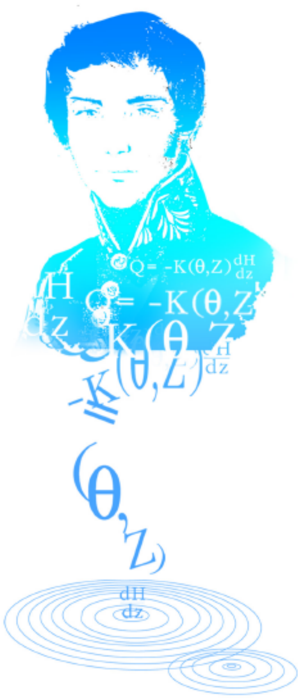
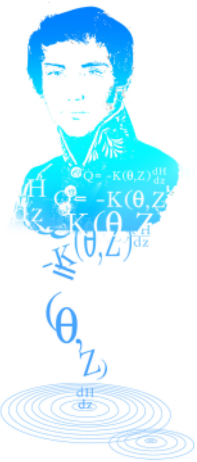


THÈME 2 / *TOPIC 2*

Réseaux de surveillance, bases de données, SIG
Monitoring networks, databases, Geographical Informations Systems



SOMMAIRE

Réseaux de surveillance, bases de données, SIG

Monitoring networks, databases, Geographical Informations Systems

References	Abstract	authors	Organizations
ORAL COMMUNICATIONS			
DARCY-21	WWHYPDA – A world wide hydrogeological properties database	Renard P. and Comunian A.	Centre d'Hydrogéologie, Université de Neuchâtel, Suisse
DARCY-43	Les Systèmes d'Information pour la Gestion des Eaux Souterraines (SIGES) : Aquitaine, Poitou-Charentes et Midi-Pyrénées	F. Bichot	BRGM, Poitiers, France
DARCY-50	Evaluating the effectiveness of Scotland's groundwater quality network for monitoring nitrate	MacDonald A.M;., Griffiths, K.J., Ó Dochartaigh B.É., Lilly A., DeGroot J. and Chilton P. J.	British Geological Survey, Edinburgh, UK. ; British Geological Survey, Wallingford, UK.; Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen, UK.
DARCY-107	La mise en oeuvre des réseaux piézométriques pour évaluer l'état quantitatif des masses d'eau souterraines : exemple du bassin Seine-Normandie	Vernoux J.F.	BRGM service EAU - France
POSTERS			
DARCY-37	The International Hydrogeological Map of Europe at the scale 1 : 1,5 million (IHME1500)	Winter, P., Struckmeier, W. and Strub, H.	Federal Institute for Geosciences and Natural Resources, Berlin, Germany.
DARCY-65	Characterization of the pesticide concentrations in the "nappe de la Craie du Nord"	de Fouquet Ch., Renard D.	Ecole des Mines de Paris, Centre de Géosciences, Fontainebleau, France
DARCY-69	Optimization of Groundwater Monitoring Network: Applications of Geostatistics With A Few Case Studies From A Granitic Aquifer In A Semi-Arid Region	Shakeel Ahmed	Indo-French Centre for Groundwater Research National Geophysical Research Institute Hyderabad-500007, India,
DARCY-78	ADES : A French National Groundwater Database A national reference for groundwater resources A freely accessible tool for water management!	L. Chery, H. Legrand	BRGM, Water Division, Orléans, MEDD Ministère de L'Ecologie et du Développpement Durable PARIS
DARCY-92	Contribution des données issues des sites industriels (installations classées) à la connaissance de la qualité des nappes souterraines	Gilbert D., Terreyre J.-L. Chartier R., Koch-Mathian J.-Y.	MEDD/SEI – DPPR/BPSPR, Paris, BRGM, Orléans, France
DARCY-127	Hydrogeological map of Africa : a prototype at scale 1:10 M	JJ. Seguin	BRGM, Orléans, France
DARCY-135	Detecting Temporal Structure of Hydrological Processes and Water Quality Using Wavelet Analysis	Shujiang Kang, Henry Lin *, William J. Gburek, Gordon J. Folmar, and Xiaobo Zhou	Dept. of Crop and Soil Science, The Pennsylvania State University, USA.

Communications orales
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DARCY 21

WWHYPDA : A world wide hydrogeologic parameters database

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Abstract
150 years have passed since the seminal publication of Darcy's work which can be considered as the starting point of quantitative hydrogeology. We argue that it is now time to construct a worldwide catalog of hydrogeological properties of rocks and spatial structures of typical hydrogeological environments. With this aim, we propose a database structure that will be open to the public. Our target is to have a first on-line version available this spring or, at the latest, this summer. The database will be protected by a GNU general public license. It means that it will be an open system where anyone can store and retrieve hydrogeological properties, notably in order to facilitate stochastic modeling. The database will provide probability density functions, variograms, and training images of the properties as a function of lithology, scale of observation, location, and geological environment.

Introduction

Since the first experiments of Henry Darcy, published in 1856, and for more than a century, hydrogeological experiments have been designed and conducted all around the world to characterize not only the hydraulic conductivity, but also porosity, specific storage or compressibility of many earth materials. Averaged properties have been obtained by calibrating regional aquifer models. All these experiments have been published in articles, books or technical reports. The data collected show the scale dependence of the parameter values (Kiraly 1975; Lallemand-Barres and Peaudecerf 1978; Gelhar and Welty 1992; Clauser 1992; Wilson and Tidwell 1999; Neuman and Di Federico 2003).

More recently, in many countries, the national geological surveys have started to centralize the geological and the groundwater data within national databases or geographical information systems. These data sets are available upon request (Allen et al. 1997; Jones et al. 2000), or via Web interfaces (for example http://www.geoconnections.org in Canada, http://www.ades.eaufrance.fr in France, or http://capp.water.usgs.gov/gwa/gwa.html in the USA). Similarly, GIS data bases are often developed to facilitate the data management within specific consulting or research projects (Barazzuoli et al 1999; Gogu et al 2001). In France, there is also a strong initiative (http://hplus.ore.fr) to manage site specific datasets in a standardized format in order to ensure their long term availability and to facilitate the collaboration among various research teams (de Dreuzy et al, submitted). In this last case, the aim is to improve the efficiency and the quality of the research, rather than to initiate a public service such as more general databases provided by geological surveys.

Parallel to the acquisition of important datasets of the parameter values, the understanding of their spatial distribution has evolved significantly, during the last 50 years, thanks to the development of the geostatistical theoretical frameworks (Matheron 1962; Delhomme 1979; Ahmed and de Marsily 1987; Dagan 1989; Gelhar 1993; Rubin 2003). Therefore, in addition to the physical parameter values themselves, corresponding statistical parameters which describe their distributions and their spatial continuities (covariance functions) have also been collected from a large number of test sites worldwide (see for example Rubin 2003 for a review).

Despite these efforts, in most sites where a hydrogeological study is to be conducted, there is still a very limited amount of data available to characterize the site. This is especially true and poses a problem when we consider the first stages of a new study. Anderson et al. (1999) estimated that in most cases only less than 1% of the total volume of an aquifer is directly sampled and studied. Even in the most extensively studied sites, the volume of the aquifer which is directly sampled remains small. In their detailed study of a braided system, Anderson et al. (1999) estimated this sampled volume to be around 20 to 40% of the total volume. One possible solution to deal with this problem is to complement the available data on a given site with the data from other similar sites and/or similar rock types.

Because of the lack of data, in many practical situations it is necessary to incorporate the hydrogeological analysis with presumed uncertainties. Stochastic techniques should, thus, be used as one component of a general framework to manage hydrogeological projects (Freeze et al. 1990). This need is clearly recognized in the academic world where the number of publications related to stochastic hydrology is extremely large, but the application of such technique in daily practice is still limited. The reasons for such limitations are diverse, as it was discussed in a special issue of the journal Stochastic Environmental Research and Risk Assessment in 2004 (Zhang and Zhang 2004). One step to improve this situation would be to provide a catalog of statistical properties of the different parameters and of the structures of heterogeneity that are typical of different geological environments (Dagan 2002; de Marsily et al 2005).

Such a catalog would be useful both in a deterministic and a stochastic framework. It could answer basic questions such as: what is the range of intrinsic permeabilities in a fine sandstone? what is the most probable value for the porosity of pillow lavas in an ophiolitic environment? or what should be a safe value for the variance of the hydraulic conductivity in a fractured sandstone to design a pump-and-treat system? It it could also provide necessary data to model the spatial heterogeneity within aquifers either with well-established geostatistical techniques (Chilès and Delfiner 1999) or with the latest and more experimental techniques such as the multiple point method (Strebelle 2002). This last technique requires as an input for the simulation a training image that describes the spatial arrangement of the different rock types.

Our vision is therefore that there is a need for a catalogue that would be able to provide information that could be used to improve the characterization of a given site by completing existing data from the site. The aim is not to offer a substitute for local investigation but to offer a well documented and scientifically rigorous complement of information when there is a lack of data.

In this paper, we present the main features and the structure of a prototype of such a catalog. We named this project wwhypda. It stands for the world wide hydrogeological property database. The database is built on Open Source software to allow a wide distribution. It will be freely accessible on the Web, both to retrieve and to add data.

Main wwhypda features

wwhypda is neither intended to be a GIS-based data repository, nor to store time dependent series of data (such as time series of piezometric heads). It is intended to store values of properties of major hydrogeological parameters, and to relate them either to a specific earth material or to an hydrogeological environment. These values can then be post-processed automatically to extract statistical moments or full probability density functions (Figure 1b). To allow such a type of queries, the data base contains an extensible catalog of typical rock types and typical geological environments. The data related to spatial statistics such as variograms (Figure 1c) are only stored in the database as they result from a complex data analysis and validation procedure.

One of the most innovative content of wwhypda is the storage of typical 2D and 3D images of lithofacies distributions (Figure 1a). These images are digitally coded representation of facies architectures for a given geological environment. The coding corresponds to rock types which are also available in the database. In this way, it is possible to obtain statistical information related to the geometry from the digital image and to retrieve statistical information related to the physical parameters themselves within the different architectural elements. The combination of these two aspects of the database could allow, for example, to simulate lithofacies distributions for a given site by combining the local borehole observations with the statistical parameters extracted from wwhypda. In a second step, the grid cells corresponding to the different lithologies will be populated by parameters values. Depending on the amount of data available on site, these parameter values can be interpolated either from local measurements, or simulated from the statistical distributions provided by the database, or by a combination of these two approaches.

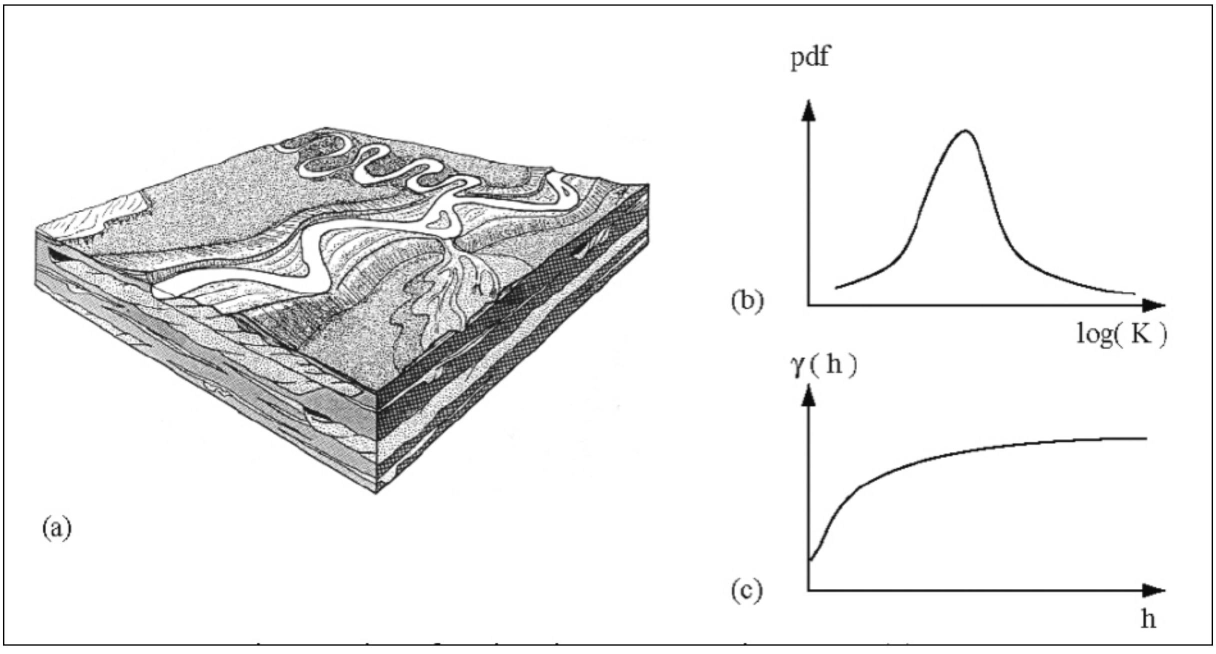

Figure 1: Typical examples of wwhypda content and output : (a) 3D training image of a molassic environment in Switzerland (from Keller et al 1990), (b) probability density function for the log-hydraulic conductivity of a given rock type, (c) variogram.

In terms of its usage, wwhypda will be available via a Web interface. Anybody will be able to consult *wwhypda*, download it, or add data, under a GNU Free Documentation License (http://www.gnu.org/copyleft/fdl.html). Such a license ensures that wwhypda will be freely available in the sense of freedom. Anyone will have the right to use, copy, and redistribute it, with or without modifying it, either commercially or non commercially.

Finally, a key feature of *wwhypda* is that it provides an interface which allows anybody to contribute. Every hydrogeologist who would like to share the results of his measurements and of his studies will be able to contribute to the database. The only requirement will be a registration step, which is necessary in order to recognize and keep track of users' contributions. The counter-part of this open policy will be a validation procedure allowing to control the quality of the data.

An international scientific committee will supervise the development of the project and promote the use of *whypda.*

Content organization, methods and technologies

A blueprint is necessary in order to develop a database capable of storing the wide variety of information depicted in the previous section. The Entity-Relationship schema (Chen 1976) is adopted in order to design the conceptual model of the database. Figure 2 is a graphical representation of wwhypda's model, obtained with a Unified Modeling Language Class diagram. It shows the entities which compose the database, their relationships and their main attributes.

The basic entity composing the database is an ensemble of values of measurements of hydrogeologic parameters (Table 1). Note that only geometry-independent parameters are considered. Information about a single measurement are stored in the entity Measure whose main attributes are:

- *value:* the measured value of the parameter.
- *delta:* the uncertainty associated with the measurement, expressed in the same unit.
- *coherence:* this attribute is computed and returned to the contributor when the measurement is added. It represents the coherence of this new data with respect to the existing data in the database (values among *low, medium, high or not computed)*. The user will choose whether to store the measure or not by considering this returned attribute value.
- *method:* the measurement method.

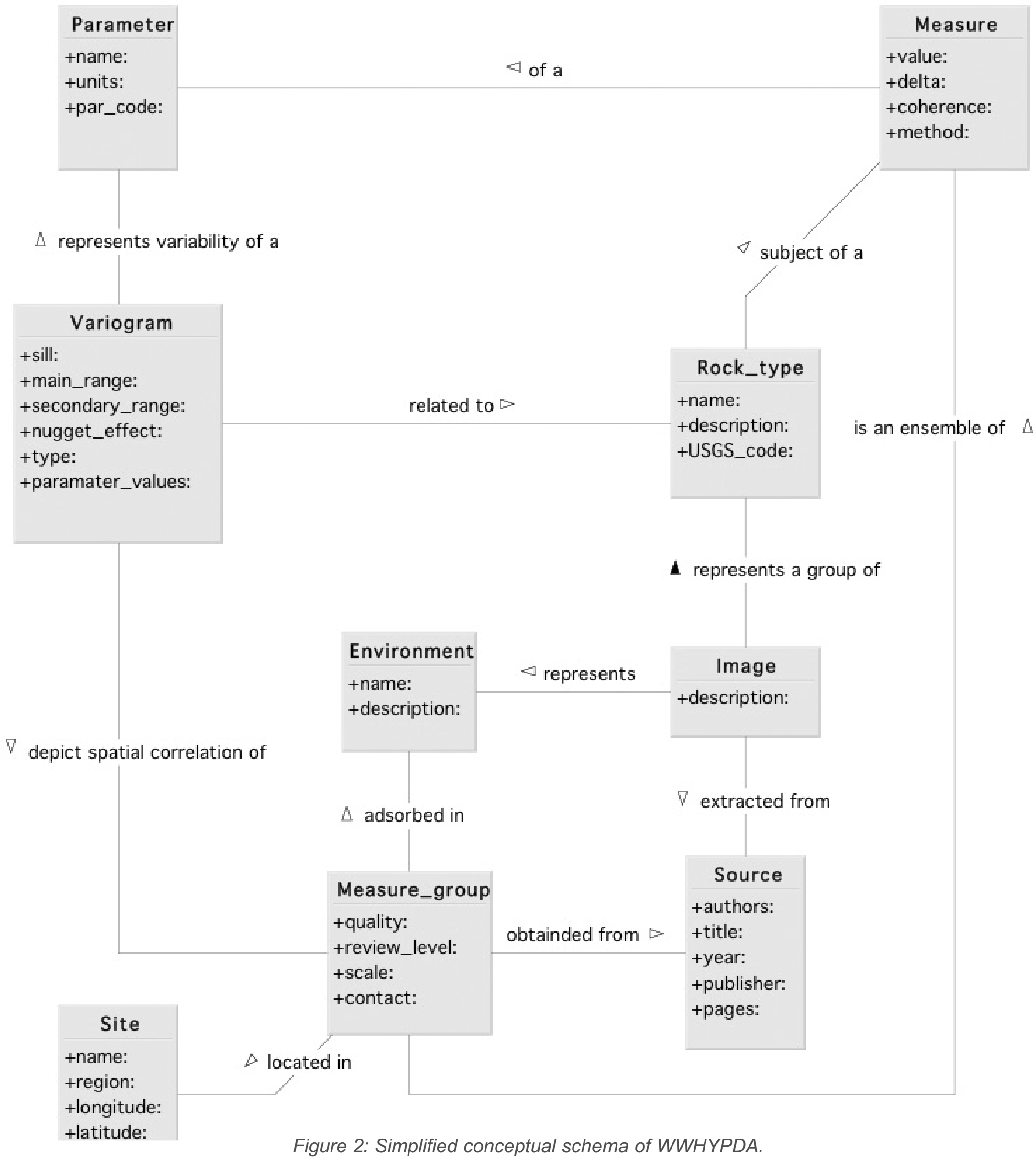

Figure 2: Simplified conceptual schema of WWHYPDA.

To minimize redundancy, part of the information related to the measure is stored in the entity *Measure_group*. It contains the information that are shared by a group of measurements, such as:

- *scale:* the majority of the parameters included in the database are scale dependent. We propose four scale classifications: *micro* (for lengths < 1 m), *macro* (1 m < lengths < 10 m), *meso* (10 m < lengths < 100 m) and *mega* (for lengths > 100 m).
- *quality:* this information reports an evaluation of the data-quality given by the user. It ranges from *low, medium* and *high*. The quality level will allow coherence value to be computed for a measurement in case of a missing delta value.
- *review_level*: this attribute depicts the level of reviews underwent by a group of measurements. Values among *not reviewed, published in technical report or published in peer reviewed journal* will be allowed for it.
- *contact:* this attribute enables the identification of the contributing person to the database, thus all information will have his signature. If the user finds some useful data, he will be able to cite the contributor. In this manner, the work and the efforts of the contributors will be credited.

parameter name	***symbol***	***units***
hydraulic conductivity	K	m_s^{-1}
permeability	k	m^2
rock compressibility	α	m^2 N^{-1}
effective porosity	n_e	%
porosity	$n=S_y+S_r$	%
specific yield	S_y	%
specific storage	S_s	m^{-1}
longitudinal and transversal dispersivities	α_L *and* α_T	m

Table 1: Hydrogeological parameters contained in wwhypda.

Every measurement is related to an earth material (rock type) or to an hydrogeological environment. To facilitate this task, the entities *Rock_type* and *Environment* contain typical sets of earth materials and environments. In practice, these two database components represent two catalogs organized and presented as a tree structure; contributors will be able to add their own *Rock_type* or their own *Environment* as branches of the proposed tree classification. The definitions of the rock types, or in other words the classification criteria, are specified by a brief description and, when possible, are followed by a *wikipedia* link (http://www.wikipedia.org) which provides a more detailed description.

Furthermore, the *Rock_type* catalog is used to associate the litofacies represented within the training images and the property values. In this way, *wwhypda* regroups information about the litofacies geometry, and their hydrogeological properties.

Variograms are stored in the homonymous entity, together with their main properties: sill, main range, secondary range, nugget and type. An internal catalog of variogram types, contributor-extensible, is available in order to easily and quantitatively define variogram models.

Finally, the only geographic information in the database will be kept in the entity site (*name, region, longitude* and *latitude*), in order to locate a measure group.

