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Current Trends and Approaches in Urban Hydrogeology

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Abstract: Urban areas are a focus of increasing conflict with regard to water use and water protection. Half of the world's population and about 73% of Europeans live in cities. In Europe numerous urban areas are located in flood plains of the rivers. Sedimentary media (alluvial sediments, deltas, etc.) form particular frequently occurring environments within these valley fills. However, sedimentary media are normally significant aquifers due to their high permeability, storage and management ability, interaction with surface water, etc.

A reliable management of the hydraulic resources in urban areas can be performed only by using modeling. The models can provide accurate results if they correctly reproduce the hydrogeological processes. Nevertheless, it is well-known that sedimentary media are normally extraordinarily heterogeneous, which is a paradox as it leads to simplified models based on the homogeneity of large zones characterizing the medium. Tools and methodologies should allow the representation in three dimensions of the of the geological record heterogeneity and its spatial distribution as well as the interaction of the groundwater with the urban infrastructure (water supply and sewer systems, drainage systems of basements, subway network, parking lots, etc.). The paper will focus on the main aspects of these instruments, which are currently developed within a national research project, that have to support the 3D hydrogeological modeling.

Within this project is developed a software platform containing methodologies and tools that facilitate the integration of the 3D geological models in sedimentary media into the hydrogeological modeling of flow and contaminant transport. This is composed by a geospatial database and a set of tools allowing accurate stratigraphical analysis. The geospatial database is used for the management of a large amount of different data types coming from different sources (geophysical, geological, hydraulic, and others). Its structure allows storing accurate and very detailed geological core description that can be straightforwardly generalized and further upscaled. An application of this platform is currently developed for the Moesic aquifer system (Bucharest city Region). This involves: (1) 3D geological characterization – application of the methodologies and developments suggested, (2) 3D parameterization of the Moesic aquifer system (Fratesti strata, Mostistea, and Colentina), (3) Management of the hydrogeological data base (tests and hydraulic parameters, level data, hydrochemical data, etc.), (4) Hydraulic definition/parameterization of facies and other geological concepts and, (5) Interaction between underground works and hydrogeology.

Keywords: 3D hydrogeological modelling, sedimentary media, geospatial databases, Geographical Information Systems

INTRODUCTION

In Europe numerous urban areas are located in flood plains of the rivers. Sedimentary media (alluvial sediments, deltas, etc.) form particular frequently occurring environments within these valley fills. However, sedimentary media are normally significant aquifers due to their high permeability, storage and management ability, interaction with surface water, etc.

Traditionally the exploitation of this kind of aquifers has been significant because, among other reasons they are frequently highly accessible (in general there is no need for complex water catchments works, but wells and/or superficial boring usually between 10 to 100 m depth is sufficient in these cases). This same reason, among others, also contributes to the fact that they are highly vulnerable. In order to secure and guarantee the time and the use of these resources, a good hydrologic management is mandatory.

A reliable water management can be obtained by groundwater modeling. The models allow conceptualizing and quantifying the hydrogeological processes and simulate various scenarios as droughts, water resource exploitation, water quality evolution and contamination aspects, interaction with civil works in terms of hydraulical and geomechanical ground behavior.

These models can provide accurate results if they correctly reproduce the hydrogeological processes. Nevertheless, it is well-known that sedimentary media are normally extraordinarily heterogeneous, which is a paradox as it leads to simplified models based on the homogeneity of large zones characterizing the medium.

It has been demonstrated that it is possible to use homogeneous representative models giving information on the behavior of the aquifer regarding the water resources. Nevertheless, these models are completely inadequate to characterize pollution problems and their remediation, where the most important point is connectivity.

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Hydrogeological modelling could represent correctly the considered processes only (1) if the genetic structure and evolution of the sedimentary medium is accurately known, (2) if the petrophysic and hydraulic properties can be correctly extrapolated, and (3) if the tools to implement these properties in the hydrogeological models are available. In order to be able to answer to these mentioned issues, available accurate and detailed geological description of the media is necessary. The information expressing this kind of description can be manipulated by spatial databases within a GIS environment.

