

Introducing *wwhypda*: a world-wide collaborative hydrogeological parameters database

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Abstract Since the seminal publication of Henry Darcy's work in the 1880s, a very large number of rock property values (such as hydraulic conductivity, permeability, compressibility, porosity, etc.) has been measured and published. These data are, however, dispersed and difficult to access. To overcome this problem and to facilitate site characterization (especially stochastic), a worldwide hydrogeological parameter database (*wwhypda*) is proposed. It is an open and collaborative catalog allowing users to store and retrieve measurements. The catalog is accessible through a web interface (<http://wwhypda.org>). Presently, it provides individual values and probability density functions of the properties as a function of lithology, scale of observation, location, and geological environment.

Keywords Heterogeneity · Hydraulic properties · Statistical modeling · Tracer tests

Introduction

Since the first experiments of Henry Darcy, published in 1856, and for more than a century, experiments have been designed and conducted at different scales and all around the world to characterize not only hydraulic conductivity or intrinsic permeability, but also porosity, specific storage or compressibility of earth materials. Large-scale equivalent properties have been obtained by calibrating regional aquifer models. All these experiments and their interpretations have been published in articles, books or technical

reports and in different fields such as hydrogeology, petroleum engineering or civil engineering.

In addition, many national geological surveys are centralizing geological and groundwater data within national databases or geographical information systems (GIS). These data sets are available upon request (Allen et al. 1997; Jones et al. 2000), or via Web interfaces—for example, the Canadian geospatial data infrastructure (CGDI 2007), the ADES groundwater national portal in France (ADES 2008), or the Ground Water Atlas of the United States by the United States Geological Survey (US Geological Survey 2000). Similarly, GIS databases are often developed to facilitate data management within specific consulting or research projects (Barazzuoli et al. 1999; Gogu et al. 2001). From a research perspective, there are also initiatives 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. 2006). 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 datasets of parameter values, the analysis and modelling of their spatial distribution have evolved significantly thanks to the development of geostatistical theoretical frameworks (Matheron 1962; Dagan 1989; Gelhar 1993; Chiles and Delfiner 1999; Rubin 2003; de Marsily et al. 2005). 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 limited amount of data available to characterize the site. This is especially true and poses a problem when one considers the first stages of a new study. Anderson et al. (1999) estimated that, in most cases, less than 1% of the total volume of an aquifer is directly sampled. Even at the most extensively studied sites, the volume of the aquifer that is directly sampled remains small. In their detailed study of a braided alluvial system, Anderson et al. (1999) estimated

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this sampled volume to be around 20–40% of the total volume if they include the geophysical measurements.

In addition, in most practical situations it is necessary to cope with uncertainties because of the lack of data. This is why the use stochastic techniques as one component of a general framework to manage hydrogeological projects is widely recognized among researchers (Freeze et al. 1990), even if the application of stochastic techniques in daily practice is still limited. The reasons for such limitations are diverse and include many practical and theoretical aspects (Dagan 2002; Zhang and Zhang 2004; Renard 2007). However, several authors have suggested that one step to facilitate the use of stochastic techniques 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 stochastic and deterministic framework. It could answer questions such as: What is the order of magnitude 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 fractured sandstone to design a pump-and-treat system? It could provide parameter distributions to use as priors or plausibility terms for inverse problem solving (Tarantola 2005; Alcolea et al. 2006). It could also provide training images describing the typical spatial arrangement of different rock types in a given geological environment that could be used as input for multiple-point simulation algorithm (Strebelle 2002; Journel and Zhang 2006).

The aim of this article is to describe a first attempt at providing such a “world-wide hydrogeological parameters database” (*wwhypda*). It is based on open source technology to allow a wide distribution and free access via Internet. The idea is not to offer a substitute for local investigation but a well-documented complement of information when there is a lack of data. In addition, an important concept is that such a catalog needs to be supported by a broad community and should therefore be based on a collaborative web site in which users can provide data. This article presents the main features and the structure of *wwhypda*.