A relational schema is adopted to implement the database's conceptual schema. Technologies to physically implement it are in a mature state. *MySQL* (http://www.mysql.com), a very popular open source relational database, appeared to be a good solution for our purposes. Besides, *PHP* (http://www.php.net), another open source solution, is the language adopted to create the web interface.

To conclude this section, let us stress that the structure of wwhypda is designed to be flexible: internal catalogs of earth materials, environments, variogram models, and measurement methods are open to user' contributions via the Web interface. Other database characteristics, such as parameter list, will also be modifiable, even if this procedure will not be as easy as the preceding. These latter modifications will be notified through a feedback form or an e-mail to the database administrator. They will be evaluated and adopted eventually.

Data quality

The evaluation of data quality is of extreme importance. In *wwhypda*, a first screening consists of rejecting data that are not acceptable from a physical point of view (porosity must be between 0 and 1, permeability must be positive, etc). Once these trivial check is satisfied, the quality of the data is evaluated evaluate the quality of the data with four criteria stored as four different attributes *(quality, review_level, coherence* and *delta*) linked either to the group of measures or to the measure itself. These criteria allow to evaluate the quality from two points of view.

The first is the *source* point of view: the measurement quality is evaluated depending on the level of reviews that it has underwent. In addition, the contributor must provide a subjective and qualitative evaluation of the overall quality of the group of measurements at the input time; this judgment is based on his own knowledge of the field conditions during the data acquisition, as well as the type of interpretations that were used for the estimation of the parameter values.

The second is the internal consistency point of view: every measurement is compared with measurements previously stored in the database. The comparison is done with values of the same parameter and of the same rock type (or environment) when it is possible, but the comparison with a broader class of rock types is used when required. The procedure to check the consistency is automatic and runs both at input time and at consultation time. The contributor will be alerted about a coherence problem at the input time. Users who consult the database have the possibility to select only the values that reached certain coherence criteria.

As described in the previous section of this article, the attributes *quality* and *review_level* are supplied with the entity *Measure_group*, while the attributes coherence and delta are supplied with the entity Measure. The attributes quality and *review_level* are selected from predefined values by the contributor at input time. The attribute delta represents the estimation of the measurement error or the uncertainty associated to a measure.

The attribute *coherence* can take only a number of predefined states: Not computed, Low, Medium, or High. The rules for the attribution of a coherence state are described in Table 2. In this table, n represents the number of measurements of a given class (i.e. a given parameter, a given scale, a given rock type, or geological environment), x_n (with n = 1, 2, ...) represents the value of the n-th measurement added to the database, and δn is the related delta value . We then define and compare a series of 4 sets (or intervals) to estimate the coherence. The basic principle is that if the interval that surround a measurement ($x_n - \delta n$, $xn + \delta n$) fall within the existing distribution, the measurement will have a higher coherence than if the interval falls outside.

Definition of the intervals		
A	ensemble of all the measurements contained in the database for a given class of measurement type (or environment).	
B	subset of A whose measurement values lie between the 1st and the 3rd quartile of A.	
C	interval $(x_n - \delta_n, x_n + \delta_n)$	
D	interval C for $n = 1$	

Definition of the coherence state		
n value	**condition**	**coherence state**
$n = 1$		Not computed
$n = 2$	if $C \cap D = \emptyset$	Low
	if $C \cap D \neq \emptyset$	High
$n > 2$	if $C \cap A = \emptyset$	Low
	if $C \cap A \neq \emptyset$ and $C \cap B = \emptyset$	Medium
	if $C \cap B \neq \emptyset$	High

Table 2: Principle of the definition of the coherence state.

Data sources

Our vision is that wwhypda should progressively assimilate data provided from diverse sources. In order to create the basic data set, we would like to import data that are already stored in existing data bases. Some negotiations are currently in progress along this line. The second most important data sources are the values published in scientific journals. The third source is the corpus of results that have been published in technical reports in various projects. There are for example a large number of data collected in the framework of the safety evaluation of nuclear waster repository. Most of these reports are open to the public and could constitute an important source of data. Within such projects, the three-dimensional architecture of the reservoirs has been studied in detail and could serve as a good source for the training images. As an example, in Switzerland the Molassic environment has been studied in detail by NAGRA, and this information will be integrated in the database.
These data sources will constitute our initial data set. But it is not possible for us to cover all the possible hydrogeological environment and rock types. Trying to get the community involved is probably the greatest challenge of this project. Without such contributions, the database would merely be limited to a few specific cases, and not as useful as it is planned to be.

Discussion

Building a database that combines standards and flexibility is not simple. We were forced to adopt restrictions and simplifications.

The first difficulty was the choice of classification for the rock types and the hydrogeological environments. There are two problems. The first is that geologists, hydrogeologists, civil engineers, and environmental engineers are not using a unique and common classification. To make matter even worse, the classifications often differ from a country to another: a fine sand may not have the same granulometry in France and in Great-Britain. Which one should we adopt? The second problem is technological: how to represent the classification in a simple and efficient way? On this topic, Davenport et al. (2002) and Struik et al. (2002) proposed interesting solutions in order to facilitate digital geological mapping. However, their solution is probably too complicated for our needs.

The solution that we propose these problems is to select a classification well documented and used by a majority of hydrogeologists. The challenge is to remain both simple and flexible. We do not want to have too detailed lithological categories, otherwise we will not have sufficient data sets to produce meaningful property statistics. A classification such as the one proposed by the British Geological Survey (http://www.bgs.ac.uk/bgsrcs/home.html) is for example too detailed for our needs. On the other hand we do not want to freeze our system such that it is not possible to provide accurate information when it is available. The solution that we propose is to organize the rock types in a tree structure (Figure 3). The base elements of the tree correspond to the most common family of rock types. The sub-elements correspond to different levels of refinement in the rock classification. Each element or sub-element contains a definition. When available, a symbolic description made with the Unified Soil Classification System is provided. Such a tree allows querying the database at different levels, depending on the amount of data available. For example, we may not find in the database a sufficient number of measurements for the specific storage for ferruginous meta-sandstone, but we may have these data at broader level of meta-sandstone or sandstone. When a rock-type is not available, the user can add it in the tree structure.

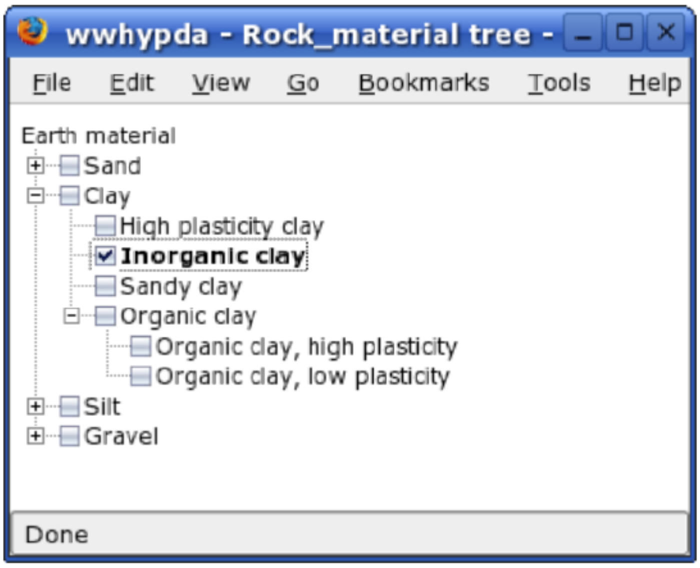

Figure 3: Example of a part of the rock classification tree within the wwhypda interface.

This approach seems to be an affordable compromise at the present state of the project. However it also has drawbacks from some limitations just like any other classification system. For example, rocks which are a mixture of different base classes have to be derived only from one parent. An equal mixture of sand and clay for example will have to be linked either to the general clay class or sand class, but not to both. Additional characterization criteria, such as the degree of fracturation or the depth of sampling, are not accounted for in the database.

Another issue is to obtain an important set of typical training images showing the internal structure of a variety of typical hydrogeological environments. Such types of images are relatively easy to find in the literature in two dimensions. Interpreted outcrops belong to this category as well as geological sketches. In three dimensions, the situation is much more difficult. In the literature, there are only a few studies that mapped successive vertical outcrops in active quarries and reconstructed the 3D architecture by interpolating between the sections (Anderson et al. 1999). There are geophysical 3D data sets. There are also simulated 3D images of sedimentary architectures that are created either by boolean techniques or by simulating the genetic processes (see de Marsily et al. 2005 for a review). The resulting images from these processes are possible candidate for the data base.

Finally, we would like to stress that the greatest challenge lies not in the technical field, but in the community involvement to enrich the database. Within our project, the database will be fed with an initial data set that will progressively increase. But this will not be sufficient; wwhypda will become a really useful worldwide reference if and only if it receives contributions from a very large community. The recent development of projects such as wikipedia and the intense activities on Internet indicates that this kind of community involvement is probably possible. We would like, therefore, to make an official call in this paper to ask for contributions whenever possible. We hope that if this call reaches some attention, wwhypda will contribute to the advancement of hydrogeology.

Conclusion

To conclude this paper, we would like to insist on one point. As in any other science, hydrogeology requires a free access to data in order to advance. In the wwhypda project, we will not be able to cover all the aspects of hydrogeology, but we aim at setting up an infrastructure that will allow all hydrogeologists to assemble and share important data sets that will help to characterize the hydrogeologic properties of the underground.

Such a project is of course utopian. But 150 years after the publication of the seminal work of Henry Darcy we think that the time has now come to follow the spirit of people like Diderot and D'Alembert. This is why we propose to the hydrogeological in hydrogeology community to participate in the creation of a world wide catalog of hydrogeological properties and hydrogeological environment architectures freely accessible through Internet. Quoting Diderot "This is a work that cannot be completed except by a society of men of letters and skilled, each working separately on his own part, but all bound together solely by their zeal for the best interests of the human race and a feeling of mutual good will".

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DARCY 43

Les Systèmes d'Information pour la Gestion des Eaux Souterraines (SIGES) : Aquitaine, Poitou-Charentes et Midi-Pyrénées

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La gestion des aquifères demande à collecter et à synthétiser un certain nombre de données de nature différente : caractéristiques hydrogéologiques (perméabilité, emmagasinement…), mesures de niveaux piézométriques, analyses physico-chimiques, débit de sources, prélèvements… C'est la vocation des SIGES qui, lancés en Aquitaine dans les années 1990, se sont développés par la suite dans les régions voisines avec des orientations relativement différentes.

Les SIGES rassemblent les données des points d'eau autour de la Banque nationale des données du Sous-Sol (BSS). Ces données sont non seulement issues des réseaux de mesures mais aussi des différents travaux (thèse, études…) anciens ou récents. Ces données sont d'une part diffusées via des sites internet régionaux spécifiques et synthétisées par système aquifère, masse d'eau ou bassin versant.

En Aquitaine, le SIGES, qui existe depuis environ 10 ans, et très consulté et sert de base à la plupart des travaux des bureaux d'études, des administrations et collectivités, des hydrogéologues agréés… Outre toutes les données piézométriques, y compris celles disponibles en dehors des réseaux de suivi, les données qualité, les prélèvements et les débits de sources, le site sigesaqi.brgm.fr fournit une synthèse par système aquifère et les périmètres de protection des captages pour l'eau potable. Les partenaires associés dans le cadre de ce SIGES, sous Matrise d'Ouvrage BRGM sont l'Agence de l'Eau Adour-Garonne, la Région Aquitaine, l'Etat à travers le SGAR, la DRIRE et la DIREN.

En Poitou-Charentes, le SIGES est sous Maîtrise d'Ouvrage ORE et associe des financements du Conseil Régional, des Agences de l'Eau Adour-Garonne et Loire-Bretagne, de la DIREN et du BRGM. Le site fournit moins d'information que sur le SIGES aquitain, se limitant pour l'instant aux données du point d'eau, aux mesures piézométriques, aux descriptions des systèmes aquifères. Des développements du site sont toutefois prévus pour 2006 avec l'extension possible vers la diffusion de données qualité des eaux et prélèvements, d'une base documentaire, d'une synthèse par bassin versant.

D'une facture plus récente que celle des SIGES précédents, le site Midi-Pyrénées diffusera prochainement non-seulement des données sur les points d'eau et les périmètres de protection mais aussi des descriptions de masses d'eau dans le cadre de la Directive Cadre sur l'Eau.

Outils de gestion des données de tous les points d'eau et entités hydrogéologiques, à la différence de la banque nationale ADES qui s'intègre dans une logique réseaux de mesures, les SIGES couvrent progressivement le bassin Adour-Garonne. Ils sont proches toutefois de certains systèmes d'information régionaux comme SILURES en Bretagne ou la banque de données depuis longtemps développée en Alsace.

DARCY 50

Evaluating the effectiveness of Scotland's groundwater quality network for monitoring nitrate

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Effectively monitoring nitrate concentrations in groundwater is fundamental to both the European Nitrate Directive (91/676/EEC) and Water Framework Directive (2000/60/EC). Although most countries expend considerable resources collecting and reporting nitrate data from national groundwater quality monitoring networks, less consideration is given to how effective the network and individual monitoring points are. In this paper we report the methodology used in Scotland to help assess the effectiveness of the national groundwater quality network for monitoring nitrate and suggest ways the network could be improved.

Evaluating individual monitoring sites

Scotland has had a national groundwater quality monitoring network since the year 2000. Initially there were 150 monitoring sites, but these have been added to, and in 2005, the number of groundwater monitoring points for nitrate was 219, comprising 139 boreholes, 51 springs and 27 shallow wells. Of the total network, 67% of the sites are in agricultural areas. The network is managed by the Scottish Environment Protection Agency (SEPA). To undertake the assessment and validation of the network the following work was undertaken:

1• Zones of influence were estimated for each monitoring point using a semi-quantitative method developed specifically for the project.

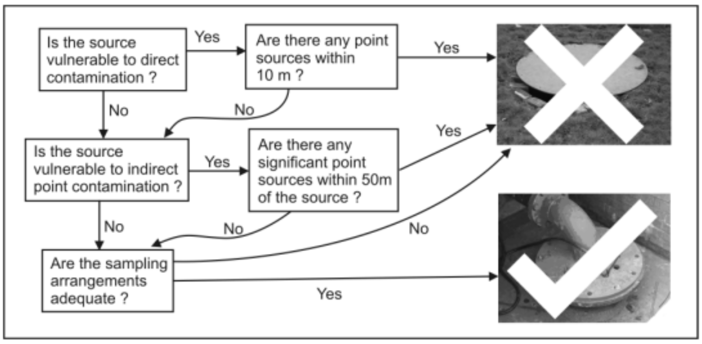

Figure 1. Outline of the methodology used to assess individual monitoring sites.

2• A risk assessment proforma was developed to systematically gather information about the source, surrounding hazards and sampling arrangements. Each site and zone of influence was visited and evaluated.
3• Groundwater samples were taken from selected sites for CFC and SF6 analysis, major and trace elements and well-head chemistry.
4• Zones of influence were combined with national datasets and field data to characterise each site.

Figure 1 describes the method used to evaluate individual sources. By using this method, more than 20% of the sites were judged to be of poor quality. Many of these were shallow large diameter wells, or low yielding springs.

Evaluating the network as a whole

Further analysis of the monitoring network was undertaken by comparing measured nitrate concentrations with modelled predictions of the likely nitrate concentrations based on the nitrogen available for leaching at the end of the growing season and the dilution effect of rainfall. This indicated that a considerable number of monitoring sites have lower nitrate concentrations than would be expected. The data indicated that there were several reasons for the discrepancy: mixing with older waters (identified from CFC and SF6); denitrification (identified from chemistry analysis); and the nature of the soil cover and superficial deposits (identified by statistical analysis of collected data).
The current network was then compared with an idealised network developed for Scotland which weighted the number of sites in different regions to nitrate pressure, land use and the hydrogeological conditions.

DARCY 107

La mise en œuvre des réseaux piézométriques pour évaluer l'état quantitatif des masses d'eau souterraines : exemple du bassin Seine-Normandie

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Les chroniques piézométriques sont l'élément de base nécessaire même s'il n'est pas toujours suffisant pour évaluer l'état quantitatif des masses d'eau souterraines. Ces données doivent permettre de dégager des tendances d'évolution de cet état, en particulier les dégradations afin de prendre les mesures nécessaires à l'exploitation raisonnée de la ressource permettant de concilier prélèvements d'eau souterraine et préservation des milieux. Les données piézométriques doivent donc être mises en regard des données relatives aux prélèvements d'eau. Par ailleurs, le choix des piézomètres est fondamental pour pouvoir caractériser globalement une masse d'eau souterraine quand on sait que la plupart d'entre elles sont hétérogènes à la fois en terme structural et en terme hydrodynamique. La distinction entre réseau de surveillance et réseau opérationnel prise en compte pour les réseaux qualité mais pas pour les réseaux quantité prendrait néanmoins ici tout son sens. Le réseau piézométrique du bassin Seine-Normandie a été mis en place à la fin des années soixante par le BRGM pour le compte du ministère de l'industrie puis de l'Agence de l'Eau. Le BRGM en a repris la maîtrise d'ouvrage en 2002. A cette époque ont été intégrés des réseaux d'autres maîtres d'ouvrage tels que des DIREN et des collectivités. Ces différentes étapes ont abouti à la constitution d'un réseau relativement dense (plus de 350 stations) mais avec des points inégalement répartis sur le bassin et surtout d'intérêt très variable vis-à-vis d'un objectif d'évaluation de l'état quantitatif des masses d'eau souterraines. Un travail vient d'être mené avec la DIREN pour analyser et hiérarchiser les piézomètres suivis par le BRGM. Les critères de hiérarchisation sont les suivants : chronique supérieure à 30 ans, fonctionnement compréhensible, influence des cours d'eau, influence par des pompages, unicité de la nappe captée, état vis-à-vis des risques d'ensablement et d'assec. Ce travail permettra d'achever la définition du réseau piézométrique de surveillance de l'état quantitatif des masses d'eau souterraines au titre de la DCE.

Abstract

Water level chronicles are basic elements requested, even if not always sufficient, for the evaluation of the quantitative status of groundwater bodies. This data should allow the determination of tendencies and in particular degradation that will support decision making for a sustainable management of the water resource keeping equilibrium between exploitation and protection of groundwater. Extracted volumes of groundwater should be compared with water level data. Choosing adequate piezometers is fundamental for a correct assessment of a groundwater body as it is usually heterogeneous from structural and hydrodynamic point of view. The differentiation between operational and surveillance monitoring defined for qualitative networks but not for quantitative networks would however make sense for this latest. In Seine-Normandie, the quantitative monitoring network was installed by the BRGM at the end of the 60s' for the Ministry of Industry and later on the Water Agency. The BRGM became the contracting owner in 2002. At that time, other networks from various institutes such as DIREN, were integrated to the main water level monitoring system. These various steps lead to the construction of a relatively dense network (more than 350 monitoring sites) but not spatially evenly distributed and not always adequately located for a correct evaluation of the quantitative status of groundwater bodies. A recent work, carried out in collaboration with the DIREN permitted analysing and prioritizing water level monitoring sites. The criteria for this prioritization are: chronicles longer than 30 years, comprehensible hydrogeological functioning, surface water influence, uniqueness of the exploited aquifer, state as regard to sand

silting and exsiccation period. This work will permit completing the design of the network for the quantitative surveillance of groundwater body as defined by the WFD

Les nouveaux besoins d'exploitation des réseaux piézométriques

La Directive Cadre Européenne (DCE) sur l'eau du 22 décembre 2000, a défini un cadre de gestion et de protection des eaux par grand bassin hydrographique, au plan européen. Elle impose aux Etats membres, de parvenir à un bon état des eaux (eaux de surface - eaux douces et côtières - et eaux souterraines) avant fin 2015.

Cette Directive implique le renforcement des réseaux de surveillance, pour:
- mieux connaître les ressources sur les trois plans, quantitatifs, qualitatifs et atteintes anthropiques, pour pouvoir décider en connaissance de cause.
- surveiller les évolutions, à titre préventif, de toutes les ressources économiquement et écologiquement pertinentes, dans le cadre d'une disponibilité durable, équilibré et équitable d'eau de bonne qualité,
- contrôler l'efficacité des actions correctives pour rétablir le bon état des ressources là ou elles sont mises en œuvre.

En France, pour répondre à cet engagement communautaire, le MEDD a engagé la structuration d'un Système d'Information sur l'Eau (circulaire du 26 mars 2002 du MEDD) qui met en place « des programmes de surveillance de l'état des eaux » afin de dresser un tableau cohérent et complet de chaque district hydrographique ».

Cette surveillance des masses d'eau souterraines concerne autant l'état quantitatif que l'état qualitatif avec les exigences suivantes :

- respect de la DCE,
- dispositif de suivi des plans d'actions prévus par la DCE,
- optimisation de la police de l'eau,
- dispositifs d'alertes vis-à-vis des inondations et des sécheresses,
- information du public.

Ces exigences sont formalisées par un « cahier des charges pour l'évolution des réseaux de surveillance des eaux souterraines en France » diffusé par le MEDD par la circulaire DCE 2003/07 du 8 octobre 2003 et complété par la circulaire DCE 2005/14 du 26 octobre 2005.

