DATABASE AND GENERAL MODELLING CONCEPTS FOR GROUNDWATER MODELLING IN THE SQUASH PROJECT

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ABSTRACT: *Groundwater management at the basin scale, and particularly large-scale physically based groundwater flow and transport models, require large amount of data. To manage efficiently the data, to automate as much as possible the development of the models, and to optimize the flexibility of the approach, the Hydrogeology Group (HG) of the University of Liège has developed a methodology using database, GIS and models. Partner of the NATO project "Quantitative and qualitative hydrogeological study of the alluvial aquifer of Somes-Szamos", the HG team has proposed to test this methodology for the creation of the model of the alluvial aquifer.*

Key words: Large-scale modelling, flow, transport, groundwater, database, GIS.

1. Introduction

Water management at the basin scale represents a key issue to insure a sustainable quantity production and a good water quality for different uses. The European Council has introduced these concepts in the European law through the Water Framework Directive (2000/60/EC) that requires an integrated water management by "hydrological districts". Such districts can sometimes be transboundary. In each district, groundwater bodies, considered as management units, have to be delineated, characterized, managed, protected against further degradation and if possible, restored. The study of the alluvial aquifer of Somes-Szamos basin can be considered as a representative example for the application of the EU Water Framework Directive.

Classical groundwater flow and transport modelling techniques are not adapted at such a large scale. Large data sets such as geological maps, piezometric level maps, hydrogeological parameters (hydraulic conductivity, specific yield, porosity...) etc., have to be managed to build, calibrate and validate the model. To face these issues, the Hydrogeology Group of the University of Liège, Belgium has developed a new general methodology including data management, link between database, geographical information systems and groundwater numerical modelling tools. This methodology has been applied in the framework of the NATO project "Quantitative and qualitative hydrogeological study of the alluvial aquifer of Somes/Szamos".

2. Data management

Performing a large scale hydrogeological study implies handling a big amount of data, such as topography, land use, land cover, soil, hydrology, geology, hydrogeology, meteorology. These data come from different sources, namely water regulators, water companies, environmental agencies, research offices, industries, public or private institutions, farms etc. Moreover, they are often available in different formats, such as paper or digital diagrams, images, maps, spreadsheets, logs. Therefore, processing such heterogeneous and complex data sets is a real challenge.

The solution is to have a coherent and logical structure supported by a computing environment. A hydrogeological database proves to be a powerful tool, offering an easy way to encode, store, analyse, display, edit, query, control, and update data. It is an ideal basis for hydrogeological studies concerning groundwater quality, for drawing hydrogeological maps, for groundwater flow and contaminant transport modelling or for vulnerability assessment.

The database is a good support for various studies and data exchange between different institutions and it allows a dynamic connection with Geographical Information Systems (GIS) that are increasingly used in groundwater management because of their ability "to carry out spatial operations, linking data sets using location as the common key" (***, 1997b).

GIS are defined as systems for the input, the storage, the manipulation, and the output of geographically referenced data (Goodchild, 1996). They provide a means of representing the real world through integrated layers of constituent spatial information (Corwin, 1996). Geographic information can be represented in GIS as objects or fields. The object approach represents the real world through simple objects such as points, lines and polygons. The objects, representing entities, are characterised by geometry, topology, and non-spatial attribute values (Heuvelink, 1998).

Before building a database, suitable data types must be defined, taking into account the purpose of the database, the potential users and the available data. Figure 1 shows an example of primary and secondary data.

After defining the data that feed the database, the relationships between these data must be set, as well as the geometry of each type of data. There are three types of geographical objects: points, arcs and polygons. Table 1 presents some data types and the geometry associated with them.