Main *wwhypda* features

wwhypda is designed to store values of the most important properties of earth materials, and to relate them either to a specific material or to a hydrogeological environment. These values can then be post-processed automatically to extract statistical moments or full probability density functions (Fig. 1a). To allow such type of queries, the database contains an extensible catalog of typical rock types and typical geological environments.

Because the aim of *wwhypda* is to provide essentially statistical distributions of rock properties that can be borrowed from one site to be used in another site, the

exact location of the measurement is not crucial. Therefore, *wwhypda* is not based on a GIS, even if optional information about the measurement site location can be stored. For the same reason, time dependent data such as time series of piezometric heads are not considered in the present work.

In terms of its usage, *wwhypda* is available via a Web interface. Anybody can consult the database, download it, or add data, under the terms of an open licence which ensures that *wwhypda* is and will be freely available. More precisely users are free to consult, copy, distribute, display, and make use of the database, provided that a proper reference is made to the *wwhypda* project (detailed license terms are provided online).

Finally, a key feature of *wwhypda* is that it provides an interface which allows users to contribute. The only requirement is a registration step, which allows user contributions to be recognized and tracked. The counterpart of this open policy is that even if a validation procedure is used to control the quality of the data, it is not possible to exclude erroneous measurements, which will become part of the database. This is why the database is provided without any warranty.

Content organization, methods and technologies

The entity-relationship schema (Chen 1976) was adopted to design the conceptual model of the database. Figure 2 is a simplified graphical representation of *wwhypda*'s model, built with a unified modeling language diagram (UML). 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 hydrogeological parameters (Fig. 3). Only geometry-independent parameters are considered. Information about a single measurement is stored in the entity *Measure* whose main attributes are:

- *value*: the measured value of the parameter.
- *error*: if the value is obtained as mean value of many measurements, this parameter will represent the associated uncertainty, otherwise it should be used to store an estimate of the uncertainty related to the measurement technique and interpretation.
- *quality*: this information reports an evaluation of the data-quality given by the user. It can be set to *low*, *medium* or *high*.

Every measure is related to a description of the experimental procedure (such as a pumping test, a slug test, etc.) as well as the interpretation method that was used to analyse the data. This information is stored in lists that can be extended when required.

Measurements of different properties can be made on the same sample. The database structure requires the user to link each measurement with a sample. This allows, for example, the user to study the correlation between