Ce cahier des charges définit les nouveaux besoins d'exploitation des réseaux de surveillance, et engage une forte évolution des réseaux actuels, sur trois axes principaux :
- augmentation importante du nombre de points de mesure pour assurer une couverture nationale de toutes les masses d'eau (tableau 1) et en particulier les ressources en eau enregistrant des situations de crise (forte pression anthropique, crue, étiage),
- raccourcissement du délai de mise à disposition au public de l'information.
- maîtrise des coûts, par des choix techniques et organisationnels.

Ces choix entraînent de nouvelles contraintes sur la conception de la chaîne de mesure, qui pour la surveillance quantitative des ressources en eau souterraine, va du matériel de mesure des niveaux piézométriques à la diffusion des données sur Internet avec la mise en œuvre d'outils de traitements pour l'analyse et la gestion des alertes. Cette problématique est commune aux autres réseaux de surveillance, même si dans l'état actuel des techniques, la surveillance de l'état quantitatif (niveaux et débits) est plus accessible à l'automatisation que les mesures des réseaux qualité.

Pour les réseaux de surveillance de l'état quantitatif, les fluctuations de la quantité sont directement liées soit aux fluctuations de débit d'une source qui est un exutoire de la nappe, soit aux variations de hauteur mouillée de l'aquifère, accessibles par la mesure des variations du niveau d'eau dans un puits ou un forage. La mesure de débit d'une source par mesure d'une hauteur d'eau au droit d'une section de contrôle qui a été tarée, ou la mesure de la hauteur d'eau dans un puits ou forage, sont des mesures physiques déjà largement automatisées. Les données stockées sur des enregistreurs numériques sont facilement accessibles à la télétransmission.

<table>
<tr><th colspan="4">Type de la masse d'eau</th><th>Densité minimale (nb/km^2)</th></tr>
<tr><td rowspan="5">Sédimentaire</td><td rowspan="3">Libre (s) et captif dissociés</td><td rowspan="2">Libre</td><td>Karst</td><td>1/500</td></tr>
<tr><td>Non Karst</td><td>1/500</td></tr>
<tr><td colspan="2">Captif</td><td>1/3000</td></tr>
<tr><td rowspan="2">Libre (s) et captif associés</td><td colspan="2">Captif dominant</td><td>1/3000</td></tr>
<tr><td colspan="2">Libre dominant</td><td>1/500</td></tr>
<tr><td colspan="4">Alluvions</td><td>1/500</td></tr>
<tr><td colspan="4">Socle</td><td>1/7000</td></tr>
<tr><td colspan="4">Edifice Volcanique</td><td>1/7000</td></tr>
<tr><td colspan="4">Intensément plissé</td><td>1/7000</td></tr>
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Tableau 1 : Densité minimale par type de masse d'eau recommandée par la DCE

La mise en place des réseaux de mesures piézométriques en France

Des réseaux piézométriques se sont développés dès la fin des années soixante à partir d'initiatives locales avec des densités de stations et des fréquences des mesures très inégales. La nécessité de disposer d'un réseau national plus rigoureux a été formalisée en 1999 avec la création d'un réseau national des eaux souterraines (RNES), résultant d'un protocole entre le ministère chargé de l'environnement et les agences de l'eau. La circulaire du 26 octobre 2005 stipule que le RNES constituera à terme, après restructuration, le futur réseau de contrôle de surveillance de la DCE. Il s'agit d'un méta-réseau correspondant à un ensemble de points appartenant à des réseaux élémentaires. Ces réseaux élémentaires répondent à un objectif commun, mais n'ont pas nécessairement le même maître d'ouvrage. L'objectif est d'identifier les stations des réseaux élémentaires qui constitueront le réseau national de surveillance de l'état quantitatif des masses d'eau souterraines au titre de la DCE. Ce travail a été réalisé dans certains bassins mais doit être achevé et harmonisé au niveau national d'ici fin 2006.

La création de la banque nationale d'Accès aux Données sur les Eaux Souterraines (ADES) a permis d'identifier un certain nombre de réseaux piézométriques élémentaires, de localiser les stations de mesures et d'accéder aux résultats des mesures quantitatives. Actuellement ADES réunit les données des réseaux mis en place par les Agences de l'Eau, les DIREN et le BRGM et les réseaux des collectivités territoriales. Au 15 avril 2006, 67 réseaux de suivi quantitatif étaient recensés dans ADES avec 2833 stations de mesure dont 2592 en France métropolitaine (figure 1)

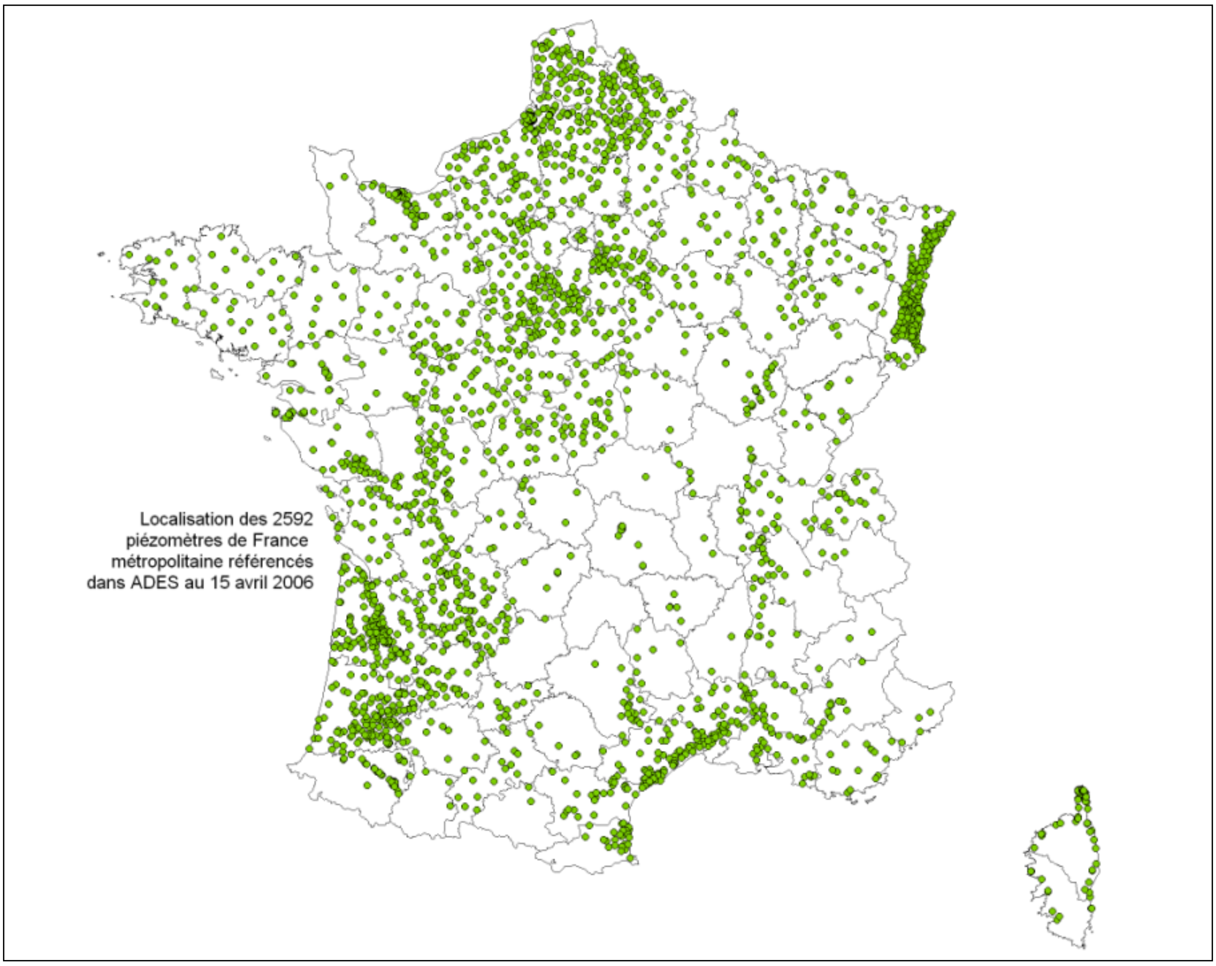

Figure 1 : Carte des piézomètres recensés dans ADES

Historique et fonctionnement du réseau de bassin Seine-Normandie

En 1996, le Ministère de l'Environnement a invité les Agences de l'Eau à prendre la maîtrise d'ouvrage et à renforcer leur financement sur les réseaux de connaissance patrimoniaux dans le domaine des eaux souterraines. En 1997, l'Agence de l'Eau Seine-Normandie a confié au BRGM la gestion du réseau piézométrique du bassin Seine-Normandie dans le cadre d'une convention annuelle, reconduite jusqu'en 2002. Cette période a permis de d'assurer la pérennité du réseau et de l'améliorer avec d'une part un effort d'équipement en matériel de mesures (capteurs de pression, centrales d'acquisition, modems) et des restructurations locales du réseau (suppression de points non pertinents, transfert du réseau de bassin vers des réseaux locaux ou inversement). A l'inverse, le réseau étant déjà constitué de plus de 200 points de mesures, peu de nouveaux points ont été créés. L'équipement en matériel de mesure a permis de raccourcir le temps de mise à disposition des données, qui ont été mise en ligne sur un site internet dédié (http://seine-normandie.brgm.fr), site toujours opérationnel.

La circulaire du MEDD du 26 mars 2002 a mis en place une nouvelle organisation de gestion et de suivi des données sur l'eau. Cette circulaire confie la maîtrise d'ouvrage des réseaux piézométriques au BRGM et aux DIREN. Pour le bassin Seine-Normandie, la maitrise d'ouvrage se répartit entre BRGM, DIREN Bourgogne, DIREN Centre, DIREN Basse-Normandie et le Syndicat des Eaux de l'Orne. Le réseau de bassin est passé de 218 stations de mesures en 2001 à 270 ouvrages début 2006 auquel il faut ajouter les réseaux de collectivités, soit au total 323 points de mesure (Figure 2). Durant ces 4 dernières années, un effort important a été fait pour moderniser le matériel, équiper les ouvrages en télétransmission, ce qui permet de les interroger tous les quinze jours, voire toutes les semaines, et ainsi de disposer de données quasiment en temps réel, susceptibles d'anticiper des situations de crise (cf. exemple d'utilisation des données piézométriques pour gérer les problèmes de sécheresse en Ile-de-France.

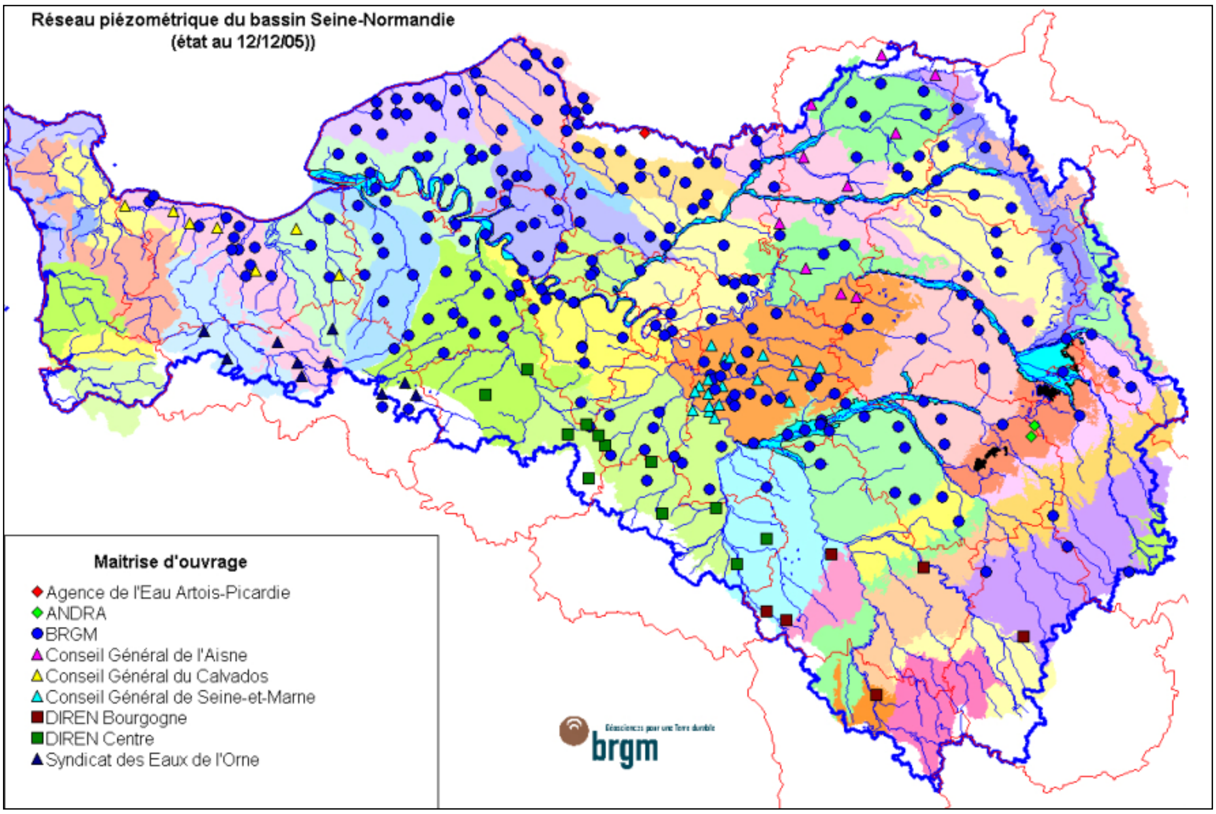

Figure 2. Etat des réseaux piézométriques du bassin Seine-Normandie à fin 2005

Pour les piézomètres sous maitrise d'ouvrage du BRGM, le processus de récupération, validation et chargement des données en banque peut être résumé de la façon suivante (figure 3) :

- Interrogation des stations télé transmises toutes les deux semaines : contrôle du fonctionnement de la centrale d'acquisition ; intervention sur le site si nécessaire, chargement des données dans la banque de données du BRGM.
- Lors des tournées de terrain (tous les 3 mois pour les stations équipées de centrales d'acquisition de données et tous les 6 mois pour les stations équipées de centrales d'acquisition de données télé transmises) : mesure à la sonde et test du capteur ; étalonnage du capteur, si nécessaire ; récupération des données ; chargement dans la banque.
- Lors du chargement des données dans la banque : correction de la dérive (en cas de mise en évidence d'une dérive du capteur) ; affectation d'un code de validité des données (selon les spécifications définies par le SANDRE).
- Pour les stations sans équipement : une mesure à la sonde tous les mois, saisie des mesures dans la banque.
- Pour les données issues d'autres producteurs que le BRGM : chargement dans la banque à réception des données.

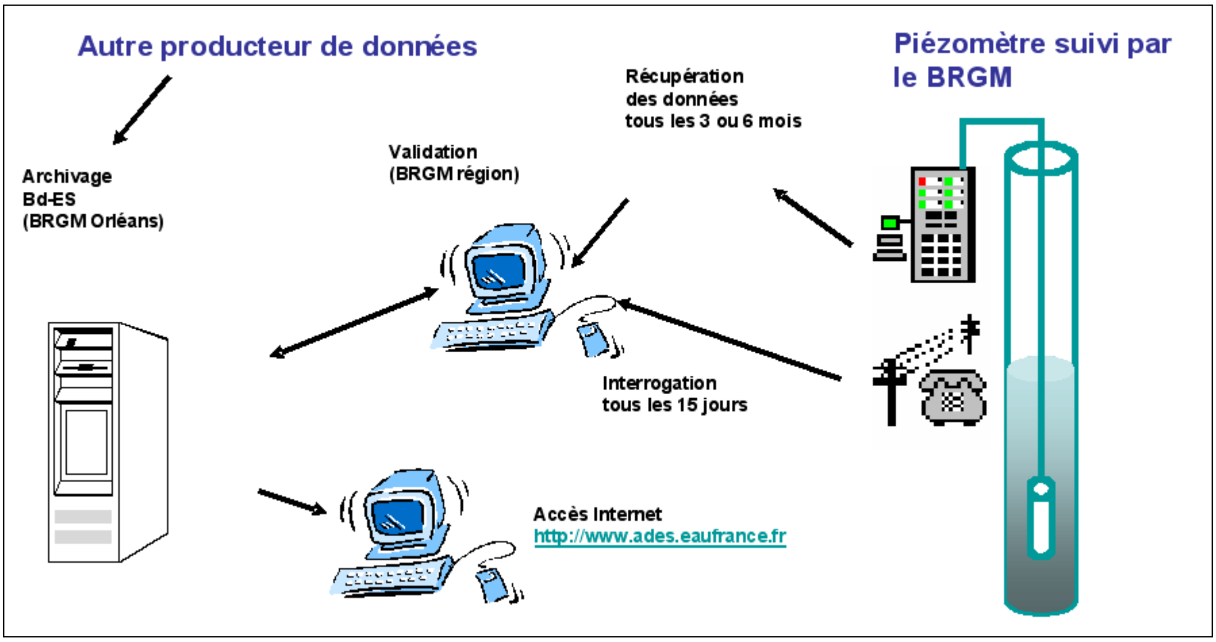

Figure 3 : Circuit de production des données du réseau piézométrique du bassin Seine-Normandie

Définition du réseau de surveillance DCE sur le bassin Seine-Normandie

Les piézomètres du bassin Seine-Normandie recensés dans ADES sont regroupés en réseaux élémentaires, gérés chacun par un maître d'ouvrage unique, dans lesquels on trouve, le réseau BRGM, les réseaux DIREN et les réseaux de collectivités territoriales

Ces réseaux élémentaires sont regroupés eux-mêmes pour les besoins de gestion et de rapportage en méta-réseaux qui peuvent ne comprendre qu'une partie des points des réseaux précédents, choisis pour répondre aux besoins particuliers du méta-réseau de regroupement. Les principaux sont par ordre d'agrégation croissant :

- les réseaux départementaux ou régionaux issus de réseaux élémentaires de collectivités locales, ou du BRGM, ou des DIREN,
- le réseau de bassin, sous la responsabilité de la DIREN de bassin.

Ces méta-réseaux agrègent les données de stations gérées par des maîtres d'ouvrage différents sélectionnées en vue d'un rapportage particulier.

Le réseau national de surveillance de l'état quantitatif des eaux souterraines, correspond à l'agrégat supérieur au niveau national de points sélectionnés à partir des réseaux de bassin. Il est destiné au rapportage de l'Etat vers la commission européenne sous la responsabilité du MEDD.

Ce travail de définition du méta-réseau de bassin est en cours. Une hiérarchisation a été réalisée sur l'ensemble de 244 piézomètres gérés par le BRGM (Putot, 2006). Regroupés par masse d'eau, les piézomètres ont été analysés et comparés en prenant en compte à la fois l'état du piézomètre, la qualité de sa chronique, le fait qu'il soit ou non influencé et sa représentativité vis-à-vis de la masse d'eau à laquelle il est associé.

Pour caractériser l'état des piézomètres et leur attribuer une note de qualité, plusieurs critères ont été pris en compte :

- La durée de la chronique.
- Les niveaux de référence (très basses eaux / très hautes eaux).
- La bonne corrélation des chroniques avec une modélisation (quand elle existe).
- La bonne compréhension du comportement du piézomètre (à partir de modélisations, de corrélation avec des points voisins ou dans les même conditions…).
- Le type de fluctuation (Pluriannuel, mixte, saisonnier).
- Les influences (pompages, réseau de surface).
- Aquifères principaux captés (unique ou non).
- L'état de la nappe (libre ou captive).
- La profondeur du piézomètre.
- L'état de l'ouvrage (« à sec », ensablé, bouché…)

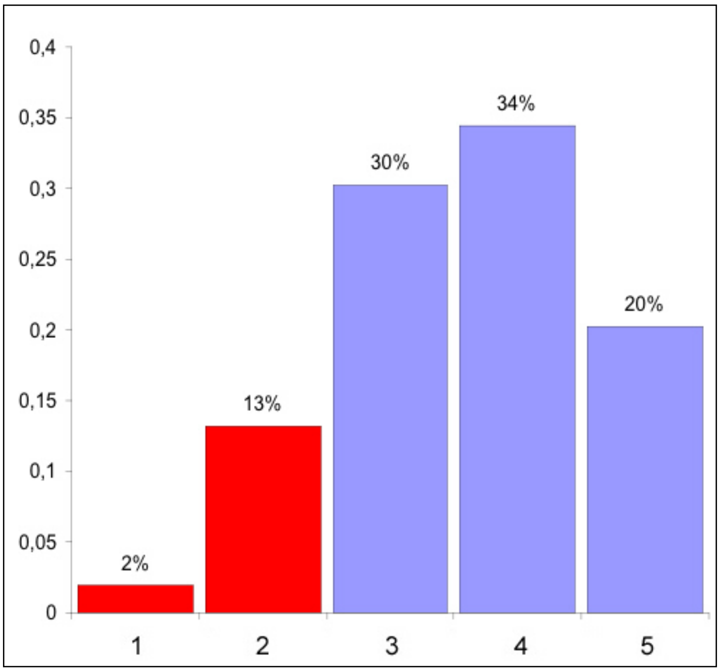

Figure 4 : Répartition des notes attribuées aux piézomètres.