A database must contain and provide a maximum storage of data with a minimum data

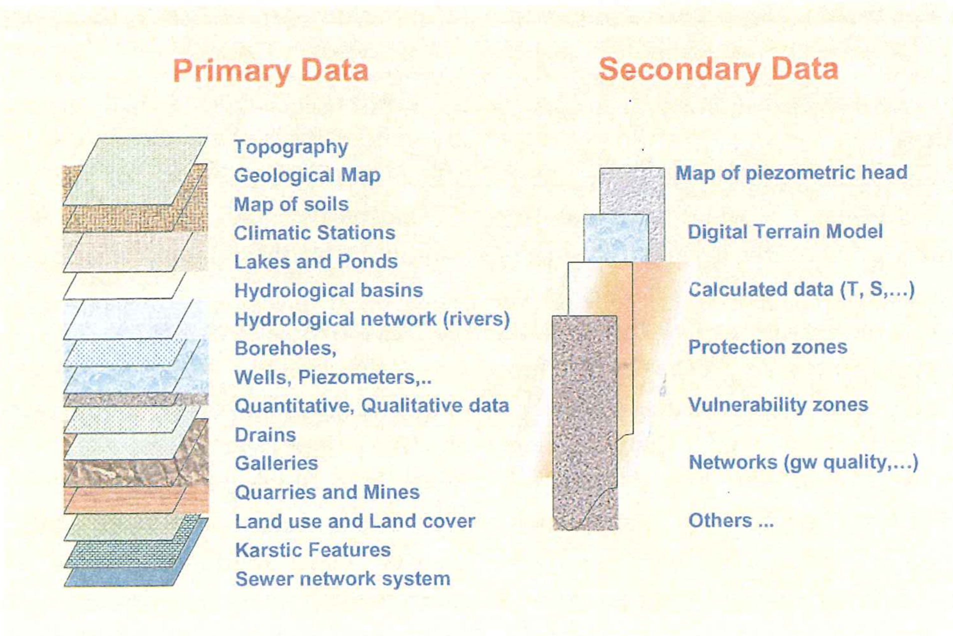

Fig. 1 Primary and secondary data used in hydrogeological studies (not exhaustive).

Table 1 Geometrical representation of data.

Data	Geometry
Groundwater (well, piezometer)	POINT
Water supply galleries, drains	ARC
Quarries, mines	POLYGON
Surface water (springs, measure stations)	POINT
Hydrological network (rivers)	ARC
Surface water bodies	POLYGON
Hydrological basins	POLYGON
Irrigation drains	ARC
Sewer network system	ARC
Climatic stations	Point

redundancy, offering an optimum retrieval of information and taking into account the memory capacity of the computer support. The Hydrogeology team of the University of Liège (Belgium) has developed a hydrogeological database in agreement with the specificity of the environment of the Walloon Region. The first version was designed in 1999 (Gogu et al., 2001). In 2001, when the SQUASH Project started, an English version of the hydrogeological database was released, with specific adaptations to this project. Since then, the Hydrological Team of the University of Liège has continuously improved and developed the existing database.

The computer application used is Microsoft MS Access(r). It is a georelational database management system of which the principal internal objects are tables (for encoding and storing), queries (for searching), forms (for encoding and query) and reports. The table is the central point of a database where all data are stored. "One-to-one" and "one-to-many" relationships can be established between tables. Forms are windows objects used to view and/or to enter data in the database. A query must be created to retrieve necessary information for a specific purpose (geocentric queries or based on owner, on topographic map etc.). A form can combine data that are part of one or more tables or queries.

Adapting the database to the specificities of the Romanian and Hungarian data was a real challenge. The most difficult problem to overcome at the beginning of the project concerned the selection of a common coordinate system. The coordinate system used in Romania is Gauss-Krueger (Pulkovo, 1942) but other systems, such as Stereo 70, are also used. The altitude reference is the Black Sea but some data can be found with a Z coordinate referring to the Baltic Sea. In Hungary, the (X,Y) coordinates are in the EOV system and the altitudes are given with respect to the Baltic Sea level. However, some altitudes are also measured using the Adriatic mean sea level. Finally, the system that was adopted for the SQUASH Project was the Gauss-Krueger (Pulkovo, 1942) for (X,Y) coordinates and the Baltic Sea reference level for altitudes. The Hungarian data in EOV system have been converted in Gauss-Kruger system through a conversion software.

The hydrogeological database used in the SQUASH Project contains 73 tables concerning groundwater and surface water. The main tables for point data concerning groundwater are presented in the Figure 2.