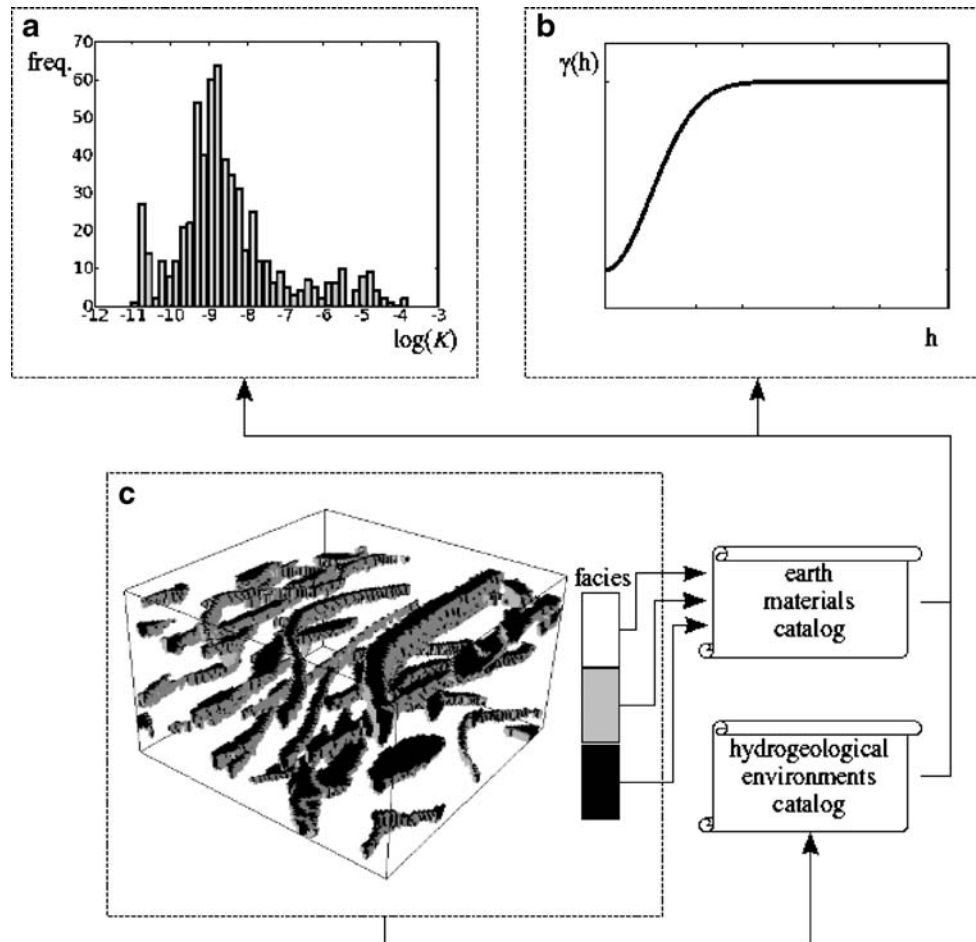


Fig. 1 Typical examples of *wwwhyda* content and output: **a** histogram of the log-hydraulic conductivity (K) for one facies. **b** Variogram (γ) describing the correlation of the properties versus the distance (h). **c** Three-dimensional training image of the internal architecture of a fluvial plain obtained from a *fluvsim* simulation (Deutsch and Wang 1996)

parameters. The entity *Sample* has the following main attributes:

- *scale_value*: the majority of the parameters included in the database have statistical distributions that are scale dependent (Kiraly 1975; Gelhar et al. 1992; Neuman and Di Federico 2003). The scale of observation is described by four classes: *micro* (for lengths <1 m), *macro* (1 m < lengths <10 m), *meso* (10 m < lengths <100 m) and *mega* (for lengths >100 m).
- *fracturation_degree*: this is a characteristic which strongly affects the values of the measured properties.

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

- *review_level*: this attribute depicts the level of reviews undergone by a group of measurements. Values among high (such as a paper published in a peer reviewed journal), *low* (such as an internal report or a MSC

thesis), *medium* (such as a PhD thesis or a reviewed technical report) and *not reviewed* are allowed.

The entity *Measure_group* also contains a link to the entity *Contact* in order to identify the contributor.

Every sample is related to an earth material (rock type) or to a 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 tree structures; contributors are able to add their own *Rock type* or their own *Environment* as branches of the proposed tree classification. The definitions of the rock types are specified by a brief description and, when possible, are followed by a link to the free encyclopedia *Wikipedia* (<http://www.wikipedia.org>), which provides a more detailed description. Finally, geographic information is stored in the entity *Site_info* (*site_name*, *region*, *longitude* and *latitude*), in order to locate a measure group.

Open source technology is used to implement the conceptual schema in a relational database with Sun

