HydroCube: a new entity-relationship hydrogeological data model

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Complete List of Authors:	Wojda, Piotr; Université de Liège, ArGEnCo Geo^3-Hydrogeology and Aquapôle; European Commission DG Joint Research Centre, Institute for the Protection and Security of the Citizen (IPSC) Brouyère, Serge; Université de Liège, ArGEnCo Geo^3-Hydrogeology and Aquapôle Derouane, Johan; Service Public de Wallonie, DGARNE, Division de l'Eau, Direction des Eaux Souterraines Dassargues, Alain; Université de Liège, ArGEnCo Geo^3-Hydrogeology and Aquapôle
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HydroCube: a new entity-relationship hydrogeological data model

P. Wojda[1], S. Brouyère[1,2,*], J. Derouane[3], A. Dassargues[1]
[1]Hydrogeology & Environmental Geology, GEO[3] Department and [2]Aquapôle – ULg,
University of Liège, Belgium
[3]Direction Générale des Ressources Naturelles et de l'Environnement, Walloon Region
Administration, Belgium
*Corresponding author: Serge.Brouyere@ulg.ac.be

Abstract

Managing, handling, and accessing hydrogeological information depend mainly on the applied hydrogeological data models, which differ between institutions and across countries. Growing interest in hydrogeological information diffusion, combined with a need for information availability, require the convergence of hydrogeological data models to make hydrogeological information accessible to multiple users such as universities, administrations, water suppliers, and research organisations. Furthermore, because hydrogeological studies are complex, they require a large variety of high-quality hydrogeological data with appropriate metadata in clearly designed and coherent structures. A need therefore exist to develop and implement hydrogeological data models that cover, as much as possible, the full hydrogeological domain. To respond to these requirements, a new data model, called HydroCube, has been developed for the Walloon Region in Belgium. The HydroCube model presents an innovative holistic "project-based" approach, which covers a full set of hydrogeological concepts and features, allowing for effective hydrogeological project management. This approach enables to store data about the project localisation, hydrogeological equipment, related observations and measurements. In particular, the model focuses on specialized hydrogeological field experiments, such as pumping and tracer tests. This logical data model uses entity-relationship diagrams and it has been implemented in the

MS Access environment as the HydroCube database. It has been additionally enriched with a fully functional user-interface.

1 Introduction

Recently, decision makers and professionals in environmental sectors have witnessed a great change in data and information management. Data should be accessible to and shared between multiple institutions such as administrations, water suppliers, research organisations, and consulting companies because there is a growing interest in hydrogeological data and information availability. Efficient cooperation and information exchange are necessary at different levels, between field specialists, regional watershed and basin responsible parties, and international managers. Reliable analyses require high-quality data with appropriate metadata (Batcheller, 2008). It is also important to have access to individual research projects, whose results should be disseminated or integrated into larger national information structures. Furthermore, the hydrogeological community requires holistic approaches and all the necessary hydrogeological information and concepts should allow for projects management in their entirety. Information management and sharing is very complex and requires common designs, standards and methodologies. Unambiguous data structuring can be achieved by elaborating and implementing hydrogeological data models. Geomatics is the discipline of knowledge and technology that models, acquires, stores, analyses and displays spatial data referred to the Earth. It provides a framework and tools that can be used to make hydrogeological information modelling and sharing possible. As a consequence of the recent changes in information carriers and new needs for seamless data exchange, existing hydrogeological data models have to be adapted and sometimes completely re-designed. Ultimately, such models should by implemented into open-source solutions, conforming with emerging Geography Markup Language (GML) technologies (Wojda 2009, Wojda et al 2010). However, a first step in that direction remains to build a holistic model for hydrogeological data management.

In this context, a new formalized logical model of hydrogeological data, HydroCube, is proposed here. The main objective of the HydroCube model is to respond to the requirements identified during discussions with actors, end-users, university teams and other institutions in the Walloon Region of Belgium. The HydroCube model promotes an innovative "project-based" approach that deals with any hydrogeological project as a whole. This includes data about the project localisation, previous hydrogeological studies, and contact people, but also information on available natural and man-made groundwater access features together with their associated quantity and quality observations and measurements. HydroCube presents also a pioneer logical model for hydrogeological field experiments such as pumping tests and tracer tests, including data about (1) experimental devices and conditions, (2) measurements taken during the tests, and (3) derived data such as interpretations.

The HydroCube data model is described by a series of normalized entity-relationship diagrams. Entities were identified and organized according to their geometry: point, arc and polygon. Spatial aspects are supported internally for point-type entities, while arc- and polygon-type entity geometries have to be handled externally. The logical model defines also permissible value domains, such as code-list entities. Furthermore, the need for hydrogeological data availability and transfer between different universities and the administration required a convergence in applied data models, HydroCube becoming a standard for data encoding and synchronisation amongst user in different locations by structured protocols. Technically, the data for each project can be stored in one database instance, or they can be differentiated by unique identifiers, where each identifier is composed of a defined prefix and an automatic number.

The HydroCube logical model has been implemented through a physical model under the HydroCube database in MS Access® and enriched with fully functional user interfaces that allow users and decision makers to focus only on the information content and management issues. The implementation platform choice was driven by the requirements of the financing institution.

The first part of the paper presents the driving concepts of the development of the HydroCube logical model, based on a review of existing geological and hydrogeological data. Then, the main entities of the HydroCube model are presented, focusing on the geometry-based classification of hydrogeological entities, topological links, and the pioneer data model dealing with hydrogeological field experiments. More details on entities, attributes and their data types are also provided in a electronic supplementary material (ESM). The user interface functionalities are then presented. The conclusion proposes new directions for further developments of hydrogeological data models, respecting international standards and norms.

2 Driving concepts and existing data models

A review of existing projects and databases was performed prior to the work on HydroCube. Five from the most interesting hydrogeological projects are technically described here after. The “HYGES hydrogeological database”, a precursor of HydroCube, was developed in the Walloon region, Belgium (Gogu, et al. 2001) based on entity-relationship diagrams. It is a GIS-based database offering facilities to model groundwater flow and contaminant transport, for groundwater vulnerability assessment and for the management of regional groundwater resources at the basin level, using both a Relational Database management System and a Geographic Information System.

The H+ database, developed in the framework of the ERO program, allows for data gathering coming from a network of hydrogeological sites (de Dreuzy et al., 2006). Its flexible conceptual model is described by an Enhance Entity-Relationship notation. H+ proposes entities for storing data coming from different experiments or surveys. It is enriched with a fully-functional web-based user-interface. However, its generic structure, proposed as a template, does not describe conceptual data model for specific tests. Moreover, storage of non-spatial data needs further developments.

The Basin of Mexico Hydrogeological Database (BMHDB) includes data on climatological, borehole and run-off variables, providing information for the development of hydrogeological models (Carrera-Hernández and Gaskin, 2008). It allows also for geostatistical analyses using data directly from BMHDB. Hydrogeological data can be accessed and processed locally or remotely through open source software: postgreSQL, R and GIS GRASS packages.

The “Australian National Groundwater Data Transfer Standard” made by The NGC Groundwater Data Standards Working Group in the National Groundwater Committee (1999), described by entity-relational diagrams using “crow’s-foot” notation, has been developed in order to unify different existing data models in Australia. It contains only basic hydrogeological features (such as wells or drains) and associated measurements.

“A geographic data model for groundwater systems” based on the ArcHydro ESRI data model, developed at the University of Texas at Austin (Strassberg, 2005) attempts to extend the ArcHydro model (Maidment, 2002) to represent groundwater systems. It uses specific notations to describe the geodatabase structure and it focuses mainly on hydrogeological features used for groundwater flow modelling. It can be coupled with the Groundwater Modeling System (GMS®) software.

Nevertheless, the presented models do not deal with the hydrogeological domain in its entirety. They address specific hydrogeological issues and functionalities. They do not cover all the necessary hydrogeological concepts in order to deal with an entire hydrogeological project, while the current trends focus more and more on integrated, project-based, management solutions. In particular, to the exception of H+, these models do not allow storing hydrogeological data coming from field tests, such as pumping tests and tracer tests, or to manage topological relationships (for instance spatial relationships between an exploitation well and its protection zone). All these projects can be considered as interesting first steps and sources of ideas for further developments, but they must be extended or adapted in order to respond to current needs.

