologie des aquifères. Rapport BRGM/RP-56884-FR

BARAN N., BOURGINE B., GOURCY L., GUTIERREZ A., LOPEZ B., MARDHEL V., PINSON. S, STOLLSTEINER P., SURDYK N., THIÉRY D., WUILLEUMIER A. avec la collaboration de J-P. Jégou, F. Koch et B. Mougin (2013) - Simulation de l'évolution des concentrations en nitrates dans la nappe à l'échelle du bassin d'alimentation du captage de la Ville Hellio (Plourhan, Côtes-d'Armor) – Panneau réalisé dans le cadre des RENCONTRES-ATELIERS du Creseb du 14 juin 2013

BARAN N., GUTIERREZ A., LOPEZ B., SURDYK N., GOURCY L. (2011) - Transfert de nitrates à l'échelle du bassin d'alimentation de captages d'eau souterraine du bassin Loire-Bretagne: modélisation et datation. Rapport final BRGM/RP-60280-FR.

GEOHYD (2009)- Calcul statistique de la qualité des masses d'eau souterraine du bassin Loire-Bretagne

GUTIERREZ A., SURDYK N., LOPEZ B., BARAN N., THIÉRY D. (2012) - Quelques exemples de simulation de l'évolution des concentrations de nitrates dans la nappe à l'échelle du bassin d'alimentation des captages. Poster présenté à INTERSOL 2012.27-30 mars 2012, Paris.

LOPEZ B. avec la participation de Blum A. et Baran N. (Avril 2011) - Evaluation des tendances d'évolution des concentrations en polluants dans les eaux souterraines. Guide méthodologique - BRGM/RP-59931-FR

Pinson. S, Allier D, Stollsteiner P, Mardhel .V, Wuilleumier. A, (2015) - Contribution des eaux souterraines aux écoulements des masses d'eau de surface du Bassin Loire-Bretagne : application au socle – Poster réalisé dans le cadre du colloque international CFH-AIH à La Roche-Sur-Yon du 11 au 13 juin 2015

Pinson. S, Allier D, Stollsteiner P, Mardhel .V, Wuilleumier. A, (2010) - Etude de la contribution des eaux souterraines aux écoulements totaux des Masses d'eau de surface sur le bassin Loire-Bretagne Rapport final. Rapport BRGM RP-57608-FR, 164 p, 135 illustrations, 3 annexes

SURDYK N., GUTIERREZ A., LOPEZ B., BARAN N., THIÉRY D. (2012) - BICHE: un outil d'application simple de simulation de concentrations en nitrates dans les nappes à l'échelle du bassin versant. Communication à INTERSOL 2012. 27-30 mars 2012, Paris.

THIERY D. (1990) – Modélisation des transferts de nitrates dans un bassin versant – Validation du modèle BICHE (Bilan CHimique des Eaux) et analyse de sensibilité. Rapport BRGM/RR-30976-FR