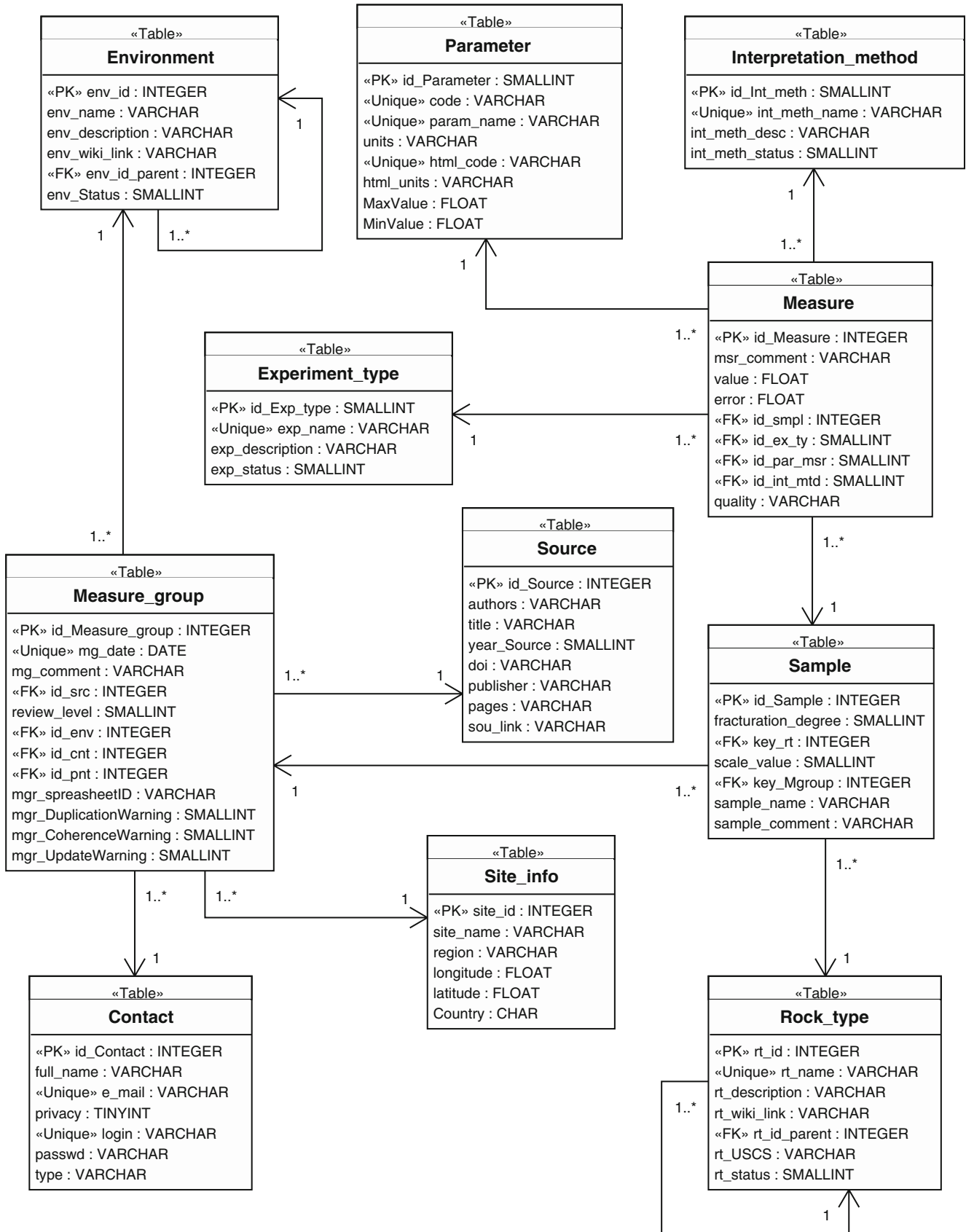


Fig. 2 Simplified conceptual schema of *wwhypda* using an UML diagram (the 1 and the 1..* represent the cardinality of the relationships between tables). The actual schema contains more than 28 SQL tables

rock type name and LINK	n_e effective porosity	K hydraulic conductivity	α_L longitudinal dispersivity	k permeability	n porosity	a rock compressibility	S_s specific storage	S_y specific yield	α_T transversal dispersivity	all param.
Basalt	0	23	0	0	0	0	0	0	0	23
Chalk	0	1097	0	0	0	0	0	9	0	1106
Clay	0	17	16	0	0	0	0	0	0	33
Clay, kaolinite	0	17	0	0	0	0	0	0	0	17
Clay, sandy	0	0	5	0	0	0	0	0	0	5
Coal	0	225	0	0	0	0	0	0	0	225
Coal, spoil	0	40	0	0	0	0	0	0	0	40
Dolomite	0	5	0	0	0	0	0	0	0	5
Gravel	0	11	3	1	20	0	0	0	1	36
Gravel, clayey	0	0	0	1	20	0	0	0	0	21
Gravel, sandy	0	0	3	0	0	0	0	0	1	4
Lignite	0	14	0	0	0	0	0	0	0	14
Limestone	0	599	0	0	530	0	1	0	0	1130
Loam	0	0	93	0	0	0	0	0	0	93
Marl	0	24	0	0	24	0	0	0	0	48