The "Groundwater" table (point geometry) contains general information associated with any type of borehole (wells, piezometers etc.): coordinates, code, accessibility, construction date, ID-s leading to several dictionaries. Dictionaries contain general information such as list of drilling companies, geological units, aquifers, tests methods, etc. The "Groundwater" table is linked to other tables describing the lithology, the equipment, tables with reference Z coordinates (soil, protective casing etc.) and others. There are also tables with tests data and results (pumping tests, tracer tests), with quantitative data (piezometric measurements, tests results, abstracted volumes...) and qualitative data (concentrations...).

Another important part of the database concerns surface water. There are point data, such as springs or measurement stations (gauging sites, hydrometric stations, ..), arc data (representing streams) and polygon data (such as lakes). Data concerning geophysical prospecting can also be stored in the database. There are other tables with climatic stations (point data) or hydrological basins (polygon data). Secondary (derived) data can also be generated, especially if it is linked to a GIS.

3. Databases linked to a GIS

The geo-referenced database can be linked to a GIS project, using spatial queries, based on structured query language connections (SQL). Data stored in the database can be easily updated and represented in the form of maps. X, Y coordinates make the link between features on the map processed in the GIS and the equivalent data stored in the database. The GIS used in the frame of the SQUASH Project was ArcView 3.2 (ESRI®).

By using a database linked with a GIS project, maps based on database attribute queries, such as time- and space-dependent parameter values, can be prepared and visualized.