For developing the HydroCube logical data model, the entity-relationship modelling has been adopted for two main reasons. First, normalized logical models expressed in entity-relationship diagrams are easy to implement in many popular and well known Relational Database Management Systems (RDBMS). This guarantees that the HydroCube logical model is easy to implement and ready to be used by most of the hydrogeological community. Secondly, whenever it turns out necessary to extend or enrich the model, one may pass to another notation, such as object-oriented modelling, using formalized mapping techniques. Nevertheless, it was assumed that comprehension and implementation of any object-oriented model require advanced knowledge and address to the specialists in geomatics. On the contrary, the HydroCube model rather addresses the users who are interested in a holistic project-based data management system better focusing on applied hydrogeology and field test data.

3 HydroCube: The Walloon Region Hydrogeological Data Model

This section describes the most important or innovative elements of the logical data model. For the sake of completeness, other more conventional components of the data model can be found in the ESM and in Wojda (2009). First, the main hydrogeological entities are presented. Topological relationship amongst them may also be stored. Second, an innovative data structure for specialized hydrogeological tests, such as pumping and tracer tests is described in detail. Finally, a brief summary of the user-interface functionalities is introduced.

3.1 Main hydrogeological entities

The HydrogeologicalFeature is the central entity of the data model (Figure 1). It has the abstract function of organizing all the elements and giving them common attributes such as a unique identifier, a name and a type. The identifier is public and unique across the model. Any external application can use this identifier to access any piece of information contained in the database. In the Figures, mandatory primary identifiers are underlined and indicated with the letter M. Foreign identifiers keep the same name, as from the original table they come from. The value of the attribute itself during encoding is physically copied by the user-interface.

Following the convention on geometric classification of primitive features (GM_Primitive) and the conventional GIS geometry-first approach, used also in the Guidance Document on Implementing the GIS Elements of the Water Framework Directive (Vogt, 2002), the hydrogeological entities of HydroCube are classified according to their basic geometric characteristics (Figure 1). This solution presents a geometry-centric data model where all the elements are represented by points, lines, and polygons, all being 1D or 2D features. The proposed HydroCube model deals directly with the geometry of Point-type entities, by explicit x, y, and z attributes. The geometry of Arc- and Polygon-type entities has to be handled externally, using a GIS-hybrid system. Time references for hydrogeological observations and measurements are managed by an additional “date” attribute in the concerned entities. Only the “Point” entity is presented here. The “Arc” and “Polygon” entities are presented in the ESM.

The most important “Point” attributes are the type of the point (well, spring, surface water observation point…), the geographical coordinates with a description of their accuracy, and the address. The “Point” entity may have 11 specialized hydrogeological features, namely

"SurfacePoint", "Sinkhole", "Spring", "Borehole", "Well", "Excavation", "InterpretationPoint", "ObservationPoint", "GeotechnicalPoint", "GeophysicalPoint" and "ClimaticStation" (Figure 2).

3.2 Topological relationships amongst hydrogeological entities

In order to deal with a hydrogeological project as a whole, it is necessary to store information about spatial associations of the different elements, using topological relationships. This may consist in information about the study zone together with hydrogeological features such as springs or man-made equipment to access groundwater. The HydroCube model uses link tables as a conceptual solution for defining and handling topological links among such hydrogeological features (Figure 3). Such link tables store many-to-many connectivity types, which identify the topologically related hydrogeological features and a link type which indicates the nature of the relationship. As an example, a link table can be used to associate a study zone and different wells and piezometers located within this zone and used in the scope of the hydrogeological project. Other useful topological relationships are links between a groundwater intake location and its protection zones based on pollutants transfer times, observation wells and a pumping well used to perform a pumping test, sinkholes and a spring in a karstic system, or, more generally, any hydrogeological feature such as wells, piezometers, rivers, springs constituting the monitoring network for a regional groundwater investigation.

3.3 Observations and measurements

Hydrogeological studies and decisions concerning groundwater resources management need to be based on reliable information about hydrogeologic conditions and parameters. Raw data can be retrieved through simple observations and measurements performed in order to have primary information on piezometric levels, groundwater fluxes and groundwater geochemical properties. In this context, the HydroCube model defines specific entities for well equipment, piezometric head measurements and groundwater chemistry data, provided in the Electronic Supplemented Material.

However, more complex hydrogeological parameters can only be obtained by performing advanced field experiments, such as pumping tests and tracer tests. Field experiments usually produce large amounts of data, sometimes difficult to handle and to analyse. In order to facilitate the management, data retrieval, and interpretations of such results, an advanced data model has been developed (Figure 4), based on a three-phase generic framework which can be described as follows. First, the experimental setup and the experimental conditions of each field test are described. Information on the experimental setup consists in the exact location of the test, available hydrogeological features used to perform the test, such as wells, piezometers, or sensors. Information on the experimental conditions consists in the period within which the test was performed, the prevailing hydrogeological conditions and more specific data such as pumping rates. Second, measurements performed at different observation points can be stored in the form of time series, such as groundwater head drawdown curves or tracer breakthrough curves. Third, hydrodynamic and hydrodispersive parameter values obtained from the interpretation of the field tests can also be managed in the data model.

For pumping tests, information is stored on the experimental device, which usually consists in a main pumping well and several surrounding observation wells and piezometers. The experimental conditions are the pumping rate profile associated with the pumping well. Time series of piezometric head levels and drawdowns measured during the pumping test are stored in relation with the different observation points. Information on interpretation techniques, together with their results (such as hydraulic conductivity, transmissivity, storativity, specific yield, and depression cone radius) can be stored separately.

For tracer tests, the experimental setup consists in the main injection point and several observation points, for instance, a pumping well, monitoring piezometers, or a spring. The experimental conditions include information on tracer injection, associated to the injection point and on tracer recoveries, associated to each observation point. Tracer injection conditions consist in the nature and quantity of the injected tracer, on a description of the injection profile (i.e. injection volume, duration and flush rate) and possibly on the concentration evolution in the injection well (Brouyère et al. 2005). Information on tracer recovery includes, among others, the tracer test method, tracer background concentration and the distance between the injection point and the recovery point. The tracer test entity can also store interpretations of results obtained using analytical or numerical simulation tools.

4 Interface to HydroCube

Because HydroCube covers a full range of hydrogeological concepts, entities and relationships, its internal structure has become relatively complex. Once implemented in a Relational Database Management System, it definitely requires the development of a user-friendly interface. A series of graphical modules have been developed to support the user in handling, storing, and retrieving hydrogeological data. Moreover, the use of user-interfaces prevents from errors while introducing data, i.e. pre-coded permissible value lists facilitate encoding. Complex searching queries give also reliable and complete results, improving finally data reliability and re-use.

Four main functionalities are provided in the HydroCube database user interface under MS Access: (1) encoding, (2) querying, (3) visualisation and (4) export. Different forms are available for “one-by-one” or “massive” data encoding. For instance, data on wells and piezometers are managed using the “Well” form, which allows encoding information such as the well name, its location etc. In this form, additional tabs of the well form allow for the introduction of related information: construction elements, identified aquifers, lithological description and others. Piezometric head level measurements or chemistry measurements performed on a water sample can be encoded through their respective Piezometric heads and Chemistry data tabs (Figure 5).

The HydroCube interface provides specific query forms that allow using one or several search criteria and combining them for more advanced queries on the hydrogeological data stored in the database. The query forms allow one to choose point, arc and polygon-type features, based on the values of their attributes. More advanced non-spatial queries can also be defined using the standardized MS Access query builder. Since the MS Access implementation platform is not spatially enabled, point-type search only is available, based on localisation attributes such as one particular region/map or based on radial functions (Figure 6). More complex spatial queries can however be performed using external GIS software.