The paper presents a software platform containing methodologies and tools that facilitate the integration of the 3D geological models in sedimentary media into the hydrogeological modeling of flow and contaminant transport. This is composed by a geospatial database and a set of tools allowing accurate stratigraphical analysis. The geospatial database is used for the management of a large amount of different data types coming from different sources (geophysical, geological, hydraulic, and others). Its structure allows storing accurate and very detailed geological core description that can be straightforwardly generalized and further upscaled.

The obtained methods and tools are used for spatial data manipulation, which support understanding the detailed geology of the sedimentary media and the integration of the geological processes that controlled their formation. From the existing data and the developed methods, the petrophysical characteristics could be extrapolated to the entire sedimentary volume considered at a local level, by using various techniques such as the deterministic or stochastic methods.

The implementation of the above mentioned information volume into the groundwater flow and contaminant transport models guarantee a sustainable management of water resources in areas showing high human pressure.

The described platform has been initially designed starting from the existing hydrogeological model of Barcelona region [10]. As consequence its concept focuses mainly a deltaic sedimentary media environment. Currently an application of this platform is developed for the Moesic aquifer system of Bucharest city area. This involves: (1) 3D geological characterization – application of the methodologies and developments suggested, (2) 3D parameterization of the Moesic aquifer system (Fratesti strata, Mostistea, and Colentina), (3) Management of the hydrogeological data base (tests and hydraulic parameters, level data, hydrochemical data, etc.), (4) Hydraulic definition/parameterization of facies and other geological concepts and, (5) Interaction between underground infrastructure and groundwater.

Study case geological and hydrogeological conditions

In the Bucharest city region, the Moesic platform shows two main aquifer types (Figure 1). One is a regional high depth fissured-karstic carbonate aquifer of the Superior Jurassic – Inferior Cretaceous and the other one is located in the Pliocene and Pleistocene raw deposits. Close to the Danube, the carbonate aquifer can be found at more than 150 m depth however in the Bucharest city region is located at depths of more than 2000m.

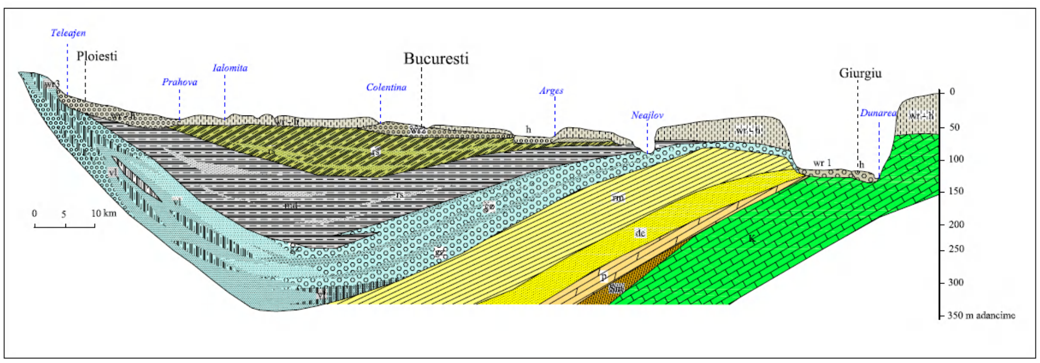

Figure 1. Hydrogeological cross-section of the study area.

The second aquifer system called “Fratesti strata” was created in the Tertiary deposits of the Upper Pleistocene and of Lower Pleistocene. This represents the main hydrogeological formation used for water supply of the South-Eastern Romania. It behaves as a confined multilayered aquifer. On the Northern side, the Fratesti strata aquifer system is made of three main layers indexed as A, B, C. These layers are regrouped in the Southern part forming a single aquifer layer. The thickness of the three layers shows a spatial variability. Depending of the extracted groundwater volumes, their hydraulic heads vary between 25 and 60 m.