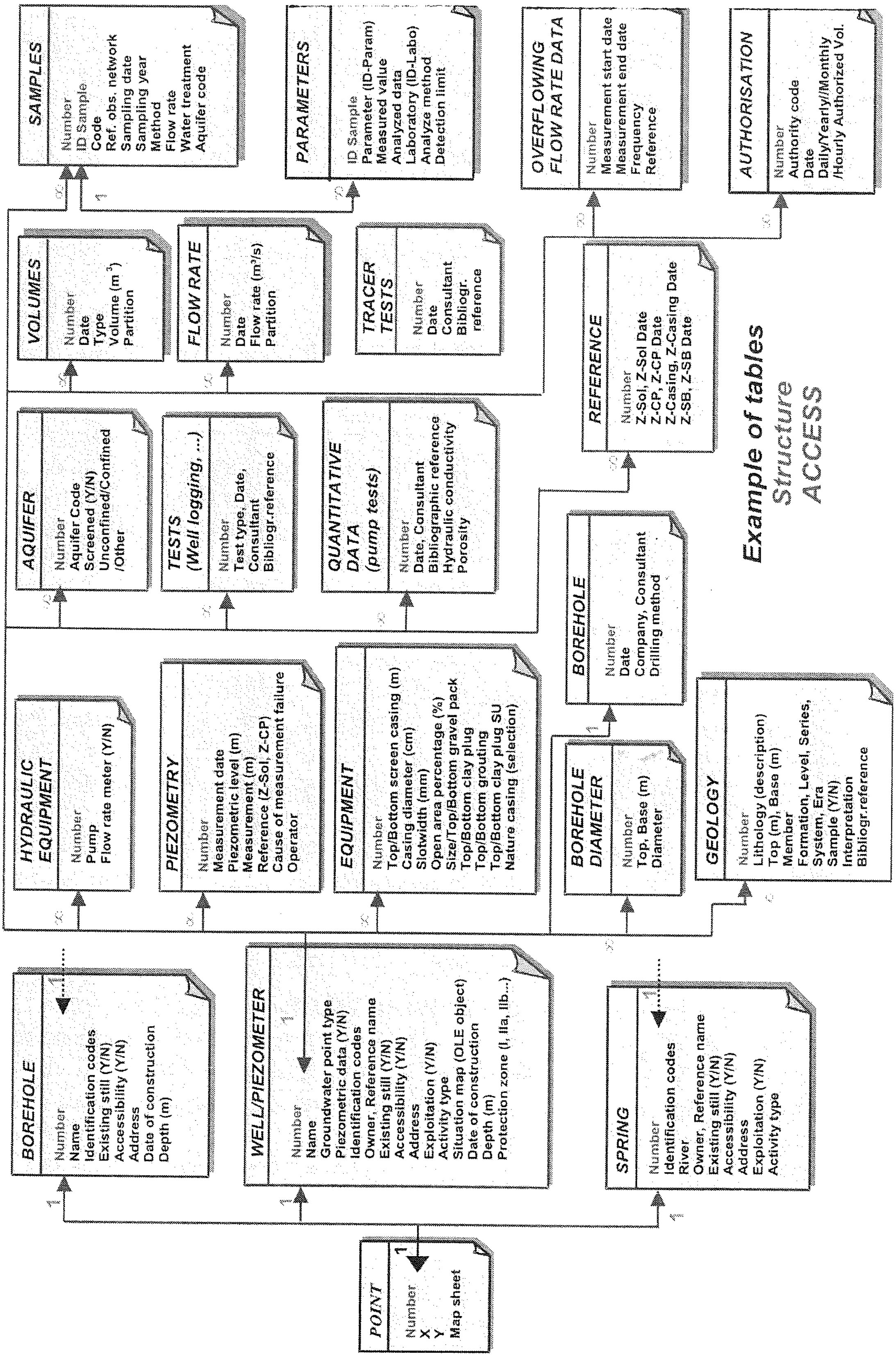

Fig. 2 Main tables for point data concerning groundwater.

Statistics related to hydrogeological entities can be displayed on screen or printed on supporting maps. Geostatistical procedures (i.e. kriging) can complete the analysis. Some of the tools needed to achieve the objectives are already implemented in the basic software package, but most of them require knowledge of GIS techniques, database philosophy, and specific programming languages.

The coupling of a database with a GIS provides a powerful tool that is now widely used to create digital geographical databases, to manipulate and prepare data as input for various model parameters and to display model output.

4. General modelling concepts

The development of physically based models at the basin scale require large amount of data. The hydrogeology Group of the University of Liège has developed a general methodology to manage the data and build the model (Figure 3). The main objectives are to automate as much as possible the development of the models starting from data existing in the database and in ArcView and to allow easy and efficient data handling, updating and modifications in the models.

To automate the development of the model, links have to be created between the database, the GIS and the model. Links can be organized between models and GIS using three techniques: loose coupling, tight coupling, and embedded coupling. Loose coupling means that the GIS application and the model are developed using distinct software packages and the data transfer is made through pre-defined input/output model files. The GIS software is used to pre-process and post-process the spatial data. An advantage is the fact that the software packages are independent, facilitating potential future changes. Tight coupling consists in an export of data to the model from the GIS, but the GIS tools can interactively access input model subroutines. In this case, the data exchange is fully automatic. An example of this coupling is the Groundwater Modeller Link (Steyaert & Goodchild, 1994) between the ERMA Spatial database scheme (supported by Modular GIS