Sur les 244 piézomètres étudiés, 212 ont une chronique assez longue pour qu'une note puisse être attribuée au piézomètre (figure 4). La tendance générale est à une bonne qualité des points de surveillance. Plus de la moitié d'entres eux sont considérés comme bons ou très bons. 5/6ème des piézomètres sont valables pour le suivi des masses d'eau. Les 15 % restants regroupent les piézomètres non représentatifs d'une masse d'eau (mais qui peuvent être intéressant à l'échelle locale), ceux dont l'ouvrage est en mauvais état et nécessitent des travaux de réaménagement et ceux qui sont à abandonner ou à remplacer.

Cette hiérarchisation doit d'une part être validée au niveau local en particulier pour les ouvrages ayant une note intermédiaire et d'autre part intégrer une sélection des ouvrages sous maitrise d'ouvrage des DIREN et le cas échéant de collectivités.

Caractérisation de l'état quantitatif des masses d'eau souterraines du bassin Seine-Normandie

L'état des lieux réalisé par l'Agence de l'Eau (AESN, 2004) montre qu'aucune masse d'eau dans le bassin ne présente de tendance durable à la baisse. Toutefois on peut cerner les masses d'eau qui présentent le plus de risques en comparant recharge et prélèvement. La figure 5 montre qu'une forte proportion de la recharge minimum des nappes (observée sur les 30 dernières années) est reprise par les prélèvements (50 à 100 %) sur plusieurs masses d'eau. Pour 4 masses d'eau, les prélèvements représentent même plus de 100 % de la recharge minimum.

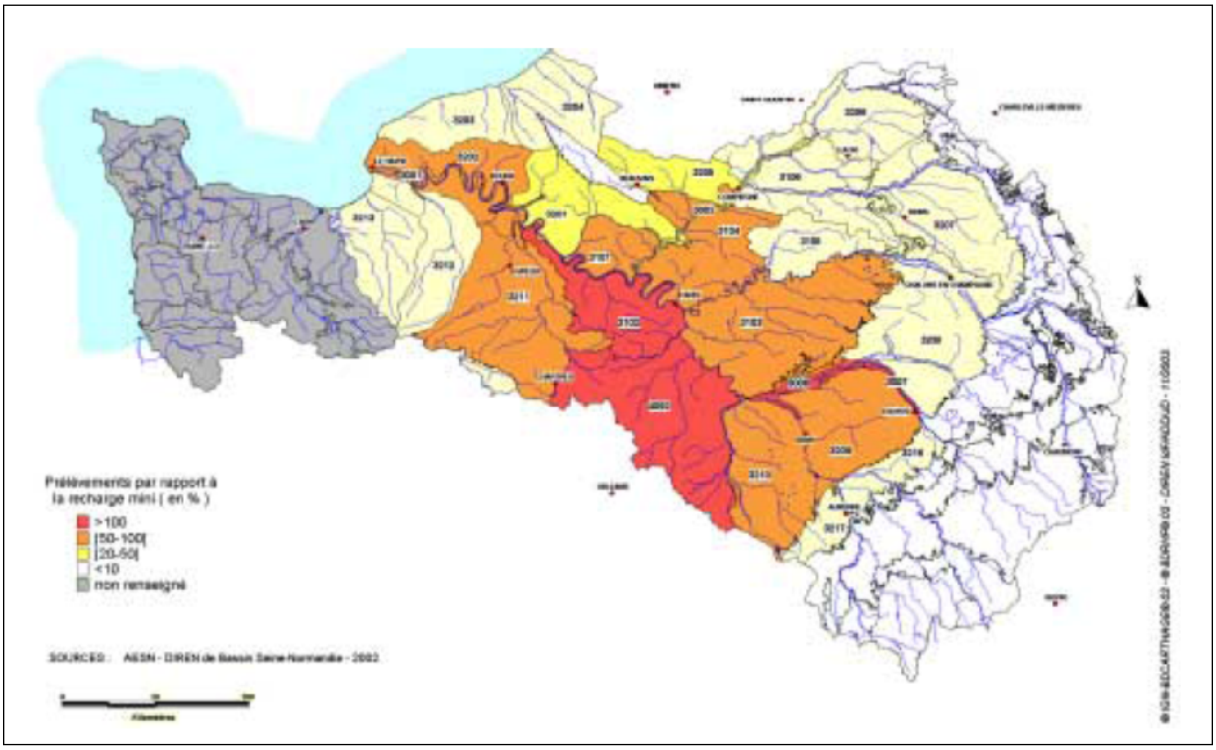

Figure 5 : Impact des prélèvements sur les eaux souterraines du bassin Seine-Normandie (source AESN)

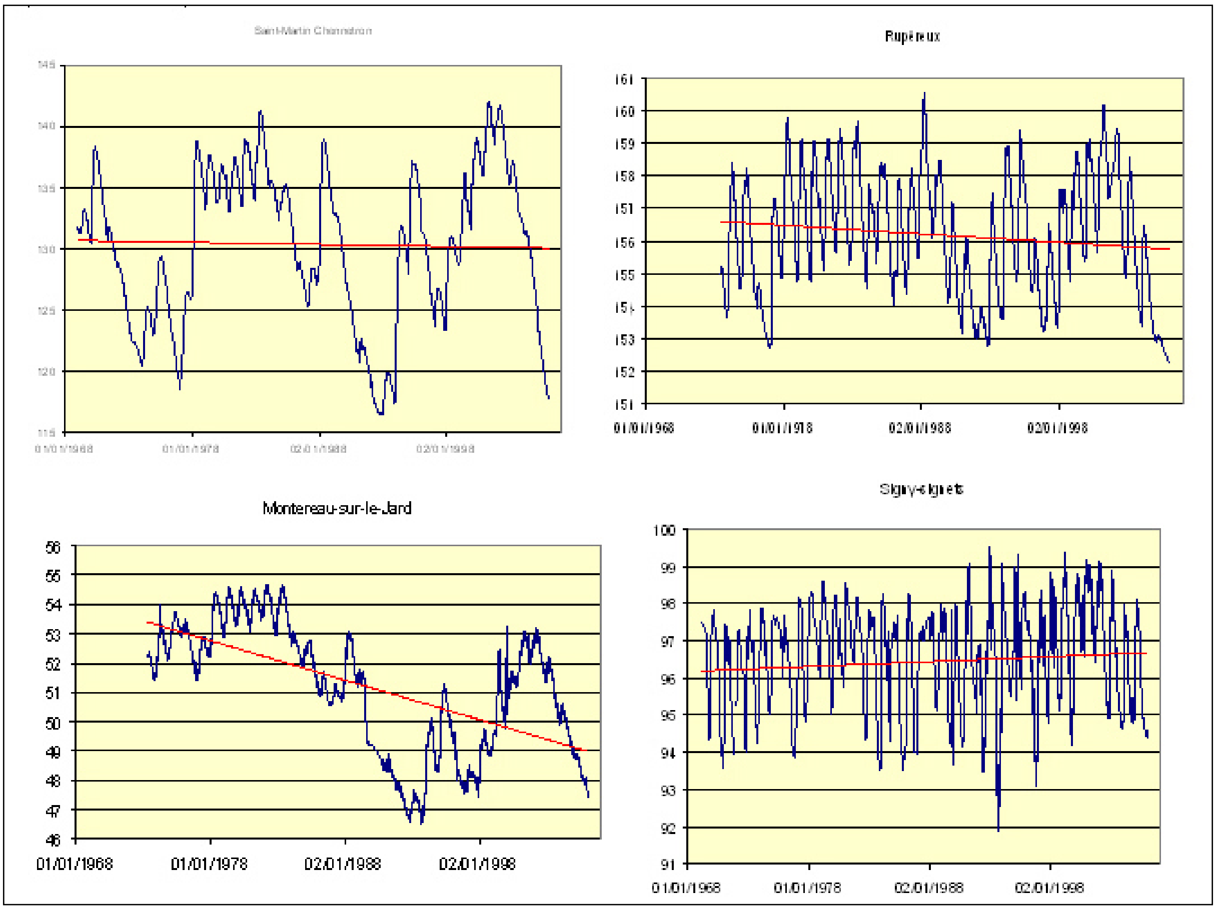

Figure 6 : Tendances d'évolution du niveau piézométrique pour 4 piézomètres appartenant à la même masse d'eau (3103)

Ces tendances à l'échelle de la masse d'eau masquent néanmoins des disparités observables grâce aux chroniques piézométriques. La figure 6 illustre ces disparités dans le cas de la masse d'eau souterraine 3103 (Brie – Calcaire de Champigny) avec 4 piézomètres montrant des tendances différentes. Ces différences sont dues à une répartition hétérogène des prélèvements. Ces phénomènes doivent être pris en compte pour caractériser l'état de la masse d'eau et son évolution à moyen et long terme, avec en parallèle une évaluation précise des prélèvements pour chaque captage d'eau souterraine.

Un exemple d'utilisation des données piézométriques : gestion des ressources en eaux souterraines en période de sécheresse en Ile-de-France

Dans le cadre d'une étude financée par la DIREN Ile-de-France, nous avons utilisé une partie des séries piézométriques issues du réseau de suivi pour élaborer des outils d'aide à la gestion des ressources en eaux souterraines notamment en période de sécheresse (Normand et al., 2005).

Ces outils d'aide sont de deux types:

- des modèles de transfert "pluie-niveau piézométrique" qui, pour chaque piézomètre, permettent d'effectuer des prévisions après une phase de calage sur les observations en générant quelques centaines de séries climatiques (pluies-ETP) et en faisant une analyse fréquentielle des niveaux correspondants (figure 7).
- des modèles probabilistes construits à partir des piézomètres retenus pour la prévision des niveaux. Ces modèles sont bâtis à partir d'une analyse fréquentielle au pas de temps mensuel des séries piézométriques par ajustement d'une loi de probabilité.

Dans l'ensemble des piézomètres disponibles gérés par le BRGM Ile-de-France, ont été écartés ceux pour lesquels les chroniques sont trop courtes, ceux qui sont trop influencés par des pompages, ceux qui captent une nappe alluviale (et influencés par le cours d'eau) et ceux qui captent la nappe de l'Albien, captive. Certains piézomètres ont également été écartés car leur fonctionnement est mal compris, ce qui signifie que leur comportement ne peut s'expliquer à partir d'un modèle pluie niveau en raison d'éléments perturbateurs importants qu'il n'a pas toujours été possible d'analyser dans le cadre de cette étude.

Vingt piézomètres ont été retenus et on fait l'objet d'une modélisation "pluies-niveaux" suivie de simulations prévisionnelles avec utilisation d'un générateur permettant de produire des séquences stochastiques de pluies et d'ETP sur la période de prévision (figure 8). Des mises à jour régulières des données de pluie, d'ETP et de niveaux piézométriques permettent de réaliser des prévisions à court et moyen terme (à un à deux ans) représentées sous la forme de quantiles correspondant à diverses périodes de retour. Des modèles probabilistes construits à partir des piézomètres retenus pour la prévision des niveaux ont été bâtis à partir d'une analyse fréquentielle au pas de temps mensuel des séries piézométriques par ajustement d'une loi de probabilité (figure 9).

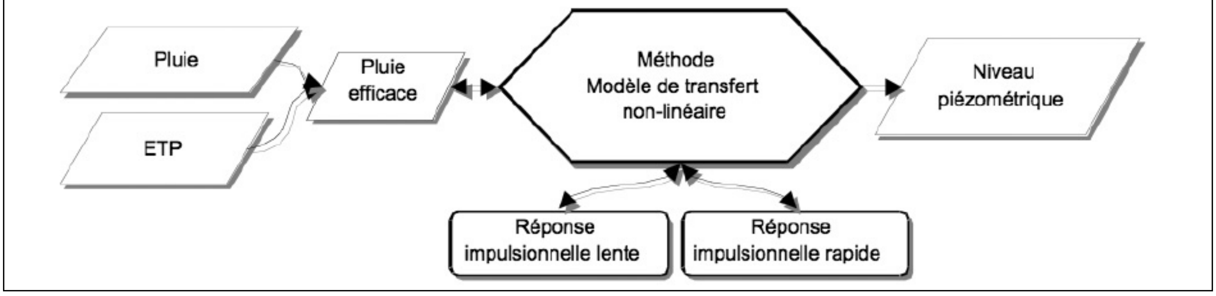

Figure 7 : Principe d'un modèle "pluie-niveau" à réponses impulsionnelles

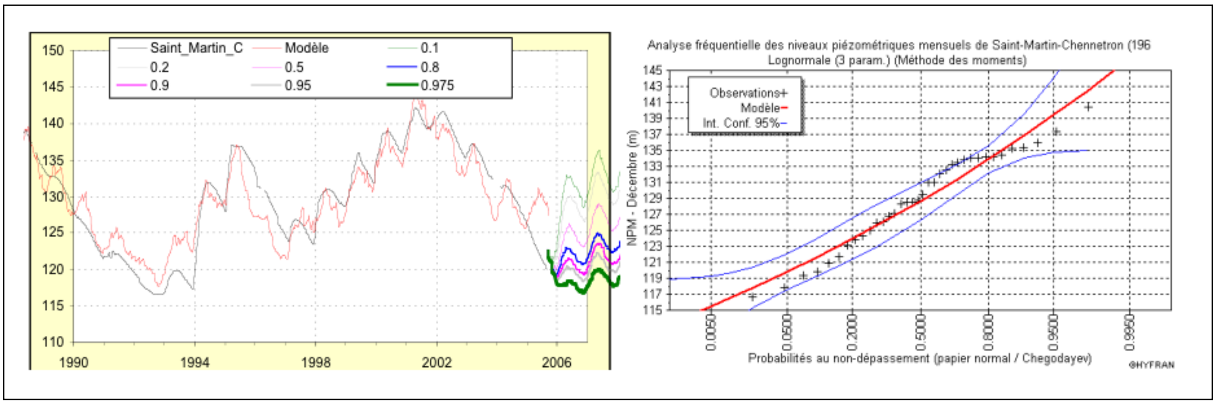

Figure 8 : Piézomètre de Saint Martin Chennetron : prévision à court terme et ajustement des niveaux piézométriques mensuels du mois de décembre à une loi log-normale à 3 paramètres

Cette analyse statistique est utilisée par la DIREN pour définir des seuils susceptibles d'être pris en compte dans les arrêtés préfectoraux limitant les usages de l'eau (figure 9).

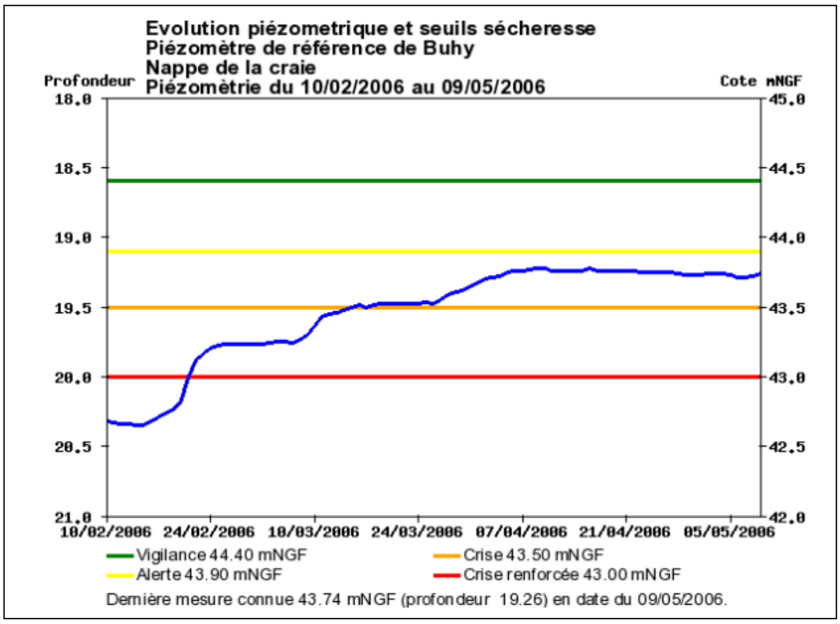

Figure 9 : Exemple de seuils pris en compte dans les arrêtés préfectoraux du Val d'Oise

Conclusion

Les réseaux de mesure (gestion, alertes, etc.) sont de plus en plus nécessaires pour les besoins de gestion de l'eau, tant au niveau national qu'au niveau européen (Le Nir, 2006).

Une nouvelle conception d'exploitation est en train d'être finalisée pour répondre aux nouveaux besoins :

- compléments de points de mesure pour un meilleur suivi des ressources en eau et leur gestion durable vis-à-vis des stress anthropiques,

- enregistrement numérique pour une fréquence de mesure adaptée à une meilleure connaissance des phénomènes naturels,
- télétransmission pour un contrôle de fonctionnement et une diffusion rapide de l'information par des banques de données en ligne sur Internet,
- plus grande autonomie et fiabilité des systèmes de mesure pour diminuer les coûts des interventions de terrain,
- maîtrise des coûts par diminution du nombre des interventions de terrain, par l'utilisation des technologies les plus modernes, pour faire face à la densification des points et des mesures, et la nécessité d'une valorisation des données plus opérationnelle comprenant la mises à disposition auprès du public.

Cette finalisation des réseaux de surveillance n'est qu'une étape sur une route bien balisée par les échéances de la Directive cadre européenne sur l'eau, qui obligent à une réactivité importante à soutenir sur le long terme :

- fin 2004 : présentation de l'état des différents usages de l'eau, de leurs impacts sur les masses d'eau ; définition des masses d'eaux où les objectifs environnementaux risquent de ne pas être atteints d'ici 2015 ; définition des zones protégées devant faire l'objet de protections spéciales,
- fin 2006 : finalisation des réseaux de surveillance, dont les mesures permettront de comparer la qualité des milieux aquatiques entre pays membres,
- fin 2009 : présentation d'un plan de gestion définissant les objectifs à atteindre en 2015, associé à un programme de « mesures » (réglementaires, financières, accords volontaires, etc.) permettant d'atteindre les objectifs,
- fin 2015 : bilan des objectifs atteints.

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Posters

DARCY 37

The International Hydrogeological Map of Europe at the scale 1 : 1,5 million (IHME1500)

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The International Hydrogeological Map of Europe, scale 1 : 1,500,000, is a series of general hydrogeological maps comprising 25 map sheets with explanatory notes, covering the whole European continent and areas adjacent to the East. The national contributions to this map series were compiled by hydrogeologists and experts in related sciences of the countries concerned under the auspices of the International Association of Hydrogeologists (IAH), Commission on Hydrogeological Maps (COHYM). The project is supported by the Commission for the geological Map of the World (CGMW).

The scientific editorial work is supported by the Government of the Federal Republic of Germany through the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) and by the United Nations Educational, Scientific and Cultural Organization (UNESCO). These organizations are responsible for the cartography, printing and publication of the maps and the explanatory notes.

The series of hydrogeological maps seeks to represent the hydrogeological setting of Europe as a whole without regard to political boundaries. Together with the information presented in the accompanying explanatory notes, the map can be used for scientific purposes, for large-scale regional planning and as a basis for detailed hydrogeological mapping.

The map sheets of the IHME1500 contain complex information on lithology, aquifer characteristics, surface catchments, groundwater divides, springs and artificial works for water management etc. The small scale of the map allows the representation of only a limited amount of hydrogeological information. Therefore, the sheets are accompanied by explanatory notes which contain additional information, e. g. on climate, chemical composition of groundwater, hydrogeological regionalization and any geological features of significance to groundwater flow. Additional drawings, hydrogeological borehole and cross sections are supplied, too.

As the finalization of the map project IHME1500 is foreseen for the end of this year the poster gives an overview about the history, the purpose of the map, its organisational structure, the content and the results of the map.

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DARCY 65

Characterization of the pesticide concentrations in the "nappe de la craie du Nord"

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Abstract

Although the number of measurements regularly increases, mapping the pesticide concentrations and their evolution along time still remains difficult. The *Craie du Nord* water sheet is selected for a methodological study sampled from 1997 to 2002 in three networks: the information (correct spatial coverage), the customary (preferential sampling) and the producer (few stations) networks. The atrazine evolution is similar when calculated either on the few stations with long time series or on the whole data set, although with different levels. Correlation between concentrations and land use is studied, but these connections remain weak.
Using the information network only, the *atrazine* concentration presents a spatial structure, modeled through a space-time variogram. The sensitivity analysis shows that the customary network improves the accuracy of the estimation. The maps of the inter-annual variations are compared to the accuracy of the estimations. As a conclusion, recommendations are made to enhance the sampling efficiency.