Data visualisation can be performed using several visualisation tools included in the HydroCube user interface. Any data previously encoded in the HydroCube database can also be exported to either MS Excel® or MS Word®. Other electronic data deliverables can be developed using standard MS® tools. Specialized field forms can also be produced for use in the field during experiments and surveys (Figure 7). Such field forms allow compiling all the available information about existing wells and piezometers prior to additional measurements in the field.

5 Conclusions

HydroCube proposes a new logical model of hydrogeological data, described using entity-relationship diagrams. The model contains a full range of hydrogeological features encountered in a project, classified into “points”; “arcs” or “polygons” according to their geometric attributes. It includes location, equipment, installations, measurements and related observations, in particular pumping tests and tracer tests which can related spatially. It is implemented in an MS Access® database with a full set of user-interfaces to encode, query, visualize and export hydrogeological data for their subsequent use in groundwater management projects.

The HydroCube model has been used for 5 years now, for hydrogeological data management in many real studies, in different universities, as well as in administrations in the Walloon Region by around 30 people. It has been continuously fed by different local and regional projects such as the Hydrogeological Maps of the Walloon Region (Bouezmarni et al., 2006), large-scale groundwater modelling projects (Orban et al., 2004), the FP6 AquaTerra Project (Batlle Aguilar et al., 2007), groundwater vulnerability mapping (Popescu et al., 2004). The HydroCube model and database being used in the Walloon region, rules have been defined for data encoding, and for semi-automatic periodic centralisation through data exchange files and programmatic procedures. Every data exchange file contains updated or added data for one period in the exactly same logical model as HydroCube, which highly improve data transcription. These files are then uploaded and data are automatically extracted to the central database. The latter is then redistributed to all the users through ftp protocols (20Mb zip-compressed file). Furthermore, the feedback from using HydroCube implied improvements in the database itself, as well as in the user-interface. For instance, new entities have been added to assure compatibility with Water Framework Directive (2000/60/EC) and Groundwater Framework Directive (2006/118/EC).

The MS Access implementation platform ensures the HydroCube high performance on the team level, using a very cost-effective relational database management system with an easy but advanced programming interface. HydroCube can easily be coupled with any GIS software, which extends the database functionalities for arc- and polygon-type spatial entities. However, MS Access is not a multi-user environment and it presents some storage capacity limits. Because of these limits, upon the request of the financing institution, migration to the ORACLE environment has already been performed. The ORACLE data model is identical to the HydroCube logical model, and it reuses its user interface. Therefore, there is a larger possibility of adding new functionalities and electronic data deliverables.

Further work on the hydrogeological data model consists in the development of an Object-Oriented form, using UML notation and XML schema. This work has been performed in the scope of the FP6 Project GABARDINE, focusing on groundwater artificial recharge based on alternative sources of water (Wojda et al., 2006). The UML methodology will enrich the model with additional functionalities such as different entities behaviour, according to their specific types, additional topological relationships rules, as well as clearer constraints, which can be used during data encoding and transfer to avoid errors (Wojda et al., 2010). This model can be made compliant with currently emerging norms and standards for geoinformation transfer such as ISO 19136 describing Geography Markup Language (GML) used for modelling, transport, and storage of geographic information (Cox et al., 2002; Lake, 2005). GML provides a large variety of objects for describing features, co-ordinate reference systems, geometry, topology, time, units of measure and generalised values (Chia-Hsin et al. 2009). GML has already been extended to three domain specific application schemas: XMML (Cox, 2004), GeoSciML (Sen and Duffy, 2005; Simons *et al*., 2006), and GWML (Boisvert, Brodeur, Brodaric, 2005).

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7 Captions

Figure 1. Basic entities of the HydroCube model. Data types and symbols notation for all the figures: A(x): characters (number); I: Integer (it can be also a primary identifier from a dictionary); F: float; SF: short float; DT: date and time; MBT: Multibyte; BL: Boolean; <pi>: primary identifier; <M>: mandatory value.

Figure 2. Entity-relationship diagram of point-type feature entities.

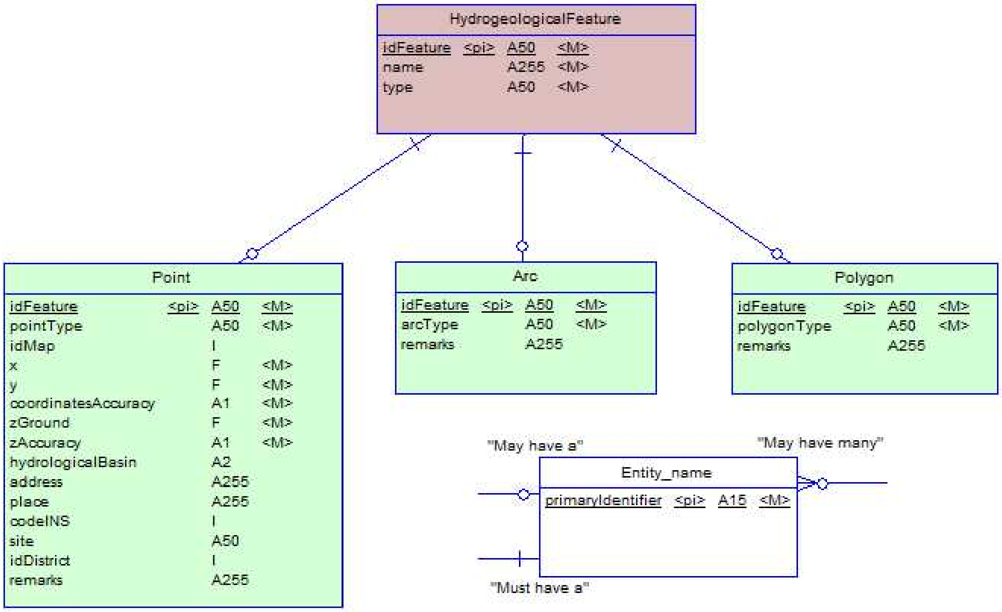
Figure 3. Links entity and related hydrogeological features.

Figure 4. Entity-relationship diagram of test sub-model for pumping tests and tracer tests.

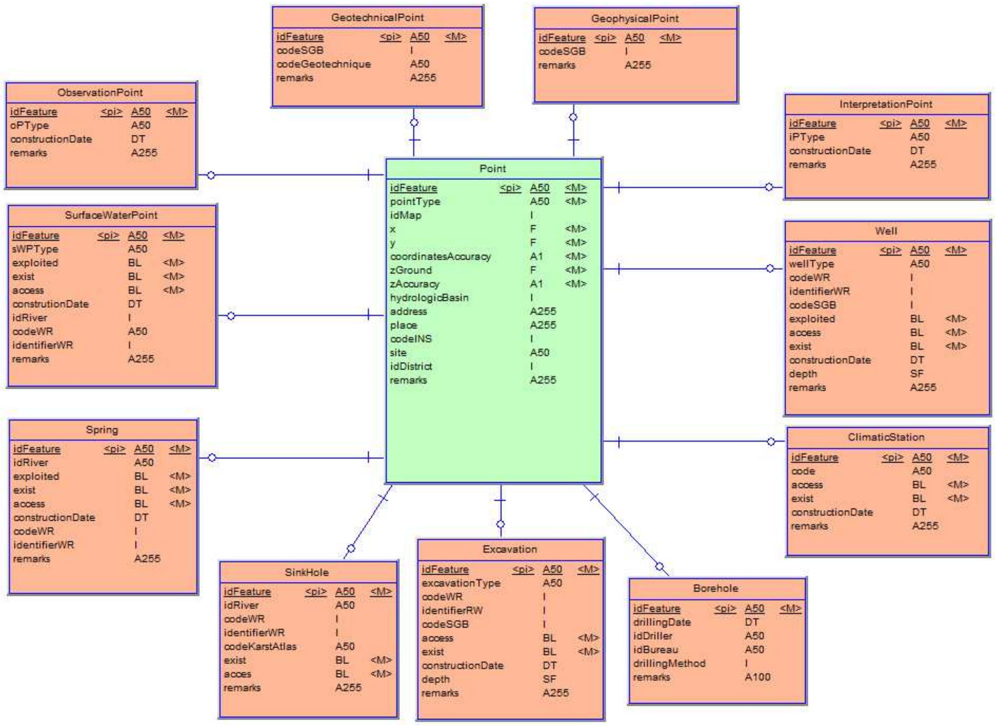
Figure 5. Well form with the Piezometric heads visualisation tab allows to view measurements for a chosen period of time.