The mean thickness of the A aquifer layer is between 25 and 35 m. Its hydraulic conductivity takes values between 12 -24 m/day and 4-12 m/day in Northern Bucharest. The specific flow rates of this layer are evaluated between 1.5 and 10 l/s/m. The B aquifer layer is located at a higher depth and its mean thickness is between 25 and 25 m. The mean thickness of the deepest aquifer layer (C) is between 25 and 30 m. Its specific flow rates vary around 8 l/s/m. Between the three aquifer layers (A, B, and C) sandy-clayey strata with a thickness variation of 40 m to 5 m can be found.

A sequence of marl and clay layers with slim sandy intercalations overlay on the “Fratesti strata”. In the

Bucharest area its thickness decreases from north to south from about 150m to 40m. The sandy layers of this sequence represent about 10% to 30% of its thickness.
The marl sequence also called “Coconi strata” is covered by a permeable raw rocks layer made of fine and medium sands with gravel intercalations. This is called “Mostistea sands” aquifer and is located at depths between 25 m and 70 m. It is a confined aquifer and its hydraulic head takes values similar to another upper aquifer layer. It has a regional extension between Arges and Ialomita rivers. In the Baragan region this aquifer can provide flow rates of 6-7 l/s showing differences in the piezometric head of about 1-2 m. The extracted flow rates show values of 3-5 l/s.

The upper aquifer stratum of these quaternary formations called “Colentina gravels” is made by gravels and sands. These are raw sediments deposed by the Arges river and its tributaries. Its aquifer thickness is reduced to north. This unconfined aquifer can be found mainly in the Bucharest city region at depths between 15 m and 20 m. It shows possible extraction flow rates of 2-6 l/s with differences in the hydraulic head of about 0.5m to 5 m. However the water quality is quite low, the groundwater level can be found at 5 to 10 m depth. The aquifer thickness is between 3 to 5 m showings a variation of the particle size distribution. The gravels located in the western part are smoothly replaced by fine sands in the east. The specific flow rates take values of about 1-6 l/s/m. The hydraulic conductivity vary between 10 m/day and 70 m/day, sometimes being higher than 100 m/day.

A clayey-marl layer is located between the “Mostistea sands” and the “Colentina gravels”. In the Vlasiei fields both aquifers “Mostistea sands” and “Colentina gravels” are framed by loess deposits.

The analysis software platform

The 3D analysis platform for groundwater modeling is composed by a hydrogeological geospatial database and several sets of instruments facilitating the development of the geological model and allowing hydrogeological analysis.
The hydrogeological database follows the geodatabase stucture provided by the ArcGIS (ESRI) concept for representing geospatial information. To date it allows storing geological and groundwater information for sedimentary media.
One set of instruments using the database spatial information is dedicated to stratigraphical analysis. It has been developed on the ArcMap software, part of the ArcGIS (ESRI) software package. This considerably extends the functionalities of ArcMap. Another set of instruments allows borehole local estimation of hydraulic conductivity for lithological strata and stratigraphical units. Both extensions have the form of a toolbar that are tightly integrated within the ArcMap environment.

The Hydrogeological Geospatial Database

The design of geospatial database has an Object-Oriented approach and is easily extensible. An important step in the database development process was the creation of a conceptual model of the required information. A large spectrum of data was identified, as many related domains are concerned: geography, geology, hydrology, hydrogeology, meteorology, water engineering, land management and others. Also, existing projects and data models were explored in order to identify possible interactions and contributions.
The architecture of the hydrogeological database follows international standards concerning geospatial data encoding and transfer. This is reflected in its object-oriented approach supported by the Open Geospatial Consortium (OGC) and the International Organisation for Standardisation (ISO).
Several existing patterns or already implemented data models have been explored as follows:
• The Australian National Groundwater Data Transfer Standard, (1999);
• HYGES hydrogeological database of University of Liege [2].
• ArcHydro: ESRI hydrological data model [5].
• Water Framework Directive and its Geospatial information working group [8].
• GML: Geography Markup Language [4].
• GeoSciML, a generic Geoscience Mark-up Language [6].
• Groundwater Model of University of Texas [7].
• XMML (eXploration and Mining Markup Language) as a GML application schema [1], [9].
Starting from these models it had been considered necessary to prepare a new, more complete and exhaustive one. This characterizes extended hydrogeological information that has to better match the particularities of sedimentary media.
The database structure allows storing an accurate and very detailed geological core description that can be straightforwardly generalized and further upscaled. It serves to improve the quantification of the hydrogeological parameters. Relationships between the petrological, paleontological, chronological data could be established. Petrological characteristics are described for clastic and carbonated sediments in terms of textural (sediment size, sorting, roundness, matrix support), lithological, colour, and others. The sedimentary structures, the geological layers boundaries, the geological units chronology or facies assignment, the paleontological content, and some complementary information are represented.