Introduction

Even when the number of samples regularly increases, accurate characterization of the pesticide concentrations remains difficult due to the following reasons:
the pesticides contain a large variety of substances which have been spread at different times and for different durations,
the measurement accuracy (from the sampling procedure to the chemical analysis) varies over time and depends upon the laboratory. The analytical inaccuracy is around 15% to 20%,
the measurement stations present short time series. The sampling periodicity depends on the network (the information network is used to monitor an area, the customary network to supervise the quality of drinking water) and is sometimes even related to the measured values.

A station is usually drilled in order to provide drinking water, and not to characterize the quality of the whole water sheet. There is a similar problem at a larger scale when characterizing the status of underground water in France [2].
What is the relevant accuracy when mapping concentrations? Can temporal or seasonal evolutions be detected? Are there any relations between the concentrations of the different substances?
The Craie du Nord water sheet has been selected for quantifying the pesticide concentrations in relation with the land use, because of its vast extension, the large number of measurements available, its vulnerability due to the quick transfer of pollutants to the ground water [1].

Sampling characteristics

The available sampling campaigns were carried out from 1997 to 2002: the base maps for *atrazine* measurements show a “shift” towards North-East (figure 1). Therefore the global statistics (mean, quantiles) are not comparable from one year to the other as they rely on different sets of stations. A more detailed study is necessary in order to derive the respective importance of the spatial and the temporal variations.

Despite the large number of data, only few stations present long time series of concentration measurements. More than 30% of the stations have one measurement only, 28% have two, with a maximum of 24 measurements for two stations.

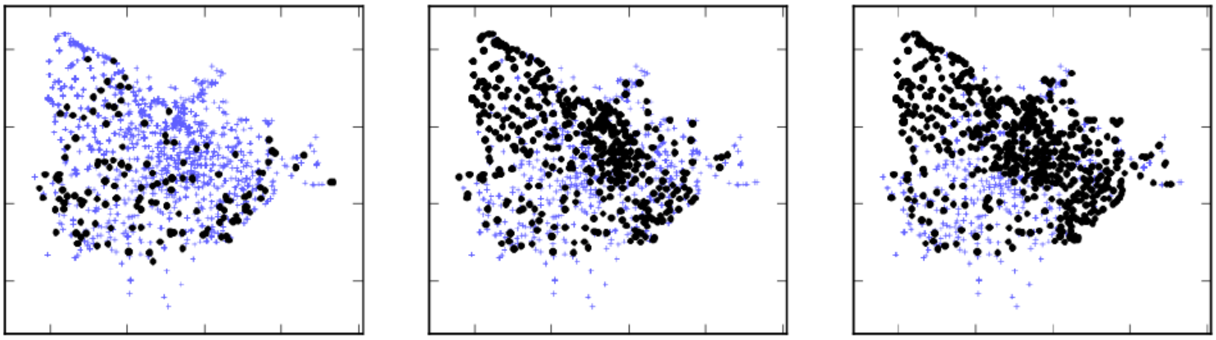

Figure 1: Base map of station locations: (+) for a station and (•) for a measurement

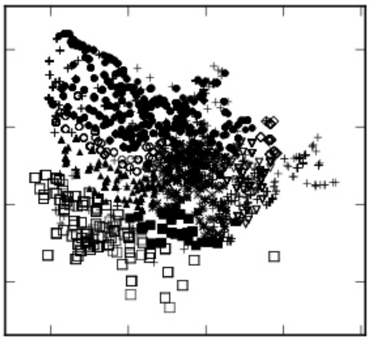

Figure 2: The 8 aquifer classes

The field contains 40 aquifers, and 30% of the stations belong to the same aquifer. All the other aquifers are sampled by less than 5% of the stations each. Aquifers have been regrouped in 8 classes. Considered together with figure 1, figure 2 shows that the sampling density per aquifer varies over time. As we ignore the depth of the measurement in each station, we have simplified the problem by considering that all samples belong to the same homogeneous water sheet.

Quantification limits

Each measurement is provided together with its quantification status. Most of measurements lie below the quantification limit (Table 1), which varies per product, per laboratory and over time. For the atrazine substance, several quantification limits are used: 0.01, 0.02 and 0.05µg/l which cannot be neglected with regard to the *drinkability* threshold (current standard value is 0.1µg/l per substance). In the rest of this study, the non quantified values (smaller than the quantification limit) are set to this conventional value which introduces a slight overestimation. Conversely, setting these values systematically to 0 produces an under-estimation which would be problematic with regard to the sanitary risk. Other more elaborated methods have been experienced, replacing these measurements by intervals between 0 and the quantification limit (soft data) [4]. This sophistication requires some strong assumptions on the statistical characteristics of the variable (stationarity) which are not always fulfilled by the concentrations.

Product	Origin	Number	Quantified %
atrazine	corn weed-killer	4374	44.7
simazine	herbicide	4243	5.3
terbuthylazine	corn weed-killer	3988	1.2
isoproturon	corn weed-killer	3753	3.4
diuron	herbicide	3751	6.0
atrazine desethyl (DEA)	derived from atrazine	3391	54.1
2-hydroxy atrazine (HyA)	derived from atrazine	3029	5.6

Table 1 – Number of measures and number of quantified concentrations per product

In order to measure the impact of these non-quantified values, we replace each measurement by a random value drawn uniformly between 0 and the quantification limit. For atrazine, the global mean decreases from 0.044µg/l to 0.036µg/l, the variance slightly increases from 0.019(µg/l)2 to 0.021(µg/l)2. This increase has no effect on the structure, in particular on variograms. The modification of the mean highlights the necessity of a low quantification limit, especially when compared to the drinkability threshold.

Different origins of measurements

The different networks do not geographically overlap (figure 4). The information network (259 stations) aims at evaluating the quality of the water sheets in time and their evolution. The customary network controls the water quality for drinkability purposes. The statistics of atrazine concentration reflect this difference in motivation: the customary network has a lower mean as it concentrates on the stations where atrazine concentration is low. As far as the variation coefficient (ratio of the standard deviation to the mean) is concerned, the explanation is more complex. The experimental variance can be considered as a dispersion variance: even in the stationary case (when both the mean and the variance do not show any trend), due to the spatial correlation, this variance increases with the surface of the investigated area. When the variance increases, the histogram and therefore the maximum are modified.

Origin	Number	Product Minimum µg/l	Origin Maximum µg/l	Number Mean µg/l	Quantified % Variation Coefficient
Information network	1319	0.003	0.76	0.050	1.17
Customary network	2831	0.000	0.28	0.040	0.80

Table 2 – Link between the statistics for the atrazine concentration and the origin of measurements (the largest customary value is considered as erroneous and has been removed)

Similarly, the quantile-quantile plot (which compares the histograms, regardless of the data location in time and space) shows the same difference according to the origin of the measurements: the values are systematically larger for the information network than for the customary network (figure 3).

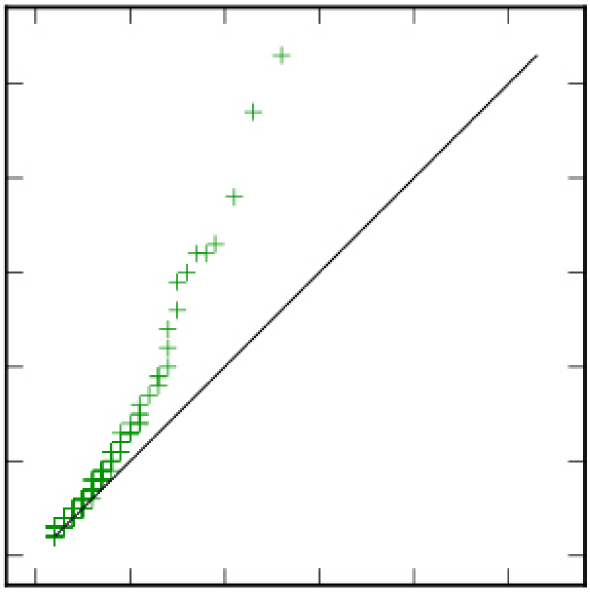

Figure 3 : Quantile-quantile plot for atrazine concentrations between customary (horizontal) and information (vertical) networks. First bisector is reported.

Semi-preferential sampling of the customary network

Mostly, sampling is done in April and October, that is to say twice a year with a six month interval (figure 4).

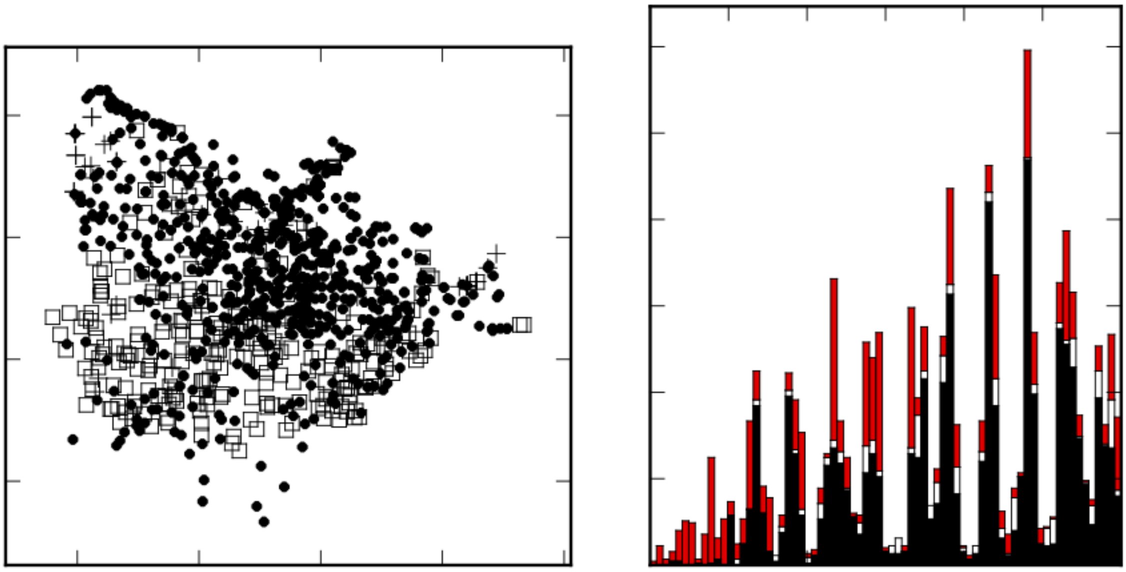

Figure 4: Sampling according to the origin of the measurements
(a) Base map: producers (+), information (□) and customary (●) networks
(b) Histogram of the number of measurements per month: producers (white), customary (black), and information (grey) networks.

In certain stations, the sampling frequency is adapted to the concentration level: the frequency decreases after a low value has been encountered and increases after a large concentration, in order to supervise the water quality. However, after a very large value, the station is abandoned and no more measurement is produced in this station (figure 5). Therefore the sampling is semi-preferential, in space and time, in a complex manner. The differences observed on the mean and the quantiles depend upon the network, due to the locations of the stations and the sampling frequency.

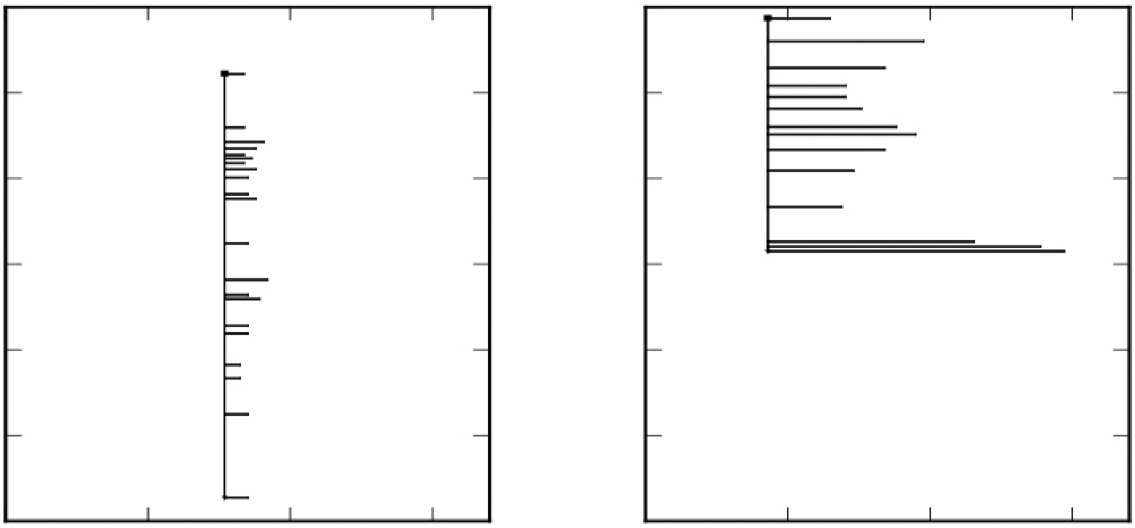

Figure 5: Preferential sampling along time.
(a) Customary station 00197X0161 (b) Information station 00461X0001

Evolution of concentrations in time

Seven stations provide long time series with 24 measurements sampled over five or six years: one belongs to the producers, four to the customary network and two to the information network (figure 6). They provide the temporal evolution of the concentration, for fixed location of the stations.
The regression, which represents the mean concentration as a function of the date, clearly shows a global decrease of the atrazine concentration, with large local variations. It is interesting to note that the linear regression along time, based on the seven long time series, shows almost the same negative slope as when calculated on the whole data set.

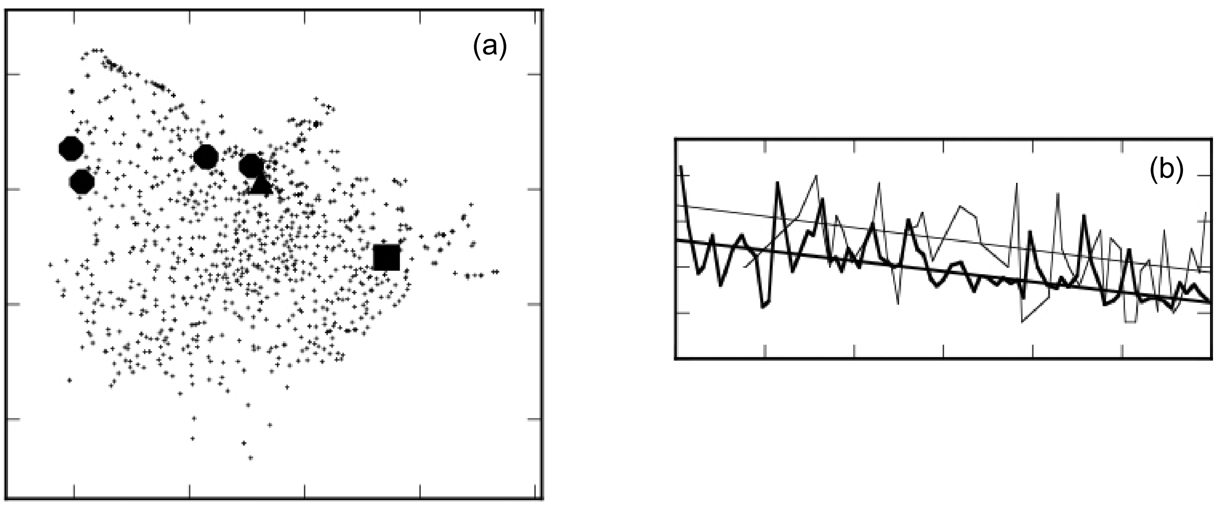

Figure 6 – (a) Long time series: producers (▲), information (■) and customary (●) networks
(b) Regressions of the atrazine along time: 7 long time series (simple line), whole data set (thick line)

Relations between substances

The graphic representation of different substances for the long time series shows different levels and evolutions according to the station (figure 7).

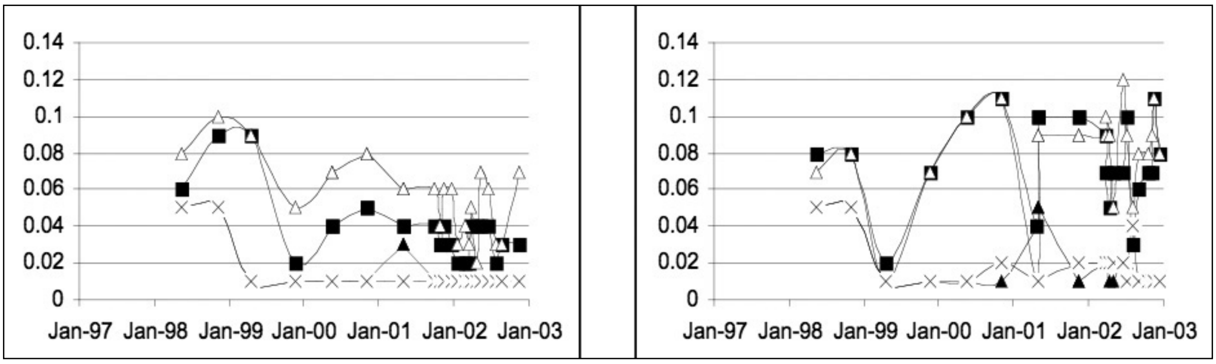

Figure 7: Atrazine (■), DEA (Δ), DIA (▲) and HyA (x) measured in two stations of the customary network (left: 00163X0081 – right: 00167X0003/F1

For the two stations selected from the customary network, the temporal evolution is rather similar for the atrazine and its derived product (DEA), but the two curves are not parallel. The scatter plot between these two products confirms the expected correlation (figure 8) with a rather moderate correlation coefficient (0.59). This cloud shows that the largest values for the two substances do not correspond to the same measurements: this is also true for other substances.

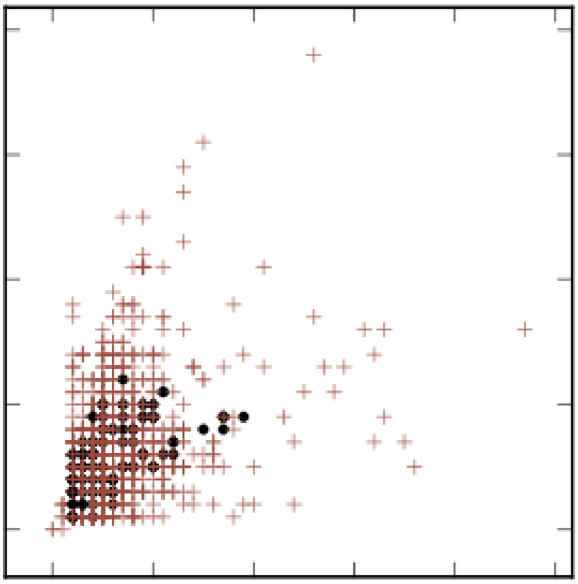

Figure 8: Correlation between atrazine (horizontal) and DEA (vertical).
Measurements from the seven long time series are highlighted

The principal component analysis is a standard procedure, based on the covariance matrix, in order to study the relationships between variables [5]. Here the results of PCA are very unstable due to the large proportion of values measured below the quantification limit, for products other than atrazine and DEA. The variances and covariances are linked to few high values which vary according to the selected samples (per year, per origin of the stations). When we discard some high values considered as unsafe, the PCA results are greatly modified.

As a conclusion, the only valuable correlation concerns atrazine and DEA: this implies that the use of the atrazine data, more numerous (table 1), will improve the estimation of DEA by a cokriging procedure.

Relationship between concentration and land use

The relationship between the pesticide concentrations and some environmental characteristics (such as the land use) can be used in order to improve the accuracy of the estimations.

As a matter of fact, several variables are usually available on a regular grid covering the area of interest.
The IDPR (Index of development and soil persistence, developed by BRGM, France) regroups topography, geological structures and soil lithology information in order to characterize the vulnerability of the water sheet (figure 9). IDPR is negatively correlated to the thickness of the non-saturated zone (figure 10): the correlation coefficient is -0.54 for the *Craie du Nord* water sheet.

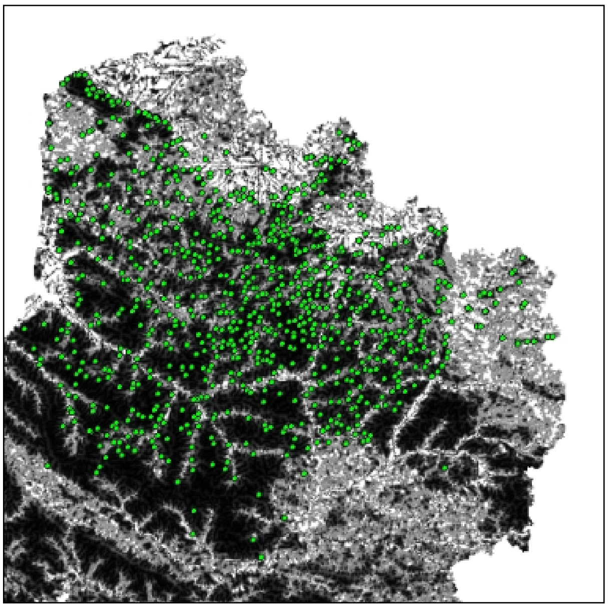

Figure 9: IDPR calculated for the Craie du Nord water sheet, with location of station

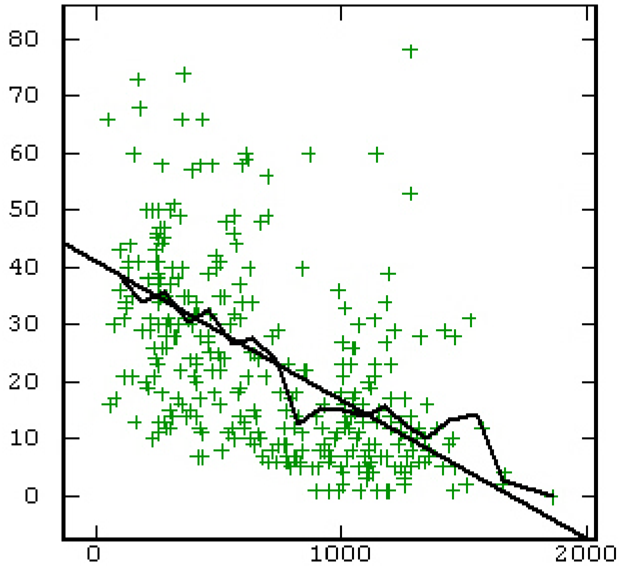

Figure 10 : Scatter plot between IDPR (horizontal) and thickness of the non-saturated zone (vertical). The experimental and linear regressions are reported.