Fig. 3 Part of the table showing rock type versus parameter, allowing for rapid search of the database

Microsystems' *MySQL* (<http://www.mysql.com>), and to develop the web interface with the content management system *Plone* (<http://plone.org>), based on the content management framework *Zope* (<http://www.zope.org>).

To conclude this section, the structure of *wwhypda* is designed to be flexible: internal catalogs of earth materials, environments and measurement methods are open to users' contributions. Other database characteristics such as the parameters list, are also modifiable if required.

Data sources

wwhypda should progressively assimilate data from diverse sources. On one hand, some efforts have already been made by various authors to collect data for specific rock types or parameters, and those existing data sets can be integrated rather rapidly. For example, Vanderborght and Vereecken (2007) contributed by providing all dispersivity values they collected for their review article. Their database was directly imported into *wwhypda*. The second important data sources are the values published in scientific journals. This information is currently difficult to access because it is dispersed in many articles and many journals. Progressively, it should be added to *wwhypda* to allow easy access. Finally, technical reports constitute another very large source of information. For example, NAGRA (the Swiss agency in charge of nuclear waste management) has founded extensive research and published reports in which they provide permeability and porosity measurements (e.g. Keller et al. 1990). Many of such type of reports are public and can be integrated in the database. Another incredible amount of measurements has been collected by oil companies. However, these data are

usually confidential and are not accessible. At the moment, *wwhypda* contains more than 20,000 measurements of properties of about 25 earth materials. This is still very little and needs to be extended with contributions from the whole hydrogeology community.

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 checks are satisfied, the quality of the data is described with three criteria stored as three different attributes (*quality*, *review_level* and *error*) linked either to the group of measures or to the measure itself.

The person entering the data has to provide subjective and, if possible, quantitative information about the data quality. Three attributes are used: the *review_level*, the *error*, and the *quality*. The *review_level* is attached with the source of the measurement. It indicates whether the source has been reviewed thoroughly such as in an international journal or not (the four states described previously are available: not reviewed, low, medium and high). The *error* is an optional attribute (because often it is not estimated) corresponding to the error range or uncertainty related to the measurement itself (Taylor and Kuyatt 1994). Finally, the *quality* attribute (which can take only the values high, medium or low) allows the user to provide a subjective judgment based on his/her 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.

In addition, it is planned that regular scan of the database will be made by the administrator in order to manually check the plausibility of the values. A tag will be used to identify measurements which have been controlled and will allow users to select only those measurements. An interface to let users correct themselves or indicate dubious measurements has still to be developed. At the moment, it is recommended that users send a message to the administrator when potentially incorrect information has been identified.

Consultation example

It is expected that most users will be more interested in consulting the database than contributing to it. Therefore the design of the web interface has been made to allow a very rapid and simple access to the data. Different search tools are available. They are freely available without any registration. The fastest is an interactive table that shows the number of measurements currently available for each

rock type and for each parameter (Fig. 3). On this table, one can see very rapidly if *wwhyda* contains the measurements that one is looking for. Suppose for example, that the user is conducting a project on an alluvial aquifer and would like to check the typical values of hydraulic conductivity of a gravely sand. For that purpose, he or she can check the table and will find that for the rock type *Sand, gravely* there are 458 hydraulic conductivity measurements available. Clicking on the number brings one to a search interface in which the main attributes were automatically set. In that window, one can specify additional search criteria and type of results that are to be obtained. For example, the user can define that he or she needs to get basic statistics for those values. He or she can also include criteria such as the scale of the measurement, or the type of experimental method used to obtain the parameter value, or a certain quality level. The result of the search is then displayed in a page like the one showed in Fig. 4. The user in this case has asked to access the raw data, including (when available) a link to the original publication. He or she can, as well,