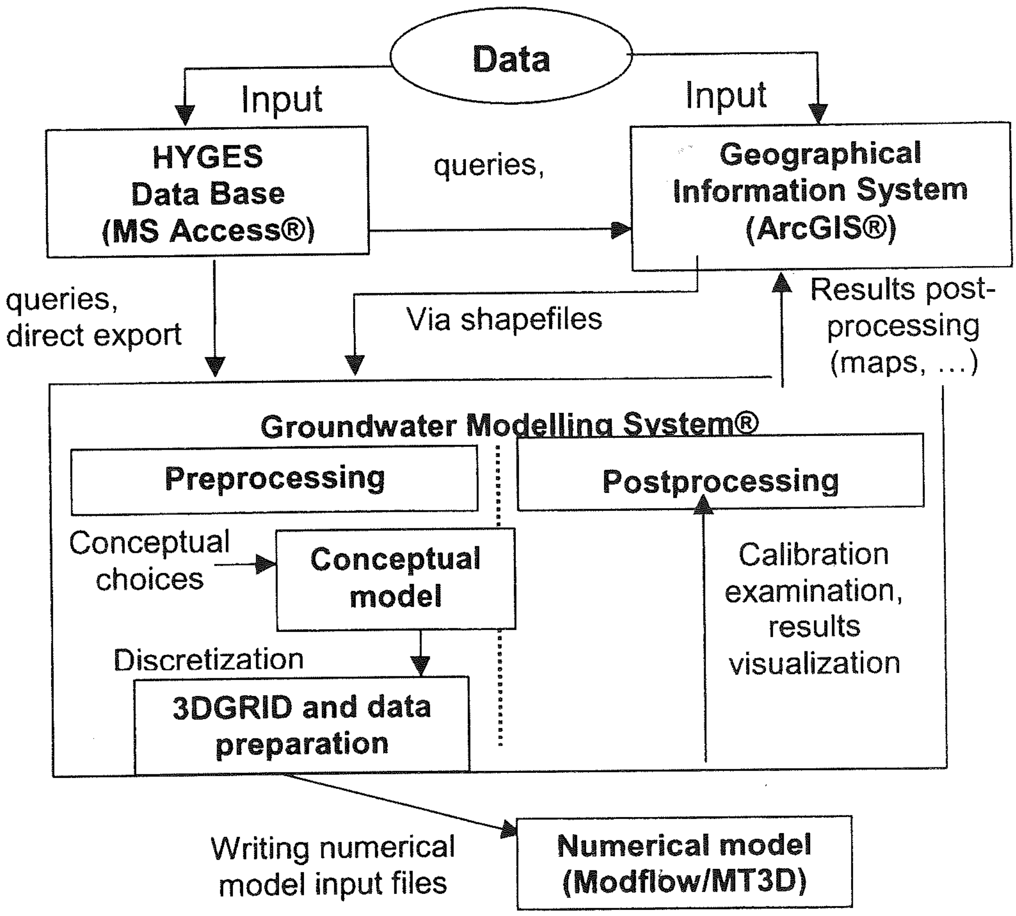

Fig. 3 Schematic representation of the general methodology adopted for developing groundwater models in the SQUASH project, using the HYGES Database, GIS and modelling softwares.

Environment, Intergraph 1995) and MODFLOW, MODPATH, MT3D finite-difference software packages. When a model is created using the GIS programming language or when a simple GIS is assimilated by a complex modelling system embedded coupling is used. Tight coupling as well as embedded coupling involves a significant investment in programming and data management that is not always justified. This coupling is also often constraining when a high flexibility is required.

In the SQUASH Project, the well-known program ArcView and GMS(r) (Groundwater Modeling System) have been chosen to manage spatial data and modelling in a loose way. GMS, developed by the EMS-I company, is a powerful pre- and post-processor for groundwater flow and transport models (Modflow, MT3D etc), with various data handling tools including GIS and database interactions.

The hydrogeological attribute data can be directly introduced or they can be imported using a specific format file. In hydrogeological models, data have to be imported in GMS at three steps: during the conceptual model design, for generating the model itself and for the calibration procedure. The conceptual model consists in defining the limits of the modelled area, the boundary conditions, the stresses (pumping rates etc) through "feature objects". Then, starting from the conceptual model, a 3D Grid can be built. The information contained in the "feature objects" is then transferred to the grid.

Groundwater flow and contaminant transport simulations are performed using Modflow and MT3D. When the simulations are completed, results can be read back into GMS for visualization and comparison with observed data (such as measured groundwater levels or concentrations). The calibration of the model can be performed using trial-and-error or automatic optimization procedures until a satisfactory fit of the data is obtained. Thanks to the flexibility in handling the data and building the model, the user can, at any step of the model construction, modify the conceptual model and regenerate, without important effort, the numerical model. Whenever new data are available (new measurement campaigns...), the database and GIS are updated and the model can be improved and reprocessed in a very flexible and easy way. Modelling results can also be exported from GMS to the GIS for post-processing.

5. Conclusions

As described in subsequent papers, the methodology developed for an efficient handling and processing of geological and hydrogeological data has been successfully applied to the development of a regional model (Drobot et al., 2004) of the alluvial aquifer of Somes-Szamos and for studying local contamination problems (Szûcs et al., 2004; Minciuna et al., 2004). The whole database - GIS - Model structure could be efficiently used as part of a general groundwater management tool for the application of the EU Water Directive in the Somes-Szamos basin, but also in other basins in Europe.

The HYGES data base used in this methodology is still under development to add new kinds of data such as results of geophysical survey useful for the building of the geometry of the model. The ESRI and EMS-I companies have also improved their software to add new opportunities of links between GIS and modelling systems.

Further steps would consist in developing a similar architecture for surface waters and then to couple groundwater and surface water for an integrated management of these resources.

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