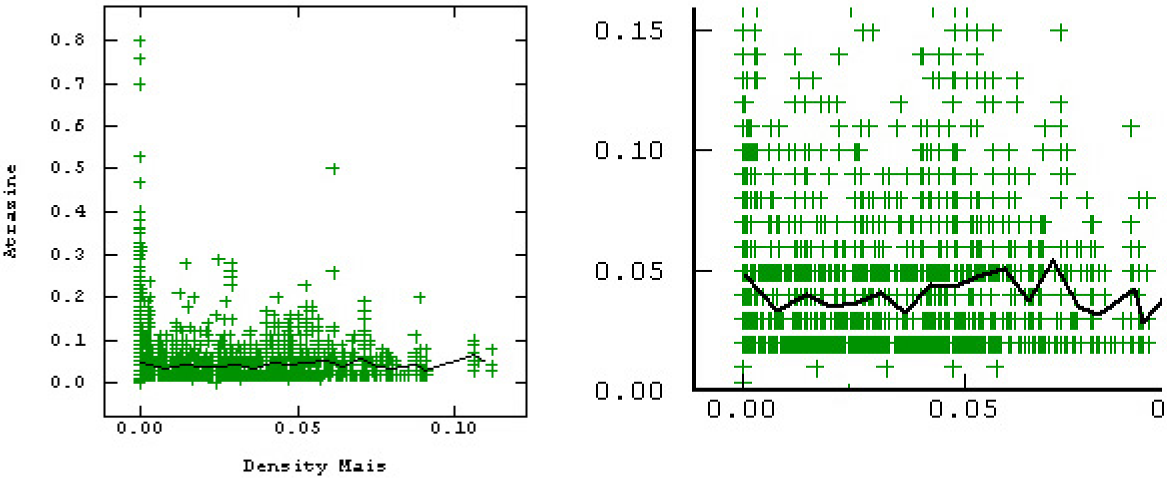

Figure 11: Scatter plot between atrazine concentration and surface of corn growing functional unit. The empirical regression is represented. Magnification for small distances (right).

Corine Land Cover has been used in order to provide the land use, and in particular to derive the surface of the area dedicated to corn growing, where atrazine pesticide is mostly used. The correlation is established by *functional unit* which is the area of the water shed located

above the station. Correlations of the atrazine concentration with the IDPR, the thickness of the non-saturated zone or the land use are weak.
On the contrary, the correlation between atrazine concentration and the corn growing surface is slightly positive (figure 11) but with a dispersed cloud. In particular, the large values experienced in the first class show that atrazine is also linked to a non-agricultural usage.
From now on, we will concentrate on the atrazine concentration.

Temporal variability

Table 3 summarizes the statistics on the global annual means, calculated on all the data set. The systematic decrease of the mean annual concentration is consistent with the previous observations.

	Number	Mean	Standard Deviation
1997	139	0.058	0.060
1998	364	0.048	0.030
1999	472	0.047	0.041
2000	476	0.041	0.035
2001	495	0.039	0.032
2002	627	0.031	0.021

Table 3: Annual mean and standard deviation per station (all data set).

	1997	1998	1999	2000	2001	2002
1997	139	87	97	77	79	86
1998	0.59	364	201	201	217	202
1999	0.35	0.66	472	236	245	272
2000	0.35	0.62	0.66	476	376	394
2001	0.31	0.54	0.65	0.75	495	396
2002	0.40	0.58	0.47	0.69	0.74	627

Table 4: Number of pairs (upper triangle) and correlation coefficient (lower triangle) of the mean annual concentrations per station.

The correlation between annual means is strong in the last years (close to 0.75) and quasi systematically decreases when time interval increases (Table 4). This high correlation level implies that the accuracy of the estimation map of the mean annual concentration can be improved by taking into account data from several neighboring years, which requires the calculation of a time variogram.

This variogram represents (one half of) the mean squared difference between pairs of data as a function of the distance (or delay) between these data. It measures the spatial or temporal variability of the concentration. As the data from the information and customary networks lead to different statistics, the spatial and temporal variability will be studied for each network separately.

The half-yearly periodicity of the measurements affects the number of pairs for each lag of the temporal variogram. The large variability at the origin relates to the measurement error variance. The time variogram presents a structure for the information network, with a larger variance consistent with the statistics of Table 2. In the case of customary network, there is no structure because of the presence of few very high concentration values (figure 12).

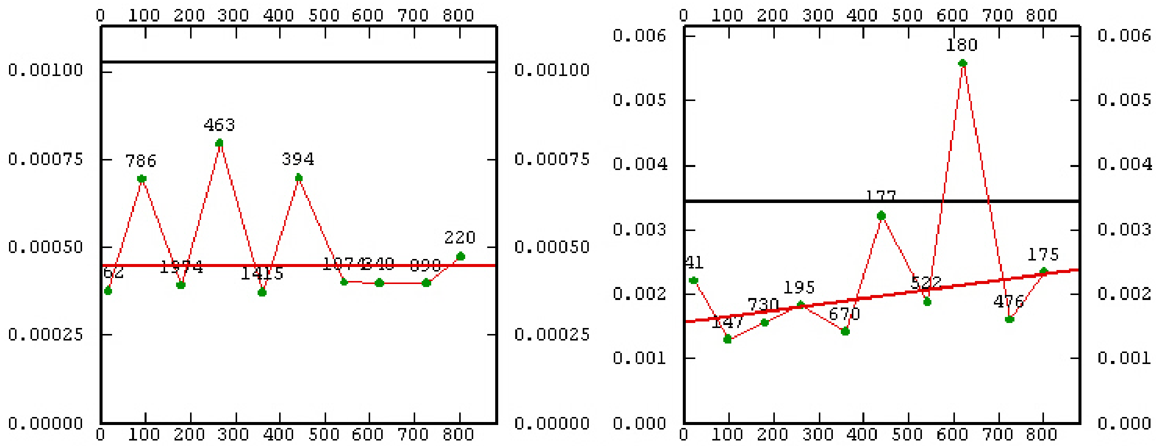

Figure 12: Temporal variograms for 10 lags of 90 days (Customary [a], Information [b] networks)

Spatial variability

The space variograms of the concentration do not show any obvious anisotropy: therefore only the omni-directional variogram is represented.

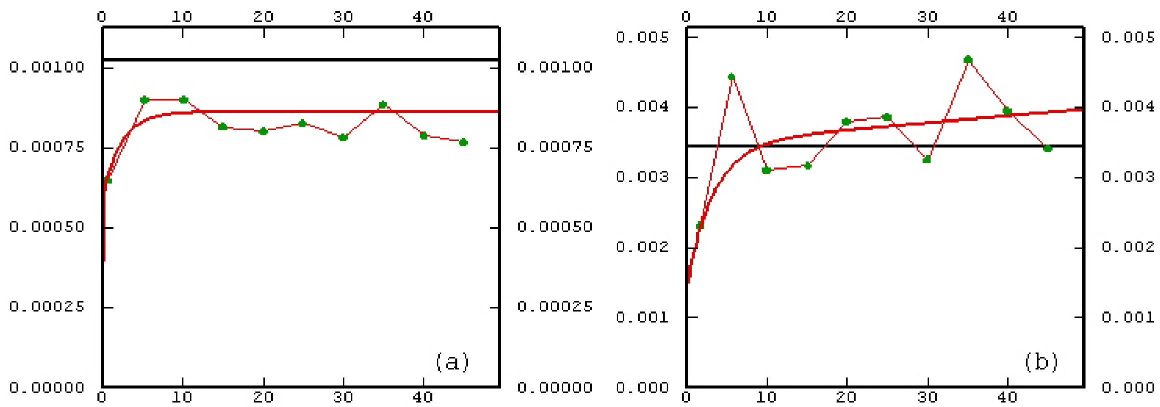

Figure 13: Spatial Variograms for 10 lags of 5km (Customary [a] and Information [b] networks)

The spatial structure presents a longer structure for the information network than for the customary network where the range is smaller than 5km (figure 13). This reflects the difference in the sampling strategy between the two networks.
As for the time variogram, the sill of the space variogram is much larger for the information network, because these data better cover the investigated area, in particular better represent the high values. Therefore the variograms of the information network will serve as a reference.

Space time variogram modeling

The space and time experimental variograms are jointly fitted by a model composed of a nugget effect, a spherical component and a linear component. A classical geometrical anisotropy between space and time is used in order to produce a tractable space-time model.

Cross-validation per network

Can the data from the customary network (more numerous but less representative) be of any help to improve the estimation? The answer is provided by the cross-validation technique where a known value is temporarily removed and estimated from the remaining information. The validation error is the difference between the measured and the estimated value; the normalized validation error corresponds to the validation error scaled by the kriging standard deviation forecasted within the model.
The estimation, performed by kriging, partially removes the sampling artifacts, as it attributes relatively smaller weights to data in dense areas (declusterizing). Conversely, kriging does not correct the preferential sampling of low or high values.

In the first case, the customary measurements are validated using data belonging to the information network. The validation errors lie within [-0.008,+0.24] with a mean of -0.0007µg/l this estimation is unbiased, with a slight dissymmetry towards high values which correspond to measured high concentrations. The scatter plot of this normalized validation error along time shows no systematic trend (figure 14).

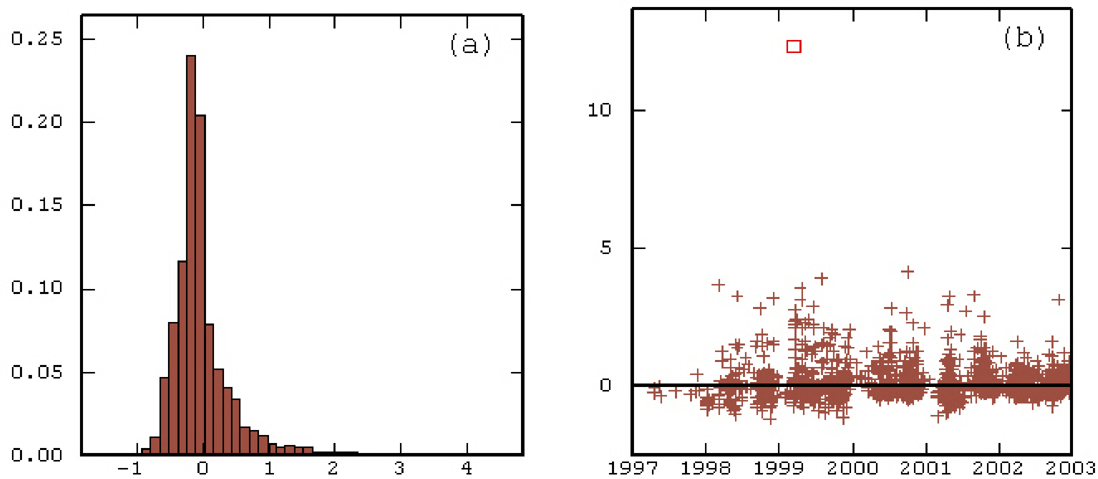

Figure 14: Estimation at customary sample using data from information network
(a) Histogram of normalized errors (b) Scatter plot of standardized error along time

Conversely, what is the influence of the semi-preferential customary network? In the second case, the information measurements are estimated using data from the customary network. The validation error lies within [-0.005,+0.72] with a mean of +0.0089 µg/l larger than in the first case (in absolute value) and with an opposite sign. However, this slight under-estimation remains consistent with the statistics of Table 2 and is smaller than the lowest quantification limit (0.01 µg/l). The histogram of the normalized validation errors shows that the estimation quality is poorer here than in the first case, with a maximum around 30 instead of 4 (figure 15).

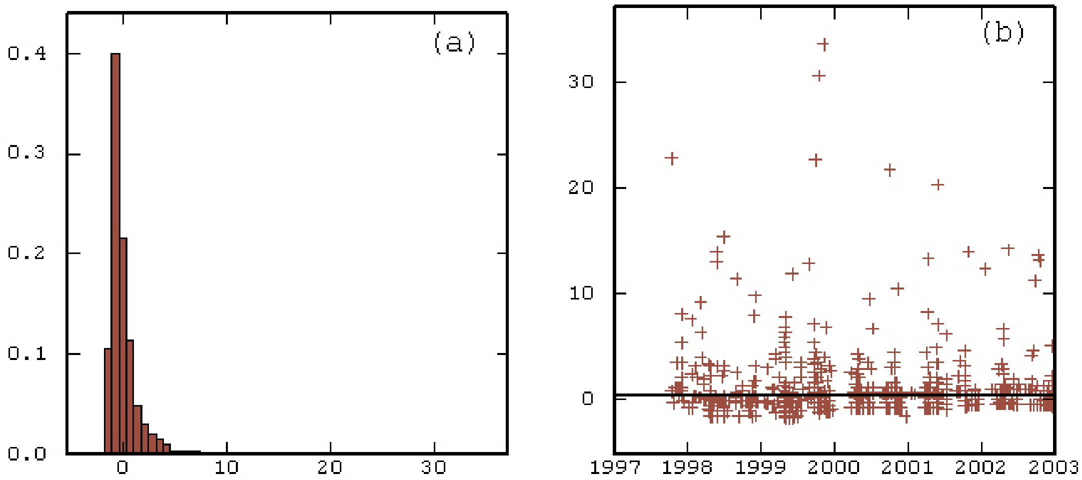

Figure 15: Estimation at information sample using data from customary network
(a) Histogram of normalized errors (b) Scatter plot of normalized error along time

Due to the high variability of the time-space variogram at the origin, it is essential to use the information optimally in order to improve the estimation accuracy. When a sufficient number of data from the information network is available, data from the customary network can also be used in the kriging procedure. But in the area with lots of stations from the information network, the estimation may be locally biased. The variance map of the kriged estimation error, calculated using the information network only, can be used to delineate these areas.

Estimation maps

The mean annual concentration is estimated on 2km by 2km cells, from data of all networks, using the variogram model derived from the information network and a space-time moving neighborhood.
The estimation maps show the global decrease of the concentration from 1997 to 2002, with some high spots whose locations vary per year (figure 16).

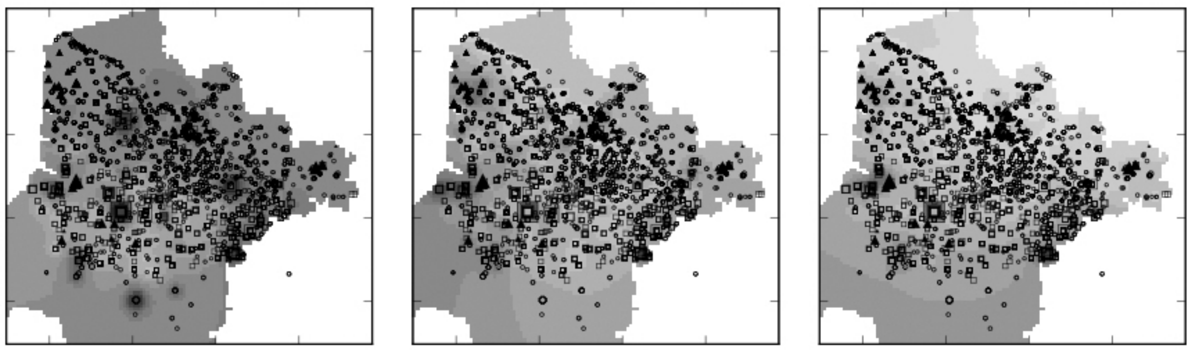

Figure 16: Estimation maps of the mean annual concentration (same grey scale for all three pictures)

The standard deviation maps show that the accuracy globally improves (more stations), in particular on the northern border, whereas the sampling becomes sparser in the south (figure 17).

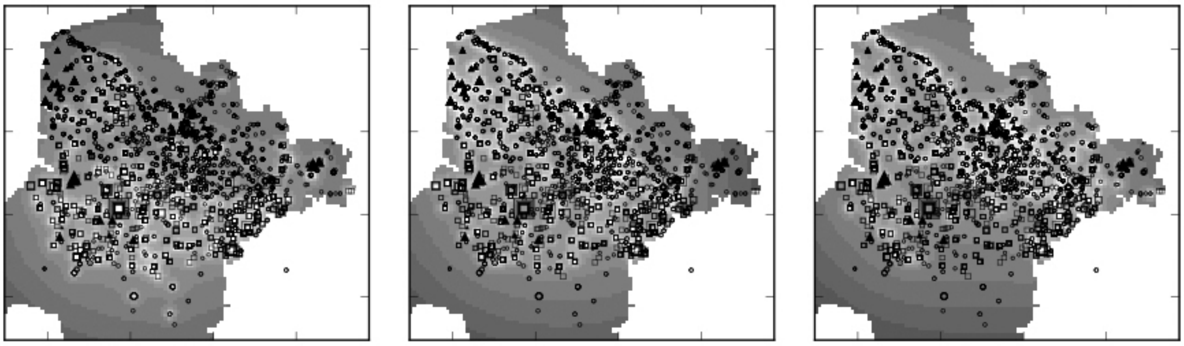

Figure 17: Kriging Standard deviation maps of the mean annual concentrations (same grey scale for all three pictures)

Inter-annual difference maps

In the same way, kriging can directly provide inter-annual difference maps [8]. These differences greatly vary between two consecutive pairs of years (figure 18). However, these variations must be considered with respect to the precision given by the kriging standard deviation maps. Moreover these difference maps show that the evolution over time cannot be forecasted with a great degree of confidence.

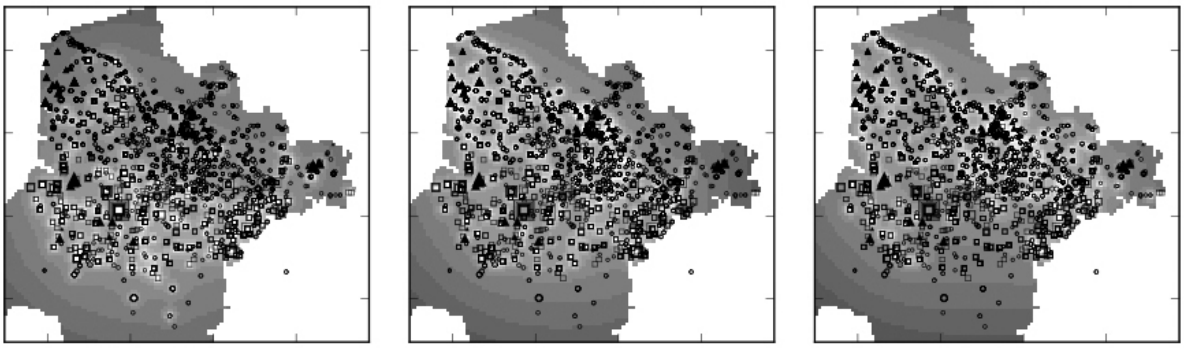

Figure 18: Inter-annual difference maps where decrease is represented using light colors (same grey scale for both pictures)

Conclusions

The customary network is designed to look after the water drinkability: therefore it corresponds to a preferential sampling which is not suited to provide an accurate image of the whole water sheet. Conversely the information network is more regularly sampled in time and space but its number of stations remains insufficient for an accurate estimation.

For atrazine, the decrease of the concentration is checked globally and is quantified spatially through maps. Nevertheless large amplitude fluctuations can be observed both over time and space. No strong relation has been established between the concentration and the land in this study: this may simply reflect the fact that the use of atrazine has been reduced during the period of time considered.

The other substances are even more difficult to evaluate due to the small number of quantified measurements. The lack of systematic joint measurements makes it impossible to highlight possible links between the concentrations of these substances, and to perform a joint estimation.

Despite inadequate sampling, a space-time structure has been observed and modeled for the atrazine concentration. This model has been used through a kriging procedure in order to produce maps of mean annual concentrations, of inter-annual difference and of the corresponding accuracy. Although kriging accounts for the data irregularities, it cannot always correct the preferential sampling, i.e. when the sampling is linked to the measured values (customary network).