Lithological and stratigraphical analysis tool

The design of the lithological and stratigraphical analysis instruments has been set up to facilitate firstly the hydrogeological data interpretation. This subset of tools is made of several subcomponents. One of them allows the visualization of the borehole core lithological and stratigraphical information.

Another one allows generating the geological profiles by query and visualization of the lithological and stratigraphical information. By using the third set of instruments, the user is able to identify stratigraphic units, analyze their characteristics, and export them in a 3D environment.

Borehole diagram instruments

This tool has been developed in order to facilitate the visualization and the analysis of the borehole detailed geological core description. To ease the analysis, the data visualization was designed following the classical geologist working bearings. By selecting a point representing a borehole on the map, the user has the possibility of querying the attached lithological and stratigraphical information. Figure 2 shown that for each lithological stratum can be visualized the petrological characteristics in terms of texture (sediment size, sorting, roundness, matrix support), lithology, and colour.

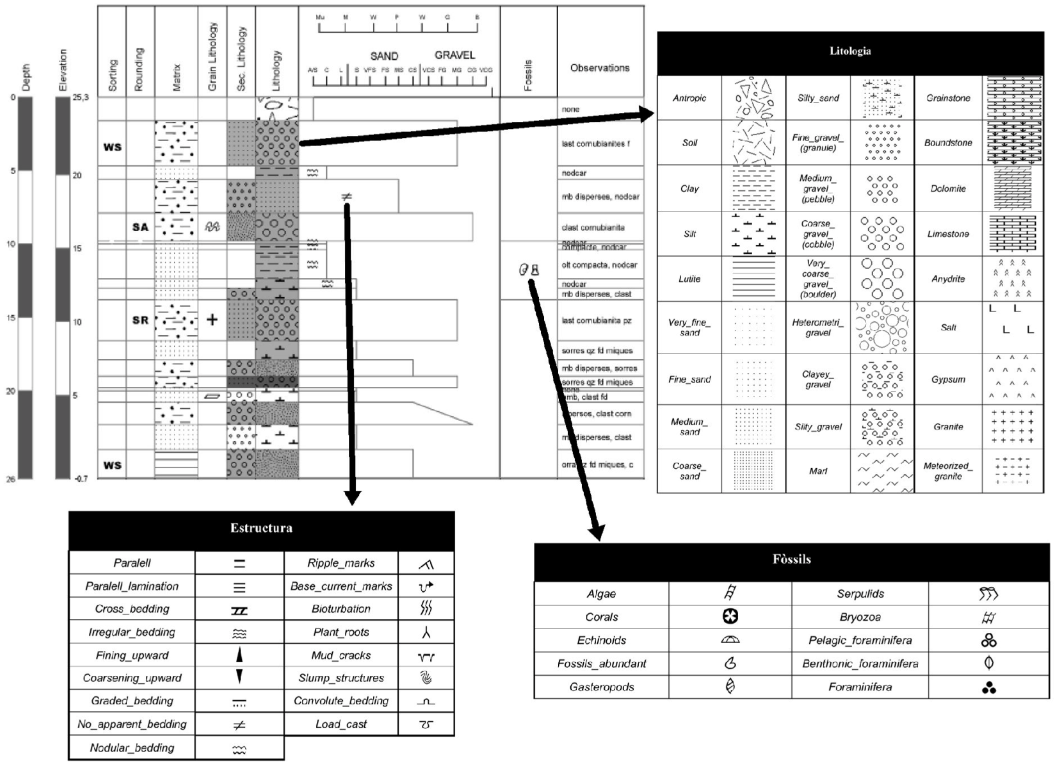

Figure 2. Description of petrological characteristics for clastic and carbonated sediments in terms of textural (sediment size, sorting, roundness,), lithological, colour, and others.

The sedimentary structures, the geological layers boundaries, the defined subdivisions in units or subunits, their chronology, the paleontological content are also displayed.

The user can generate borehole core views at distinct vertical scales, in distinct paper formats. These can be then exported in various graphical formats.

Stratigraphic cross-sections correlation tool