Figure 6. Query form for point-type hydrogeological features allows one to execute simple queries on attributes of features. Spatial queries, based on localisation or advanced queries can be performed when criteria are combined. The results of a data query is displayed in the list form and can be visualized at once, when all the features are chosen, can be exported into the MS Excel file, or can be transferred into the field form.

Figure 7. Field form facilitates the preparation phase for the field work. Once the HydroCube database is queried through a search form, the user can export information into the Field form, where additional measurements or remarks can be noted.



174x107mm (96 x 96 DPI)



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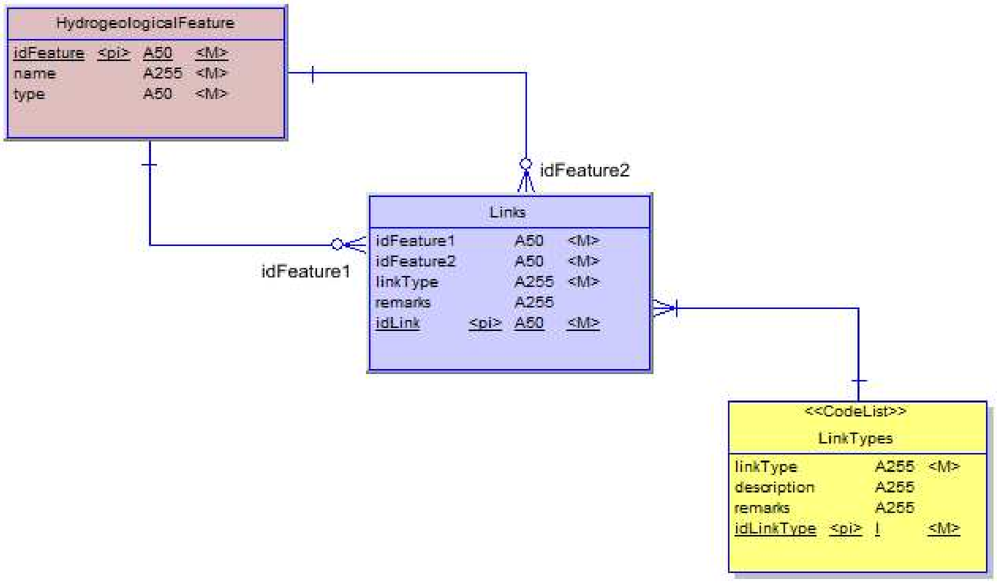
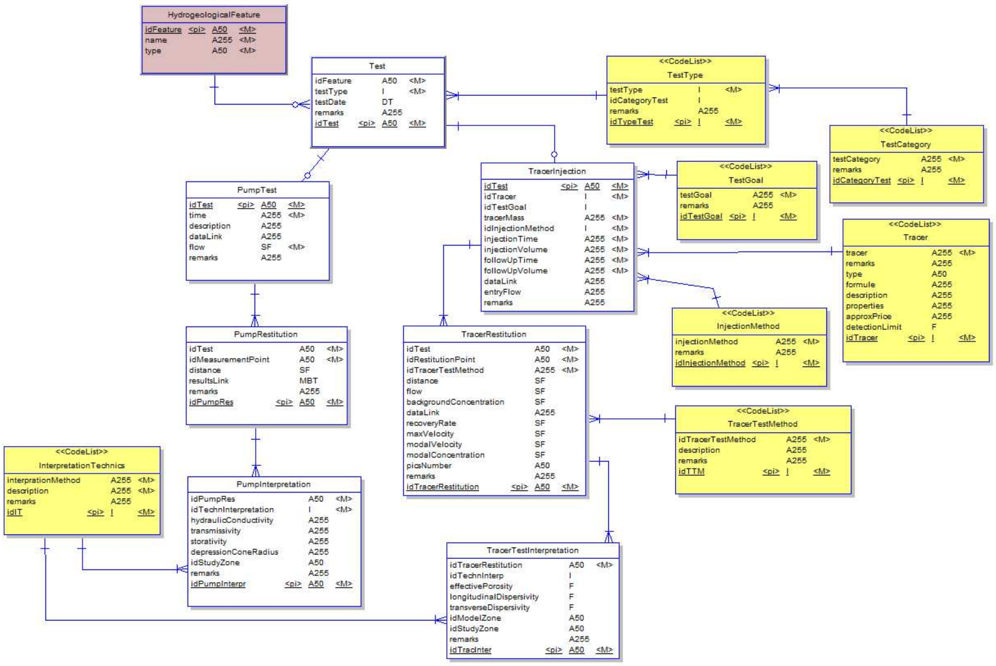


167x98mm (96 x 96 DPI)



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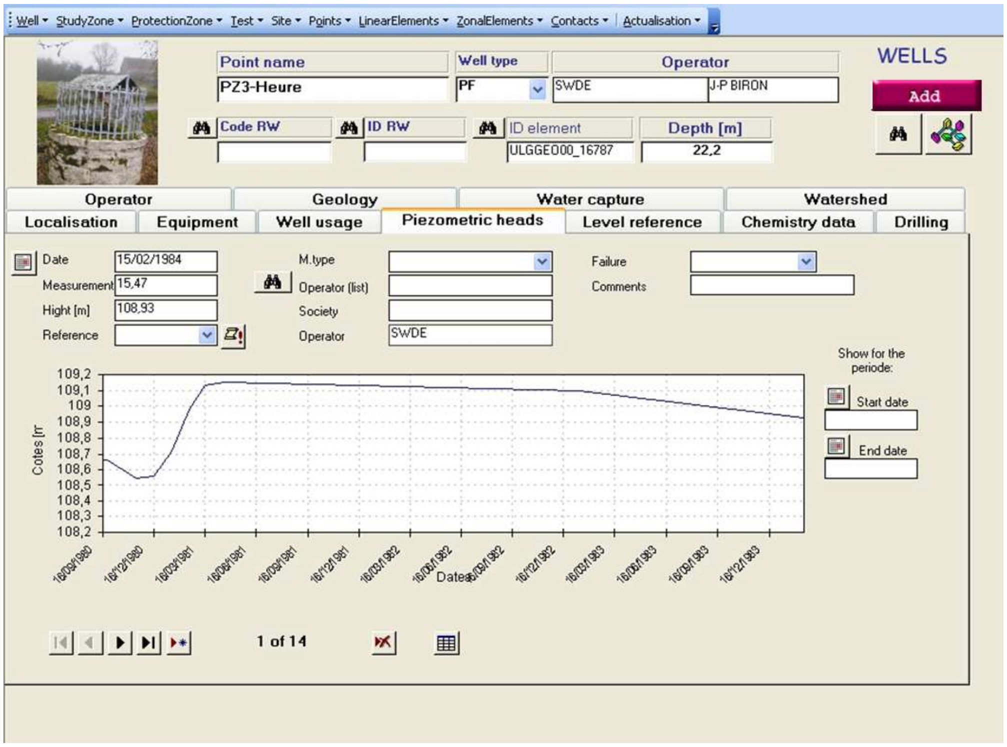


Point name: PZ3-Heure

Well type: PF

Operator: SWDE J-P BIRON

Code RW:

ID RW:

ID element: ULGGEO00_16787

Depth [m]: 22,2

Date: 15/02/1984

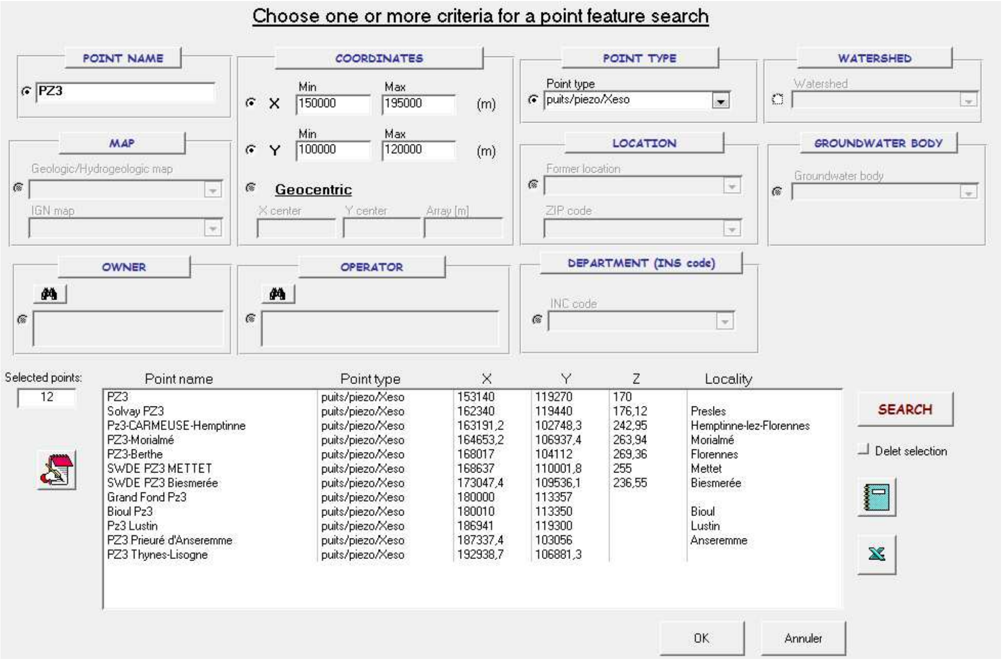
Measurement: 15,47

Hight [m]: 108,93

Operator: SWDE

1 of 14

278x206mm (96 x 96 DPI)



Choose one or more criteria for a point feature search

● PZ3

● X Min 150000 Max 195000 (m)

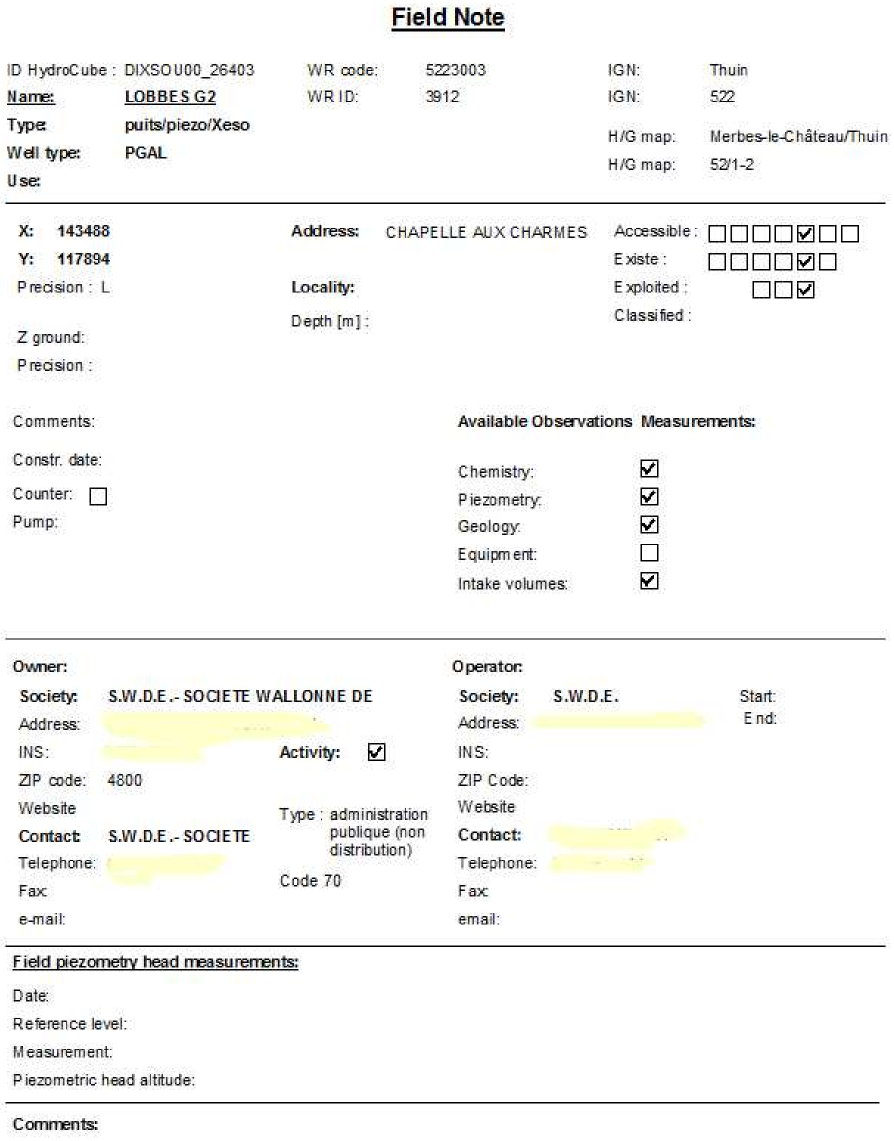
● Y Min 100000 Max 120000 (m)

● Point type: puits/piezo/Xeso

Selected points: 12

Point name	Point type	X	Y	Z	Locality
PZ3	puits/piezo/Xeso	153140	119270	170	
Solvay PZ3	puits/piezo/Xeso	162340	119440	176,12	Presles
Pz3-CARMEUSE-Hemptinne	puits/piezo/Xeso	163191,2	102748,3	242,95	Hemptinne-lez-Florennes
PZ3-Morialmé	puits/piezo/Xeso	164653,2	106937,4	263,94	Morialmé
PZ3-Berthe	puits/piezo/Xeso	168017	104112	269,36	Florennes
SWDE PZ3 METTET	puits/piezo/Xeso	168637	110001,8	255	Mettet
SWDE PZ3 Biesmerée	puits/piezo/Xeso	173047,4	109536,1	236,55	Biesmerée
Grand Fond Pz3	puits/piezo/Xeso	180000	113357		
Bioul Pz3	puits/piezo/Xeso	180010	113350		Bioul
Pz3 Lustin	puits/piezo/Xeso	186941	119300		Lustin
PZ3 Prieuré d'Anseremme	puits/piezo/Xeso	187337,4	103056		Anseremme
PZ3 Thynes-Lisogne	puits/piezo/Xeso	192938,7	106881,3		

258x170mm (96 x 96 DPI)



Field Note

ID HydroCube :	DIXSOU00_26403	WR code:	5223003	IGN:	Thuin
Name:	**LOBBES G2**	WR ID:	3912	IGN:	522
Type:	**puits/piezo/Xeso**			H/G map:	Merbes-le-Château/Thuin
Well type:	**PGAL**			H/G map:	52/1-2
Use:					

X: **143488**
Y: **117894**
Precision : L
Z ground:
Precision :

Address: CHAPELLE AUX CHARMES
Locality:
Depth [m] :

Accessible : ☐☐☐☐☑☐☐
Existe : ☐☐☐☐☑☐
Exploited : ☐☐☑
Classified :

Comments:
Constr. date:
Counter: ☐
Pump:

Available Observations Measurements:

Chemistry:	☑
Piezometry:	☑
Geology:	☑
Equipment:	☐
Intake volumes:	☑

Owner:
Society: S.W.D.E.- SOCIETE WALLONNE DE
Address: [redacted]
INS: [redacted]
ZIP code: 4800
Website
Contact: S.W.D.E.- SOCIETE
Telephone: [redacted]
Fax:
e-mail:

Activity: ☑
Type : administration publique (non distribution)
Code 70

Operator:
Society: S.W.D.E.
Address: [redacted]
INS:
ZIP Code:
Website
Contact: [redacted]
Telephone: [redacted]
Fax:
email:

Start:
End:

Field piezometry head measurements:

Date:
Reference level:
Measurement:
Piezometric head altitude:

Comments:

162x215mm (96 x 96 DPI)

Electronic Supplementary Material

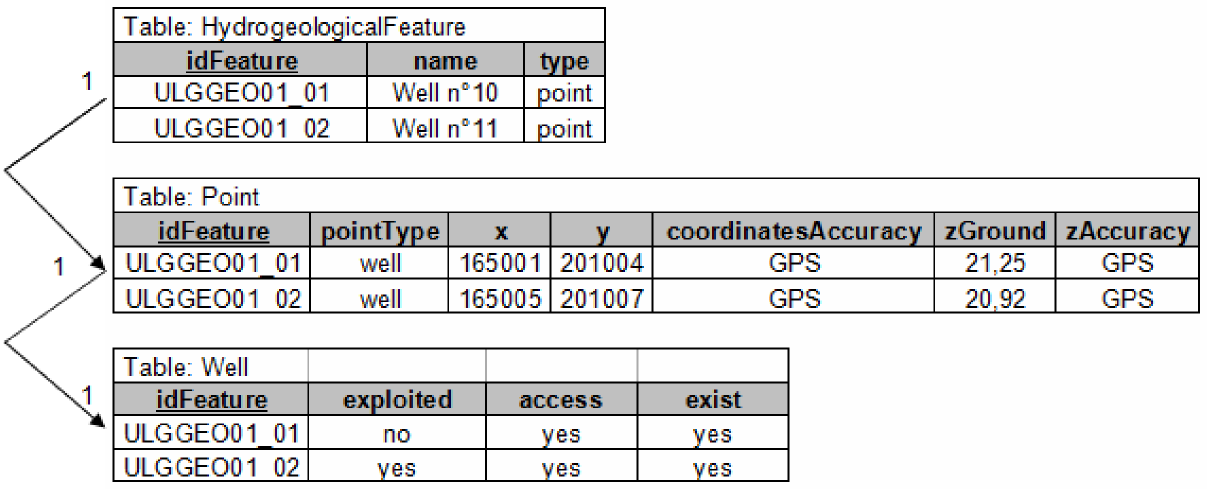


Table: HydrogeologicalFeature

idFeature	name	type
ULGGEO01_01	Well n°10	point
ULGGEO01_02	Well n°11	point

Table: Point

idFeature	pointType	x	y	coordinatesAccuracy	zGround	zAccuracy
ULGGEO01_01	well	165001	201004	GPS	21,25	GPS
ULGGEO01_02	well	165005	201007	GPS	20,92	GPS

Table: Well

idFeature	exploited	access	exist
ULGGEO01_01	no	yes	yes
ULGGEO01_02	yes	yes	yes

Figure ESM 1. Example of two well occurrences encoded in the HydrogeologicalFeature, Point and Well tables in the implemented database. Only the mandatory attributes are shown.

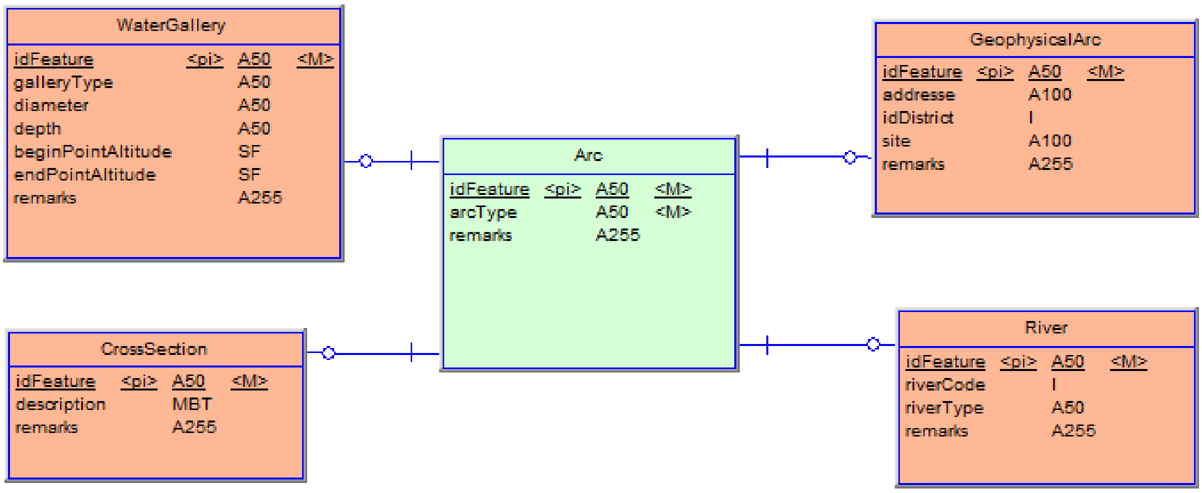


Figure ESM 2. Entity-relationship diagram of linear feature entities.

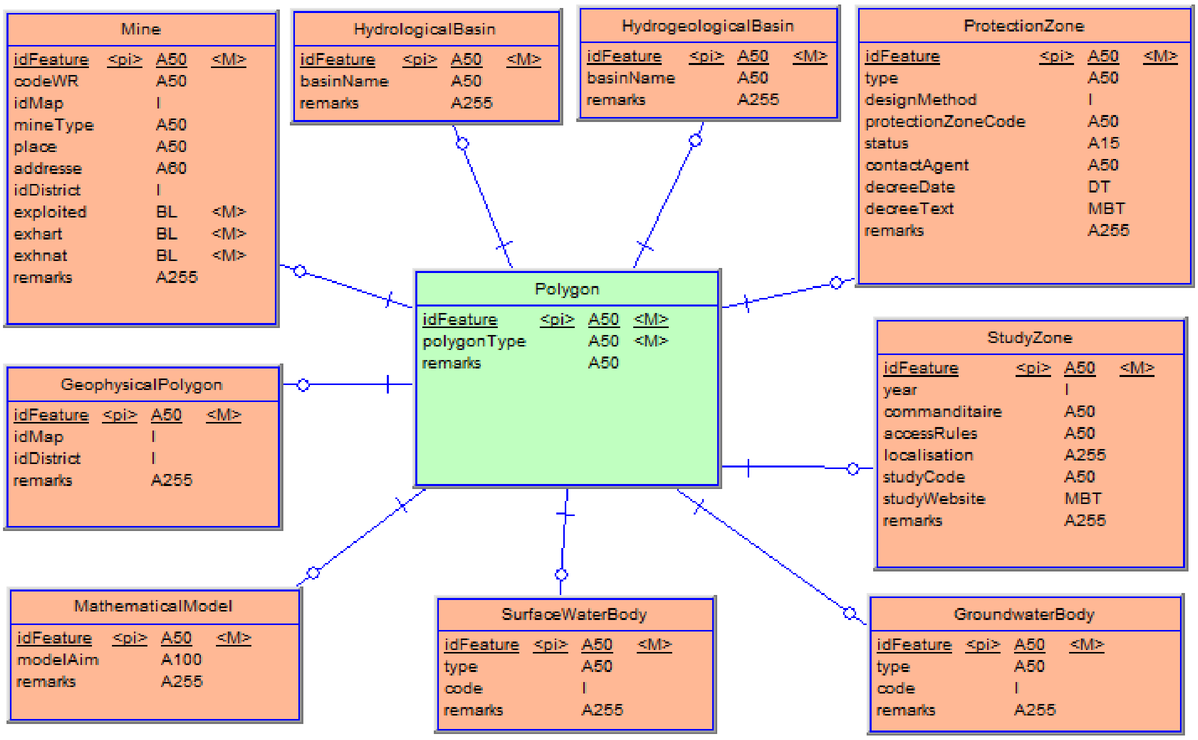


Figure ESM 3. Entity-relationship diagram of polygon feature entities.