This study leads to several recommendations on the sampling strategy, in order to qualify the status of the water sheet and to provide quantitative maps of concentrations.

First, as the pesticide concentrations show a decreasing trend, the proportion of non-quantified measurements becomes larger; this makes the mapping of concentrations more difficult. The solution would be to reduce the quantification limit, or at least to keep a large gap between this limit and the drinkability threshold.

Optimally we would need a regular sampling in space and time, covering the area of interest. Practically, given the locations of the stations, the sampling along time must be kept as regular and systematic as possible: concentrations should be measured at a regular frequency, independently from the values encountered. For example, measurements should be continued even when the station is not used for water consumption anymore.

For studying the different pesticides simultaneously, it is again recommended to carry on a multi-substance regular and systematic sampling procedure. However, if some statistical links are established, we can reduce and adapt the measurement frequency for these substances. As the concentration of each substance tends towards low values, one could also be interested in estimating the sum of concentrations, for families of substances.

This study has demonstrated that geostatistical techniques are useful to calculate the indicators (as the annual mean concentration per station). They also produce maps which highlight the variability of the concentrations in time and space, together with the corresponding uncertainties.
Finally, note that the geostatistical framework can be enlarged in order to address other problems, such as the probability for a concentration to exceed a given threshold, either locally or over a given area or a period of time [6].

Acknowledgments
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Optimization of Groundwater Monitoring Network: Applications of Geostatistics With a few Case Studies from a Granitic Aquifer in a Semi-Arid Region

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Abstract

The monitoring network consisted of 55 bore-wells out of which 25 were specially drilled for monitoring the water levels and 30 were selected from the existing irrigation wells. The analysis of the variance of the estimation error obtained using kriging technique on grids in the entire area has been the basis to discard some of the private irrigation wells. The wells were discarded such a way that the variance of the estimation error does not exceed a pre-decided value. Thus after a few iterations, a network of 40 monitoring wells has been evolved keeping the variance of the estimation error within the desired limit.

In another study a simple method has been developed using the cross-validation technique of geostatistical estimation to analyze and optimize an existing network for monitoring fluoride. In the small watershed, water samples have been collected from 60 wells and analyzed for water chemistry and fluoride. The fluoride values were analyzed geostatistically and the variogram calculated was validated through cross-validation test. Using the result of the cross-validation, it has been possible to assign a priority index to all the measurement points. It was found that monitoring fluoride from a network of only 30 wells selected using the priority index could provide almost same variability that obtained from monitoring all the 60 wells.

Introduction

The success of any scientific study greatly depends on the quality and the quantity of basic data. Scarcity of data and their collection on isolated location mainly in the field of hydrogeology makes it necessary to adopt special procedures or an estimation technique to match between field measurements and data requirements. Geostatistics based on the theory of regionalized variables has found more and more applications in the field of groundwater hydrology. Now Geostatistics has found applications in almost all domains of Hydrogeology from parameter estimation to predictive modeling including the most important one; data network designing. Geostatistical estimation variance reduction, cross-validation techniques etc. are a few procedures that could study adequacy of a given monitoring network and could evolve an optimal monitoring network with some given constraints. The advantage of the geostatistical estimation technique is that the variance of the estimation error could be calculated at any point without having the actual measurement on that point (well). Thus the benefits to be accrued from an additional measurement could be studied prior to its measurement.

The work of Hughes and Lettenmair, 1981; Carrera et al., 1984; Rouhani, 1985; Loaiciga, 1989, Gao et al, 1996 etc. are some examples of the application of Geostatistical techniques to the optimal data collection network design. However, Agnihotri and Ahmed, 1997 have brought out some crucial ambiguities in such application and thus a few modifications have been brought out to make the procedure effective and useful. The present study describes such modified/improved procedures through a few case studies carried out on designing monitoring network optimization in a fractured granitic aquifer.

Variography of a regionalized variable

The theoretical part of the Geostatistical techniques have already been dealt with earlier workers e.g., Matheron, (1971), Marsily (1986), Isaaks and Srivastava (1989), Deutch and Journal (1992), Wackernagel (1995) etc. Most of the hydrogeological parameters are defined and measured at points in a 2D space. Therefore, all the derivations and examples in the chapter are given in 2D space and point estimation is used. The main steps involved in a Geostatistical technique applied to hydrogeological parameters are: Variography i.e., structure analysis, cross-validation, estimation and backward transformation (if any). Variography in determining variability of a parameter is an important step and quality of the estimation result depends on it.

Geostatistical Optimization of the Monitoring Network developed

It is difficult to define or generalize the necessary and/or sufficient data for a particular study but availability of adequate measurements to capture the variability of the parameter is the key for a successful scientific study. Large amount of measurements will make the study easy but the project extremely ill-favoured or uneconomic but less number of data will make the study gloomy. It is difficult but important to determine the optimal requirement of data for any study. Often it depends on the scientific objective of the study also.

The main two objectives on which the optimization was based have been that the optimized network should be able to:

- represent the true variability of the parameter under study and
- provide its estimates on fairly finer grid with a desired accuracy in the form of the variance of the estimation error.

Thus the entire area is usually divided into reasonably finer grid and the variance of the estimation error are calculated through a suitable kriging technique and the same are compared with the pre-decided or desired limit of the variance of the estimation error. Thus depending on the outcome of the comparison a network is categorized into dense, sparse or near optimal. Then iteratively the network is optimized either by discarding, adding or shifting the measurement points.

Another procedure is through cross-validation tests where the variogram is very well calculated and after finalizing the variogram, the cross-validation table is analysed. The measurement points are then assigned a rank in the ascending order based on the difference in the measures and estimated values.

Description of the area and the parameters under study

In a small watershed of 53 Km^2 area (Maheshwaram watershed) near Hyderabad, India, groundwater is mainly found in a coupled system of weathered and fractured granitic rocks. The two zones could be assumed to form a single and often semi-confined aquifer. Large scale fracturing and jointing has resulted in formation of huge boulders of granite. The joints in the area strike in NE-SW direction. There is a second set of horizontal joints the frequency being about 5 to 10 m. These are filled up with the weathered material and form good aquifers with high transmitting capacities.

The water levels are being monitored through a network of about 55 bore wells out of which 25 have been specially drilled to observe comparatively undisturbed water table and the other 30 bore wells are selected based on the drainage pattern and intervals etc. from the existing private irrigation wells (Fig. 1). The water level measurements have been carried out on monthly basis for a period of almost one hydrological cycle. In addition, to investigate the water quality of the aquifer, samples from about 60 wells were taken and water were analyzed mainly for fluoride content. It was necessary to use the wells fitted with pump for sampling water for chemical analysis. Also to study the variation of fluoride in time, it was decided to optimize the monitoring network and if possible reduce it so that frequent monitoring could feasibly be done.

Optimization of Water Level Monitoring Wells in Maheshwaram Watershed

It was decided to reduce the number of IFW wells from the total 55 observation wells such that:

- all the wells are monitored in a shortest possible time say one single day,
- discard some of the irrigation wells fitted with pumps as it was difficult to monitor static levels in these wells and
- reduce the cost of monitoring also

without loosing the monitoring benefits. Thus to obtain an optimal monitoring network having 25 IFP wells and minimize the IFW wells such that the kriging estimation of water levels provide standard deviation of the estimation error not more than 8 m (against the average standard deviation of 12 m of the water level data) in the entire area. Through a special procedure the IFW wells were removed one by one and the impact with the above constraints were analyzed. Finally a network with 25 IFP wells and 15 IFW wells have been evolved for monitoring the water levels every month. It is seen that using the optimized monitoring network it is still possible to maintain the same magnitudes of σk. Fig. 1 also shows the location of wells for optimal monitoring network.

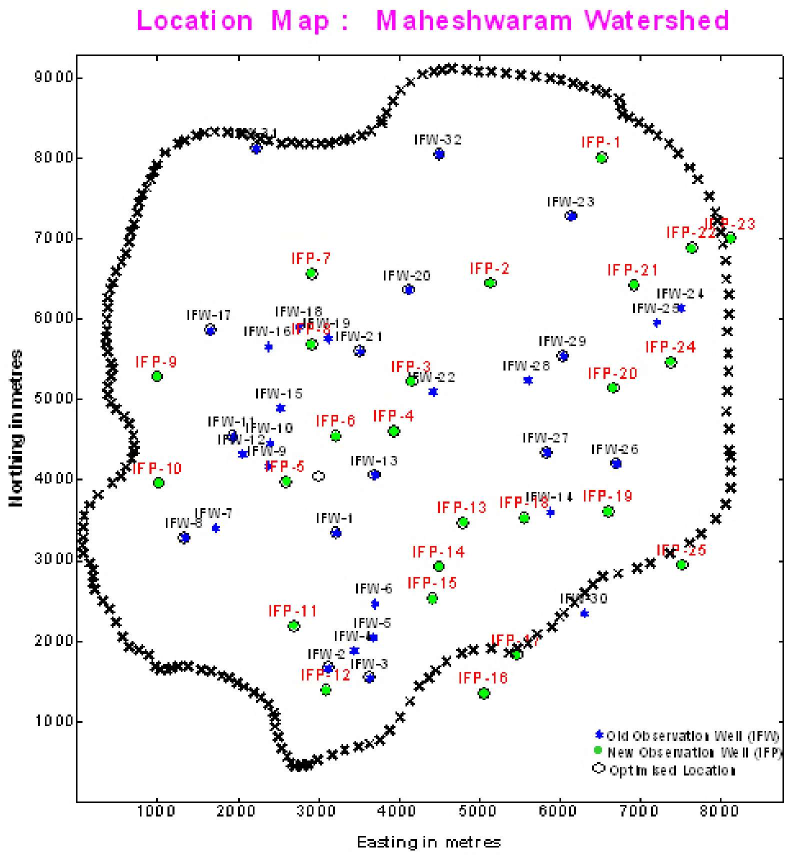

Figure 1: Location of measurement wells in total and optimized monitoring network

Ranking of Monitoring Wells for Fluoride Measurements

During July 2001, groundwater samples for the analysis of Fluoride were collected from 60 wells fairly distributed in the area. The fluoride content in the area varies from 0.5 mg/l to 2.97 mg/l with a mean value of 1.6 mg/l. Although the area is not much affected with the fluoride problems but the situation is alarming as the mean itself is exceeding 1.5 mg/l, the WHO upper limit. The variogram from the values of Fluoride has been calculated and fitted with theoretical model. The variogram parameters are as reported below.

γ (d) = 0.1 + 0.25 Sph (2000) ....(1)

A cross-validation test (Ahmed and Gupta, 1989) to validate the variogram was thus performed and the following norms are obtained while performing the cross validation test on the

$$\left| z_i^e - z_i^f \right| \approx 0.0 \qquad \forall \; i=1 \ldots N \qquad \ldots\ldots\ldots(2)$$

and

$$\left| z_i^e - z_i^f \right| / \sigma_i \leq 2.0 \qquad \forall \; i=1 \ldots N \qquad \ldots\ldots\ldots(3)$$

variogram.
where z are the values of the parameter under study e.g., Fluoride content, the suffix e stands for the estimated and f for the field or analysed values. s is the standard deviation of the estimation error. The cross-validation is performed by masking one known value from the data set

and estimating the same from the remaining values and the finally decided variogram. If the equation 3 is not satisfied, either the variogram does not represent the true variability or the data could be erroneous (Ravi Prakash et al, 1990). The values of equation 2 indicates the difference of the estimated value from the measured values and a low value of equation 2 suggests that the parameter could be well estimated at this point and need not be measured. Thus, based on the values of equation 2, a priority index could be assigned to the measurement points starting from the highest value of equation 2.

The number of wells to define desired size of the monitoring network could be decided based on the resources available including the man-power and the analyses facilities etc. Then a network could be prepared from table 2 by picking the wells with decreasing priority. Table 1 shows the statistics from the measured values for comparing the various monitoring networks. It is very clear that the minimum and maximum values measured are present in all the cases. The mean and the variance are increasing consistently as the number of measurement points is decreasing. However, the change in the mean value is almost negligible. Fig. 2 and Fig. 3 show the iso-lines of fluoride drawn based on the 60 (Fig. 4) and 30 measurements (Fig. 5) respectively coming from the network decided on the basis of the priority index. The two contours show more or less similar distribution and the regionalized picture is almost identical.

Network size	Statistics on the parameter values in mg/L			
	Minimum	Maximum	Mean	Variance
60 (july 2001)	0.67	2.97	1.60	0.286
55	0.67	2.97	1.61	0.304
50	0.67	2.97	1.61	0.324
45	0.67	2.97	1.66	0.336
40	0.67	2.97	1.70	0.352
35	0.67	2.97	1.71	0.378
30	0.67	2.97	1.74	0.426

Table 1: Statistics of measured values of F for different networks

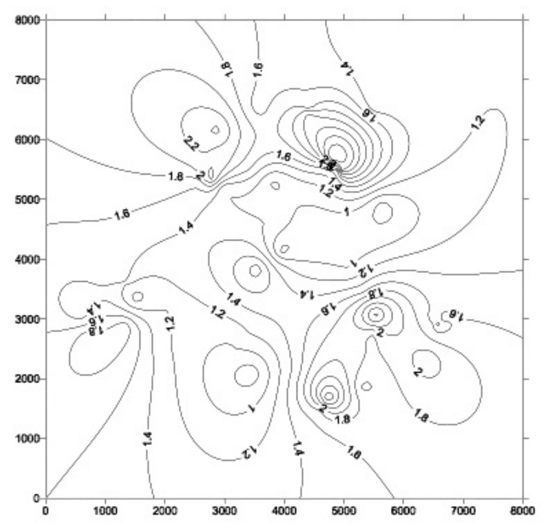

Figure 2: Error of estimation from 60 measurements

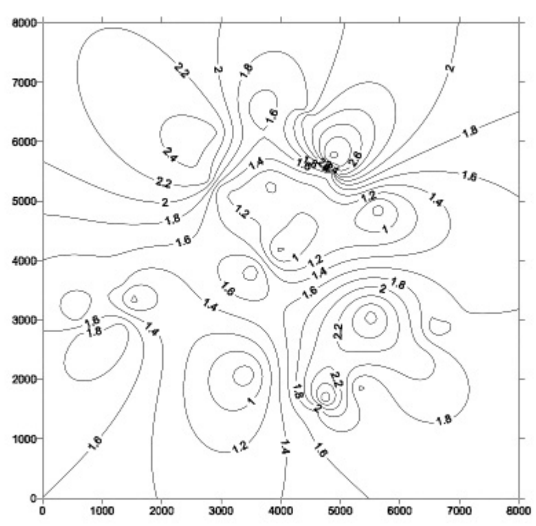

Figure 3: Error of estimation from 30 measurements

Conclusions

The constrained optimization of the monitoring network with only 40 wells will ensure that all the wells are measured in the shortest possible time every month. Also that the revised network consists all the 25 wells without pumping and one has to be only careful for monitoring the 15 private wells fitted with pumps for irrigation. This reduces the effort of collecting the water level measurements. The revised network will also provide almost the same accuracy as that obtained from the network of 55 measurement wells.

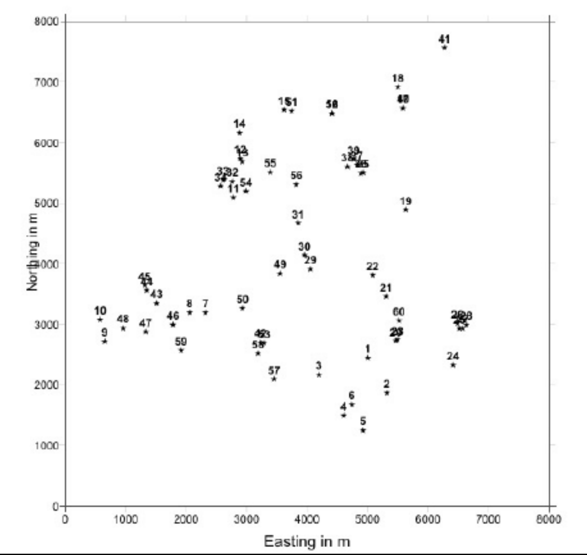

Figure 4: Distribution of 60 measurement points

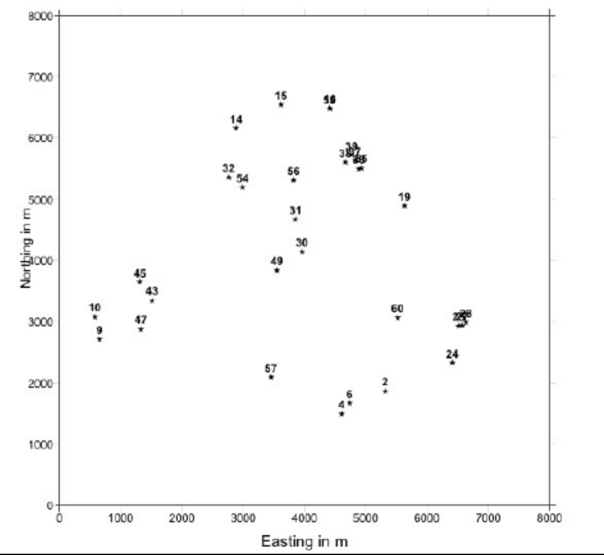

Figure 5: Distribution of 30 measurement points

In the other case study a simple and new method has been developed using the cross-validation technique of Geostatistics to analyze and optimize an existing network for monitoring fluoride in the area. Using the result of the geostatistical cross-validation, it has been possible to assign a priority index to all these measurement points and depending on the constraints such as financial and logistic, a network could be reduced without loosing the outcome. A number of monitoring networks with less number of wells have been prepared and compared. The reduced network using the reduced monitoring wells still have some clusters that could have been discarded if it was reduced without any scientific study such as the present one.

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ADES : A French National Groundwater Database
A national reference for groundwater resources
A freely accessible tool for water management!

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ADES is the national French data base on groundwater resources that joins on one web site all public data on groundwater quantity and quality with the following specific objectives:

- to provide a tool for collecting and storing information on groundwater resources,
- to be used by a large community of partner organisations,
- to allow to follow the temporal evolution of the “patrimonial state” of the resources in the aim to facilitate decision making in the field of water policies.
- to implement, at national scale, the principle of transparency and of accessibility to information on groundwater according to Aarhus Convention requirements

The use of the data base is free to all public and data consultation and extraction is possible via a GIS interface on the web site http://ades.eaufrance.fr, opened at the end of 2002.

ADES as water management tool corresponds to the needs of water management on local scale and to the priorities specified in the European Water Framework Directive: monitoring of the water status for groundwater resources, implementation and evaluation of water management plans.

The data base provides information on the geometry and density of the groundwater monitoring network and on the measuring stations and gives access to the quantitative (piezometric level) and qualitative (chemical parameters) status of the groundwater bodies. Regularly updated information are available on different spatial levels, on measuring point level, monitoring network level, aquifer level, river basin level, and for the administrative units "district" and "région". ADES greatly facilitates the establishment of monthly and annual statistics, of graphs and maps. It further allows to perform personalised queries and to access related data bases.

It privileges the uses of common data formats and standardised software by both data producers and end users. It allows installation of a local module ("Molosse"), a reduced version of ADES, that is designed for off-line storage and treatment of individual producer's data (as well as of those produced by others) and for data update and transfer to the central ADES base. Particular problems can be solved with specific modules provided together with ADES: The "Piez'eau" software package for the processing of piezometric data, and, the "SEQ-eau" tool (groundwater quality assessment system). Training courses for the users of the modules associated with ADES are proposed to the partner organisations.

The traceability of the data from the data producer to the final user, in conformity with the guidelines of the National Secretariat of Water related Data (SANDRE), guarantees a high level of confidence for the data contained in the data base : Information is given on the data source, the nature of the network, the level of validity of the data…

The ADES base is part of the SIE (Information System of Water). It is designed to evolve, thanks to an implication of a network of partners, towards a precious communication tool that facilitates the data flow and is profitable for a large public that will have free access to water related information.

ADES combines quantitative and qualitative data from numerous networks:
- The network (on national and river basin level) of information on groundwater, ordered by the Ministry of Ecology and Sustainable Development, under the responsibility of the Water agencies and the Regional Directions of Environment.
- The SISE-EAUX base of the Ministry of Health, fed by data from the sanitary control of groundwater used for drinking water supply by the Directions of Sanitary and Social Affairs on a district level. Only the data on untreated groundwaters are included in the ADES base.
- the networks of local or regional authorities
- the networks of other public organisms
- private (industrial) networks

The ADES data base on groundwater resources is the result of common efforts between the Ministry of Ecology and Sustainable Development, the Ministry of Employment, Solidarity and Health, the six water agencies. The data base is developed and managed by the BRGM.
Exploitation of these data will provide basic input to final users for all types of hydrological investigations related to the inventory, planning, and sustainable management of French water resources.