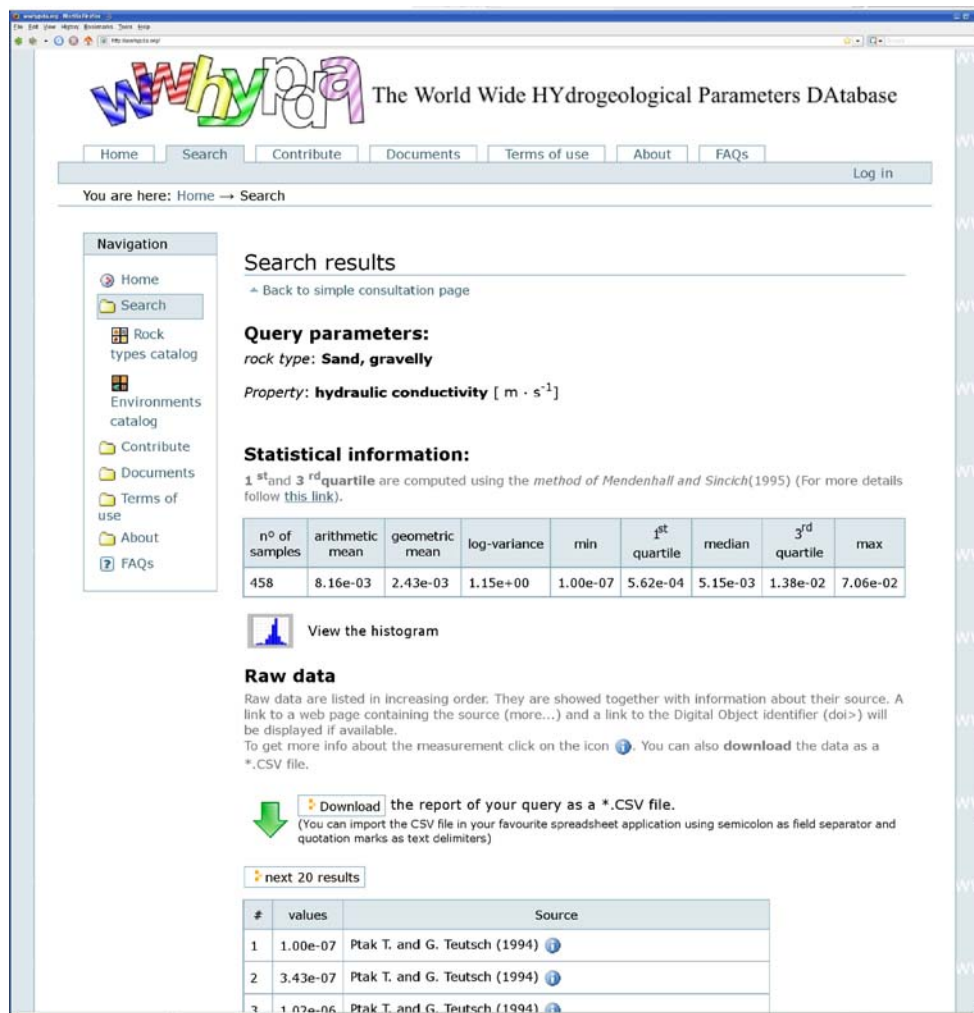


Fig. 4 Screen shot of the results page

download all the raw data corresponding to the result of the query as a csv file that can be used for further statistical treatment.

Contribution example

An important feature of *wwhypda* is that it allows for contribution to the database. The procedure for entering property values is accomplished essentially via a spreadsheet (Fig. 5) and can be summarized as follows:

- The user downloads the contribution spreadsheet from the web site either in OpenOffice Calc or MS Excel format.
- The user fills the spreadsheet off line. The web site and the spreadsheet itself contain information about how to do this. The spreadsheet (Fig. 5) contains drop-down lists from the internal catalogues such as earth materials list or type of parameters. The spreadsheet contains generic information about a set of values (such as the site description or the source of the data), data related to the samples (rock type, degree of fracturation), and then property values with their

attributes. In this way, different parameters can be linked together and relations between parameters can be studied.