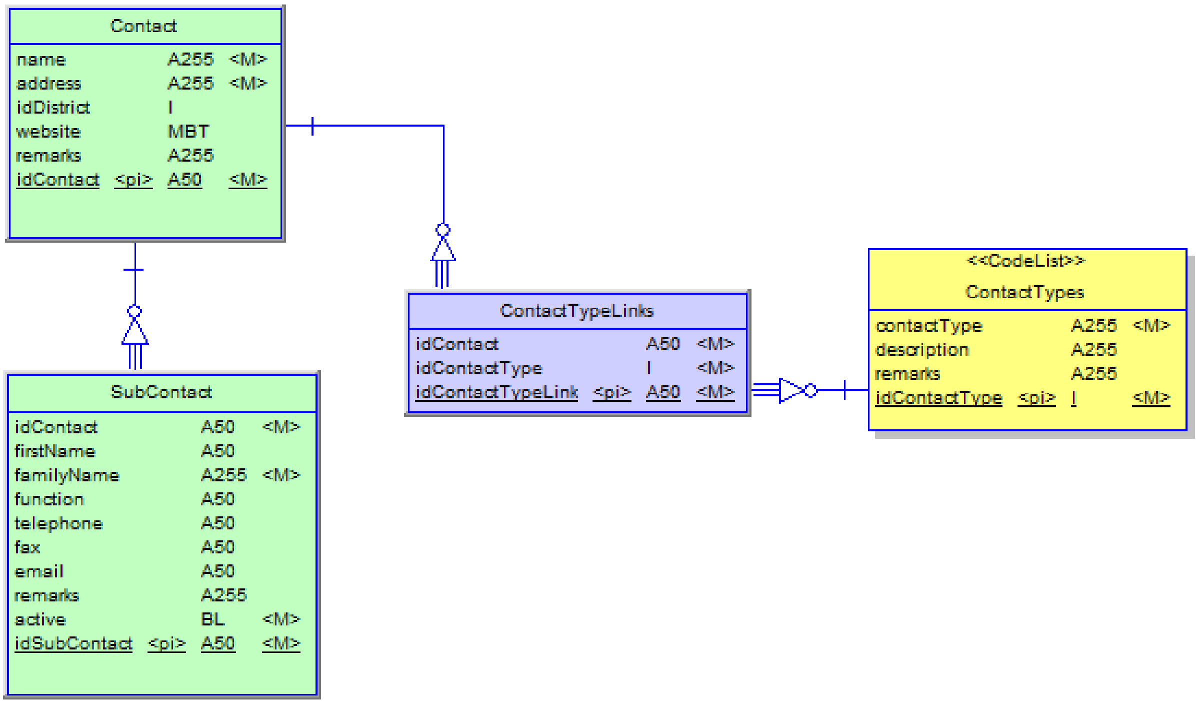
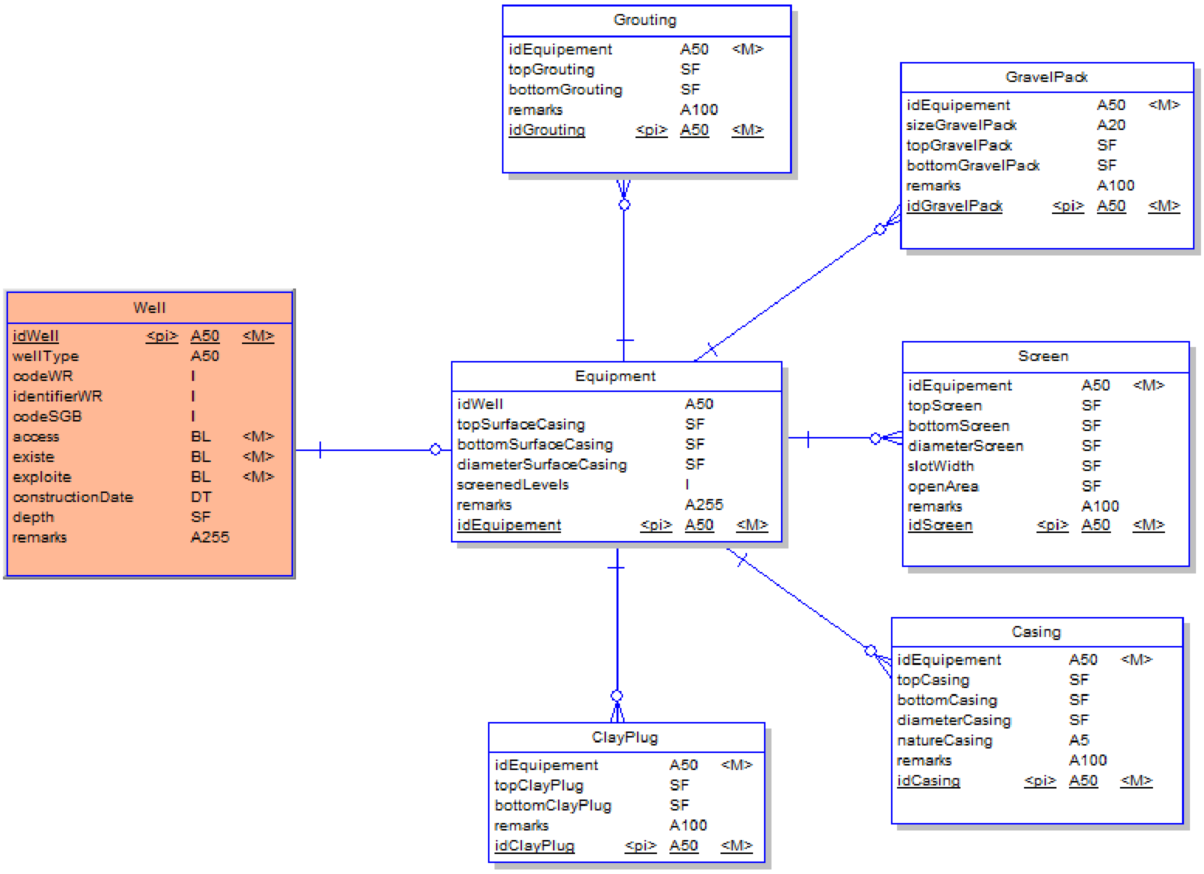


Figure ESM 4. Contact sub-model and its entities.



Grouting			
idEquipement		A50	<M>
topGrouting		SF	
bottomGrouting		SF	
remarks		A100	
idGrouting	<pi>	A50	<M>

GravelPack			
idEquipement		A50	<M>
sizeGravelPack		A20	
topGravelPack		SF	
bottomGravelPack		SF	
remarks		A100	
idGravelPack	<pi>	A50	<M>

Well			
idWell	<pi>	A50	<M>
wellType		A50	
codeWR		I	
identifierWR		I	
codeSGB		I	
access		BL	<M>
existe		BL	<M>
exploite		BL	<M>
constructionDate		DT	
depth		SF	
remarks		A255	

Equipment			
idWell		A50	
topSurfaceCasing		SF	
bottomSurfaceCasing		SF	
diameterSurfaceCasing		SF	
screenedLevels		I	
remarks		A255	
idEquipement	<pi>	A50	<M>

Screen			
idEquipement		A50	<M>
topScreen		SF	
bottomScreen		SF	
diameterScreen		SF	
slotWidth		SF	
openArea		SF	
remarks		A100	
idScreen	<pi>	A50	<M>

Casing			
idEquipement		A50	<M>
topCasing		SF	
bottomCasing		SF	
diameterCasing		SF	
natureCasing		A5	
remarks		A100	
idCasing	<pi>	A50	<M>

ClayPlug			
idEquipement		A50	<M>
topClayPlug		SF	
bottomClayPlug		SF	
remarks		A100	
idClayPlug	<pi>	A50	<M>

Figure ESM 5. Relationships between well and its equipment entities.