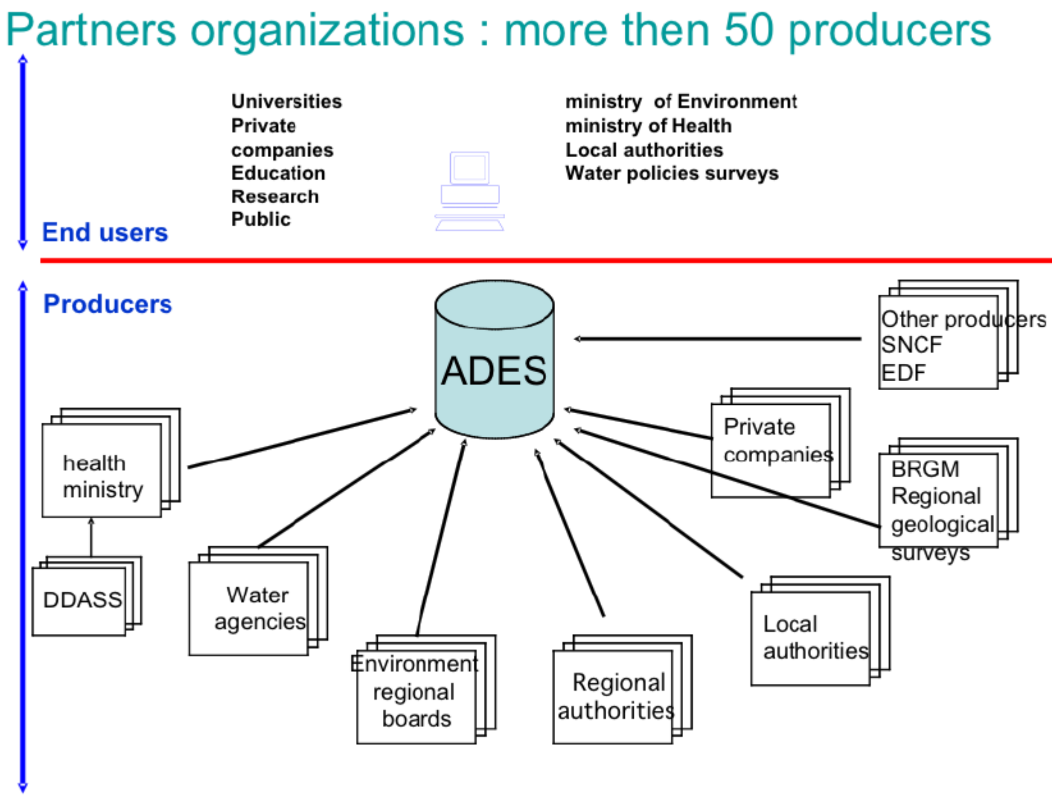

Figure 1: Partners organizations and data producers

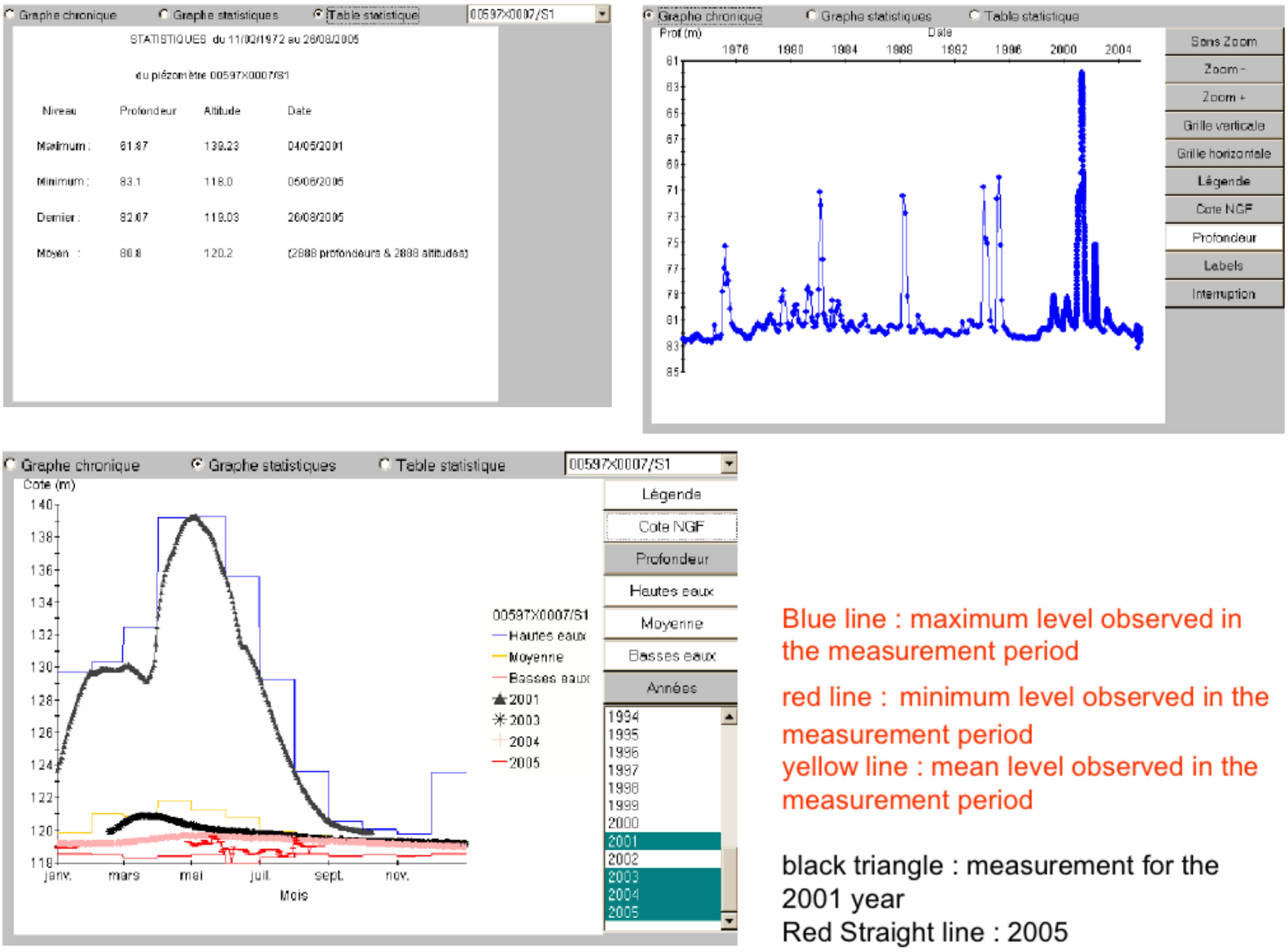

Figure 2: Informations about piezometric levels (graphics, statistical treatments)

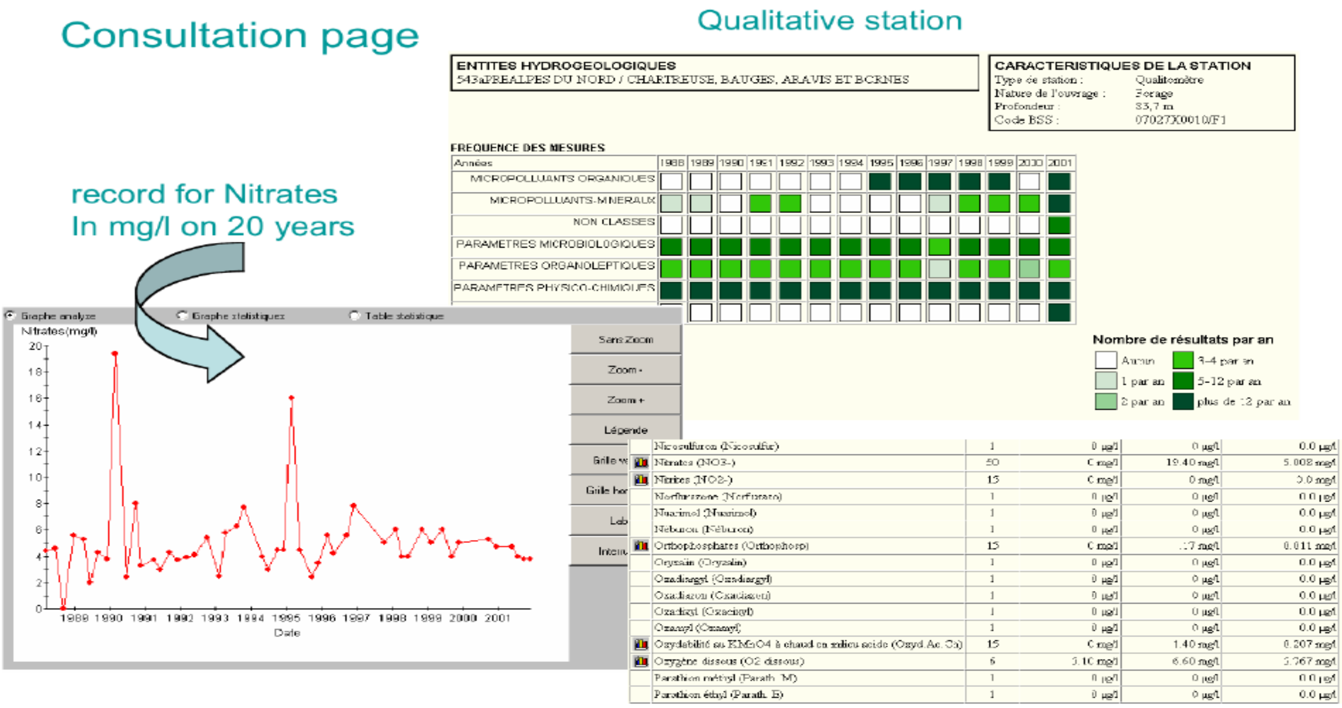

Figure 3: Informations about chemical analysis (graphics, statistical treatments)

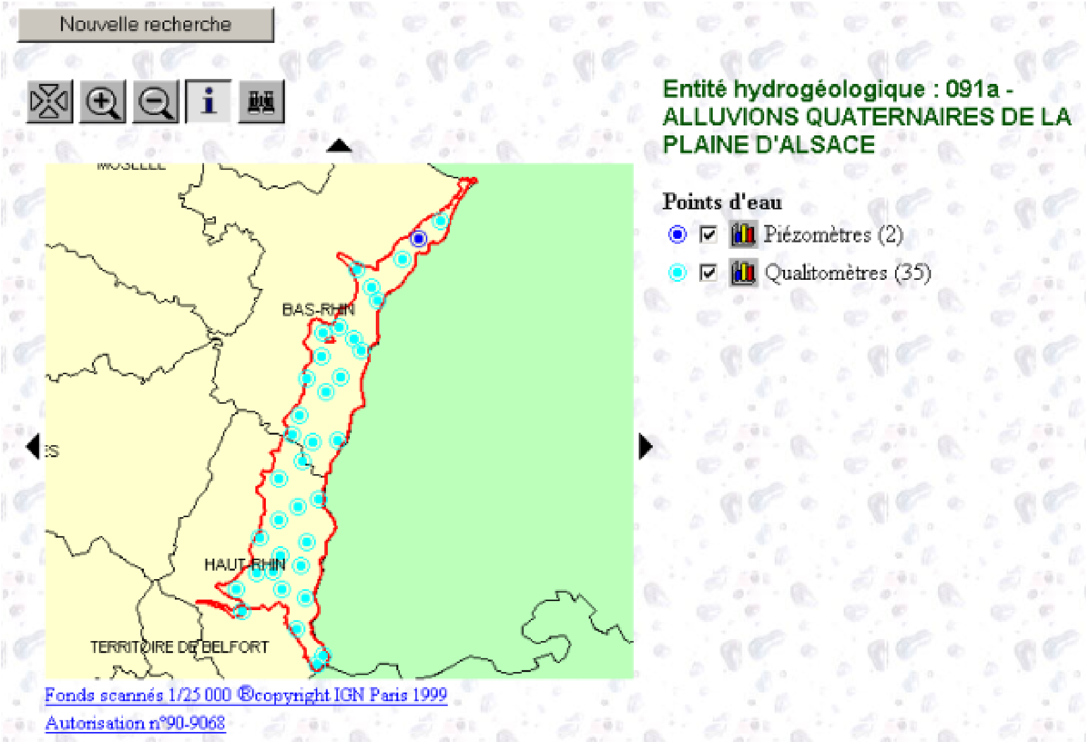

Figure 4: Network on a groundwater body map

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Contribution des données issues des sites industriels (installations classées) à la connaissance de la qualité des nappes souterraines

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La capacité à préserver les milieux naturels et à maintenir un cadre de vie de qualité est un des enjeux majeurs du développement de nos sociétés. La multiplication des programmes et travaux destinés à accompagner la mise en œuvre des réglementations européennes et nationales dans le domaine de l'environnement en sont l'illustration.

Dans le domaine de la protection de la qualité des eaux, les politiques mises en œuvre par le Ministère en charge de l'écologie au titre de l'environnement industriel contribuent fortement aux objectifs européens lié à la directive cadre de non dégradation, voire de rétablissement de la qualité des nappes souterraines. En effet, la priorité donnée à la protection des eaux et décidée par le Ministère se décline au travers de réglementations nationales spécifiques, mais aussi au travers des réglementations relatives aux installations classées et de la politique relative aux sites et sols pollués.

Dans ce domaine, la connaissance de l'état des milieux est l'outil indispensable d'aide à la mise en place de politiques environnementales et de suivi de l'efficacité de ces politiques. Si les données acquises dans le cadre des programmes publics s'avèrent constituer la base des réseaux de contrôle et de connaissance de la qualité des eaux souterraines, les données existantes et dispositifs de collecte s'avèrent insuffisants et peu adaptés au suivi des pollutions dites ponctuelles.

A cette fin, les données acquises au travers des dispositif de surveillance des sites industriels (installations classées ou sites pollués) relevant de la réglementation existante s'avèrent plus pertinentes. Cependant, à l'exception de quelques régions métropolitaine, l'intégralité de ces données, bien que publiques, demeurent valorisées par les seuls industriels et par les service de l'état instructeurs des dossiers (DRIRE).

Pour pallier ces manques et satisfaire les besoins liés à la mise en œuvre de la directive cadre européenne sur les eaux, le Ministère en charge de l'écologie à décidé, à l'issue de deux études à caractère méthodologique et technique, de lancer un programme triennal visant à permettre la bancarisation et de valorisation de ces données. Ce programme, qui doit s'appuyer sur des financements publics, s'oriente autour de 3 axes : 1) le rattrapage historique des données acquises depuis 1998, année de mise en place d'une surveillance renforcée des installations classées ; 2) le développement des outils de bancarisation et de valorisation des données issues des sites industriels, de façon complètement intégré aux programmes du SIE dans le domaine, et avec l'utilisation de la banque ADES pour le stockage des données ; 3) la mise en place d'outils et d'une réglementation devant permettre la saisie des données par les industriels producteurs eux-mêmes.

Le programme actuel, déjà mis en place sur certaines régions administratives françaises avec le concours des agences de l'eau, du BRGM et du ministère de l'écologie, laisse entrevoir la bancarisation et la valorisation de données issues de plus de 2000 sites industriels, sur un total estimé au double, considérant la priorité donnée aux ressources principales considérées comme vulnérables ou à usages sensibles. Ce premier programme représente une perspective de bancarisation des données issues de 24 000 forages, représentant plusieurs centaines de milliers d'analyse annuelles.

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Carte hydrogéologique de l'Afrique: une maquette au 1 / 10 000 000

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Cadre du projet

La carte hydrogéologique à l'échelle du 1/ 10.000 000 (= 1/10 M) de l'Afrique a été réalisée dans le cadre du projet "Réseau SIGAfrique". Ce projet (Mars 2003 - Décembre 2005) a été financé par le Ministère français des Affaires Etrangères (MAE), coordonné par le CIFEG (Centre International pour la Formation et les Echanges en Géosciences) et mis en œuvre techniquement par le BRGM. Son principal objectif est la création d'un partenariat pour la valorisation et la diffusion de l'information sur le sol et le sous-sol du continent africain. Un "Système numérique d'Informations Géoscientifiques" a été ainsi mis en place, partagé entre les partenaires africains du projet, représentant 11 pays:

• 6 pays d'Afrique de l'Ouest: Burkina Faso, Guinée, Mali, Mauritanie, Niger, Sénégal
• 4 pays d'Afrique de l'Est: Ethiopie, Kenya, Tanzanie, Madagascar, groupe auquel s'ajoute l'Angola,

et deux centres régionaux africains: le SEAMIC en Tanzanie et l'UEMOA au Burkina Faso.

Pendant la durée du projet, deux points focaux, l'un à Ouagadougou au Burkina Faso, l'autre à Dar Es Salaam en Tanzanie, ont permis, par l'intermédiaire d'ateliers, de mener des actions de formation et de recherche scientifique, notamment sur la thématique « Eau ». Un site Internet a été créé: www.sigafrique.net.

Caractéristiques de la carte

Jusqu'à présent il n'existait pas de carte hydrogéologique numérique de l'ensemble du continent africain. La seule carte continentale disponible est la "*Carte Hydrogéologique Internationale de l'Afrique*" à l'échelle du 1/5 M, publiée en 1992 par l'OACT (Organisation Africaine de Cartographie et de Télédétection).

Le travail réalisé dans le cadre du projet "Réseau SIGAfrique" jette donc les bases d'une cartographie hydrogéologique numérique de l'Afrique à l'échelle du 1/10 M, supportée par un Système d'Information Géographique. Il a permis de rassembler au sein de ce SIG des données du continent africain auparavant dispersées, notamment dans plusieurs bases internationales: Digital Chart of the World, Aquastat (FAO), Hydro1K (USGS).

Le principe directeur mis en œuvre dans la construction de la carte est la combinaison de deux catégories d'information fournissant une indication sur l'importance des ressources en eau d'une formation géologique affleurante. Il s'agit:

- 1- du type de réservoir, sachant qu'un réservoir à porosité d'interstices (milieu poreux des grands bassins sédimentaires) est a priori plus productif qu'un réservoir fissuré/fracturé du socle cristallin ou de terrains sédimentaires anciens consolidés;
- 2 - de la fraction des précipitations susceptible d'alimenter ces réservoirs, c'est à dire la recharge.

Entités hydrogéologiques

L'échelle de travail à 1/10 M ne permet pas de localiser précisément les formations réellement non aquifères. A la notion d'aquifère on a donc substitué la notion d'entité hydrogéologique potentiellement aquifère. A partir de la carte géologique de l'Afrique au 1/10 M (Milesi et al., 2004), qui fait apparaître les affleurements de 36 formations géologiques, des regroupements litho-stratigraphique ont été opérés aboutissant à 11 entités hydrogéologiques. La carte identifie donc, sur une base géologique, un réservoir, qui sera, potentiellement, plus ou moins aquifère, suivant la nature de l'entité et la zone climatique dans laquelle il se situe.

Estimation et zonation de la recharge

L'estimation de la recharge et sa zonation sont issues des travaux d'évaluation de la recharge (avec une résolution spatiale de 0.5°) menés à l'Université de Francfort en Allemagne (Döll P., Flörke M., 2005).

Système d'Information géographique associé

Outre les entités hydrogéologiques et la zonation de la recharge, le SIG-Afrique EAU intègre de nombreuses couches d'informations que la carte permet également de visualiser, par exemple:
- les limites des grands bassins sédimentaires contenant des systèmes aquifères multicouches, la plupart à ressources en eau non renouvelable (ou très peu) et partagés entre plusieurs pays, par exemple le Système Aquifère du Sahara Septentrional et le Nubian Sandstone Aquifer System.
- les directions des écoulements dans les aquifères profonds captifs partagés entre plusieurs pays, information intéressante dans le cadre d'une gestion partagée de la ressource.
- les grands bassins hydrographiques, les grands fleuves (Nil, Congo, Niger, Sénégal, ….) et leurs principaux affluents, éléments géographiques permettant de situer les entités hydrogéologiques dans de grands ensembles hydrographiques et de faire apparaître les échanges éventuels entre aquifères et cours d'eau (par exemple, le Nil, le Niger).

Références (une sélection)

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Detecting Temporal Structure of Hydrological Processes and Water Quality Using Wavelet Analysis

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Temporal structure analysis of hydrological processes and water quality can enhance the understanding of contaminant transport processes and water quality monitoring in aquifers and watersheds. We have used a continuous wavelet analysis to detect temporal structures of well water level and stream water flow collected over a 20-year period in an agricultural watershed in central Pennsylvania, USA. For long-term unevenly sampled water quality indicators (nitrate-N, chloride and sodium), the weighted wavelet Z-transform method was applied. At a long time scale, a strong annual seasonal structure of the well water level was found, but not for the stream water flow. The minor and weak temporal structures of the stream water flow and well water level detected by the wavelet analysis were related to the large variations of stream flow and well water level at specific times. For the wavelet analysis of a hydrological year, wet season and large variation of well water level and stream water flow can be precisely reflected by their temporal structures. Water quality temporal structures for the long-term monitoring period can not be related to those of well water level and stream water flow; however, for a hydrological year, they can. Nitrate concentration showed a different temporal structure from that of chloride and sodium, while the temporal structures of chloride and sodium were similar. This study demonstrates that wavelet analysis is an effective tool for investigating hydrological processes and contaminant transport in aquifers and watersheds through their relationships to temporal structures across temporal scales.