- Finally, the user has to upload the spreadsheet on the web site. This last action is available only for registered users. The spreadsheet is then checked by an automated procedure; if all checks are successful, the information is inserted into *wwhypda* and available for consultation.

Discussion

Building a database that combines standards and flexibility requires some restrictions and simplifications to be adopted. The first difficulty is the choice of a classification system 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 matters even worse, the classifications often differ from one country to another: fine sand may not have the same granulometry in France and in

Measurement "Sample" (the bc				
	A name to identify the sample in the Measurements table.	the name of the rock type	the scale to which the measurements are made	the degree of frac of the volum investigatec
#	smp_l_name	rock_type	scale	fracturation_d
1	sample01	Sand, gravelly	micro (lengths < 1 m)	null
2	sample02	Sand, gravelly	micro (lengths < 1 m)	null
3	sample03	Sand, gravelly	micro (lengths < 1 m)	null
4	sample04	Sand, gravelly	micro (lengths < 1 m)	null

Fig. 5 Screen shot of a part of the contribution spreadsheet

Great Britain. Which one should be adopted? 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 was too sophisticated to be implemented within the framework of this project.

Among the classifications, the challenge is to remain simple and flexible. A classification such as the one proposed by the British Geological Survey (BGS) is, for example, too detailed for *wwhypda* needs at the moment (BGS 2008). But even if the classification needs to be simple, it should allow coding an accurate geological description when it is available. Thus, it was decided to store the classification in a tree. The base elements correspond to the most common families of rocks (such as basalt, chalk, etc.). The sub-elements correspond to different levels of refinement in the classification (for example one branch of the tree is Clay, Organic clay, High plasticity organic clay). Each element or sub-element contains a brief definition. When available, a symbolic description made with the Unified Soil Classification System (ASTM 1985) is provided. Such a tree allows querying the database at different levels, depending on the amount of data available. For example, it may not be possible to find in the database a sufficient number of measurements for the specific storage for ferruginous meta-sandstone, but there may be enough data at a broader level to characterize the meta-sandstone or sandstone. Furthermore, when a rock-type is not available, the user can propose to add it in the tree structure.

This approach seems to be an affordable compromise at the present state of the project. However it also has limitations just like any other classification system. For example, rocks that 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 depth of sampling, are not accounted for in the database for the moment.

At present, the main focus of the work is related to data acquisition and interface development for the hydrogeological properties. However, the database is designed to store spatial statistics too such as variograms (Fig. 1b) and typical two-dimensional and three-dimensional images of lithofacies distributions (Fig. 1d), which could be used as training images for multiple-point statistics simulations (Strebelle 2002). These images are digitally coded representations 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, simulating 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 could be populated by parameters values. Further work is now required to develop the web interface and obtain training images showing the internal structure of a variety of typical hydrogeological environments that could be stored and distributed in *wwhypda*.

Finally, it is important to stress that the greatest challenge lies not in the technical aspects of the database, but in the community involvement to enrich the database. Within the project, the database is fed with an initial data set that will progressively increase; however, this is not sufficient. *wwhypda* can really become a useful worldwide reference if and only if it receives contributions from a very large community. The recent development of projects such as *Wikipedia* and other intensive user collaborations on the Internet indicates that community involvement is feasible.

Conclusion

wwhypda is certainly a utopia; however, 150 years after the publication of the seminal work of Henry Darcy, the authors think that the time has now come to follow the spirit of people like Diderot and D'Alembert. This is why the hydrogeological community is invited to participate in the creation of a world-wide catalog of hydrogeological properties and hydrogeological environment architectures freely accessible through the Internet. Quoting Diderot (1755) "This is a work that cannot be completed except by a society of men of letters and skilled workmen, 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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