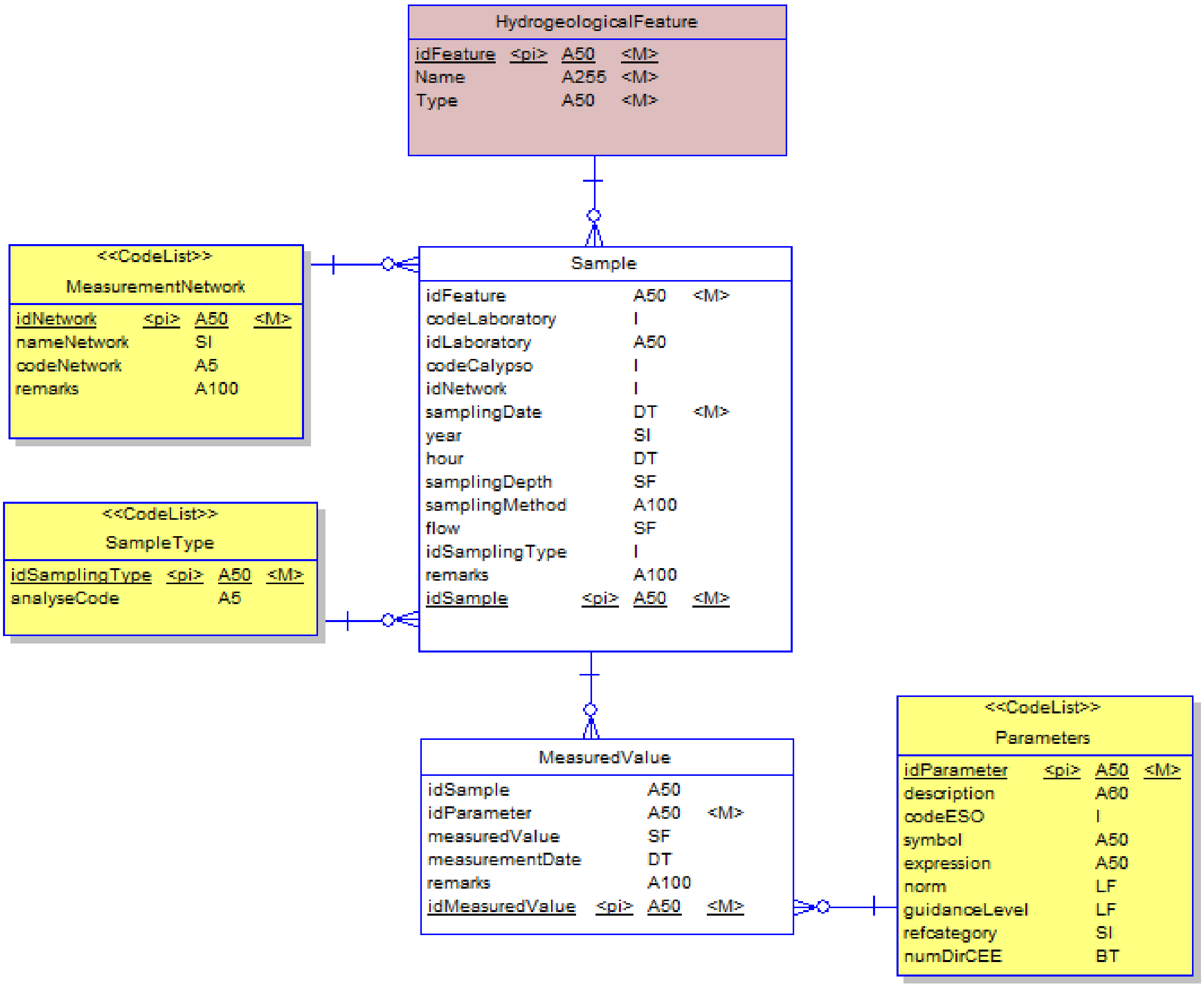
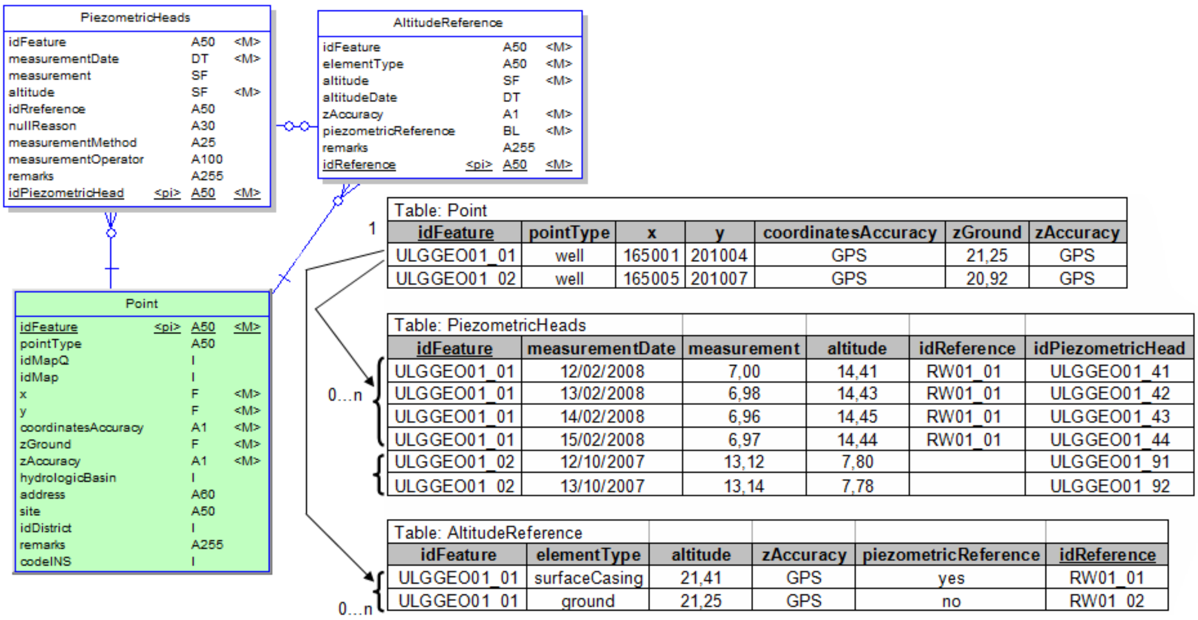


Figure ESM 6. Entity-relationship diagram for chemical analysis sub-model.



PiezometricHeads			
idFeature		A50	<M>
measurementDate		DT	<M>
measurement		SF	
altitude		SF	<M>
idRreference		A50	
nullReason		A30	
measurementMethod		A25	
measurementOperator		A100	
remarks		A255	
idPiezometricHead	<pi>	A50	<M>

AltitudeReference			
idFeature		A50	<M>
elementType		A50	<M>
altitude		SF	<M>
altitudeDate		DT	
zAccuracy		A1	<M>
piezometricReference		BL	<M>
remarks		A255	
idReference	<pi>	A50	<M>

Point			
idFeature	<pi>	A50	<M>
pointType		A50	
idMapQ		I	
idMap		I	
x		F	<M>
y		F	<M>
coordinatesAccuracy		A1	<M>
zGround		F	<M>
zAccuracy		A1	<M>
hydrologicBasin		I	
address		A60	
site		A50	
idDistrict		I	
remarks		A255	
codeINS		I	

Table: Point

idFeature	pointType	x	y	coordinatesAccuracy	zGround	zAccuracy
ULGGEO01_01	well	165001	201004	GPS	21,25	GPS
ULGGEO01_02	well	165005	201007	GPS	20,92	GPS

Table: PiezometricHeads

idFeature	measurementDate	measurement	altitude	idReference	idPiezometricHead
ULGGEO01_01	12/02/2008	7,00	14,41	RW01_01	ULGGEO01_41
ULGGEO01_01	13/02/2008	6,98	14,43	RW01_01	ULGGEO01_42
ULGGEO01_01	14/02/2008	6,96	14,45	RW01_01	ULGGEO01_43
ULGGEO01_01	15/02/2008	6,97	14,44	RW01_01	ULGGEO01_44
ULGGEO01_02	12/10/2007	13,12	7,80		ULGGEO01_91
ULGGEO01_02	13/10/2007	13,14	7,78		ULGGEO01_92

Table: AltitudeReference

idFeature	elementType	altitude	zAccuracy	piezometricReference	idReference
ULGGEO01_01	surfaceCasing	21,41	GPS	yes	RW01_01
ULGGEO01_01	ground	21,25	GPS	no	RW01_02

Figure ESM 7. Point entity with its piezometric heads measurements and an example of implementation.