The basic idea of this instrument is to facilitate the process of stratigraphic well correlation to the geologist. This kind of perception pulls on the understanding of geological processes, examination of exposures, and theoretical knowledge gathered by the modeller.

This set of tools starts from the creation of a geological profile (Figure 3) by querying a buffer zone line on a map, the user is drawing on screen.

The profile is generated automatically by displaying the boreholes lithological columns together with the defined stratigraphical units/subunits. Complementary information is shown like the surface terrain profile extracted from the DEM, the distance between the boreholes, and the depth of each stratum

On this basis, an interactive analysis environment is created for a subsequent set of instruments. The user is able to analyze and to vectorize on screen the identified existing stratigraphical elements by using lines, polygons, or points. For each feature a set of attributes like the type of the contact surface, the position between the hydrogeological units or subunits as well as different hydraulic parameters or other observations can be stored. Possible existing faults and fractures can be identified and drawn on screen within the same environment.

The obtained information, represented by the user identified geological features, can be then converted within a 3D environment (Figure 4). The export procedure provides spatial features as points, lines, or polygons with their attached attributes. The resulted 3D features could be then used within the same GIS environment or by external software packages for further stochastic analysis or to build-up the geological 3D model

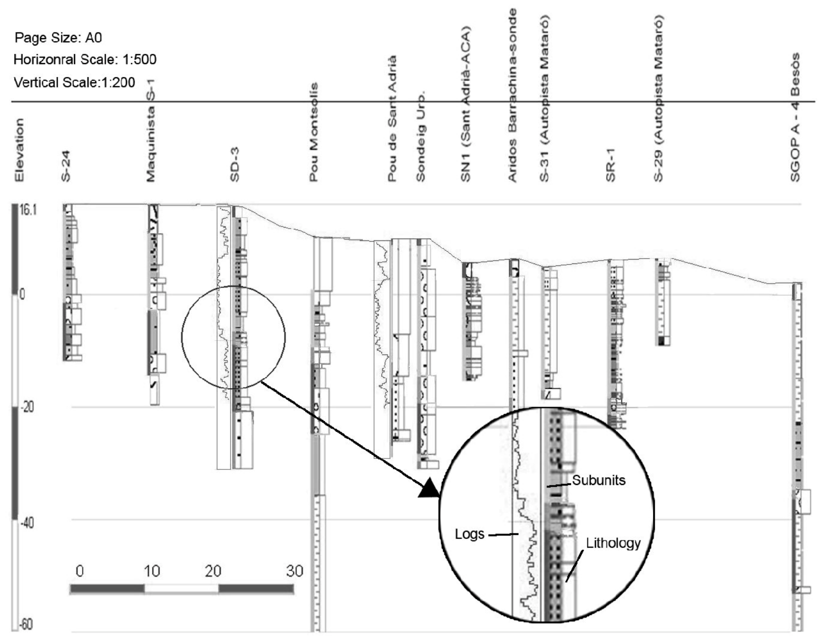

Figure 3. Geological profile generated by displaying the boreholes lithological columns and the related stratigraphical subunits.

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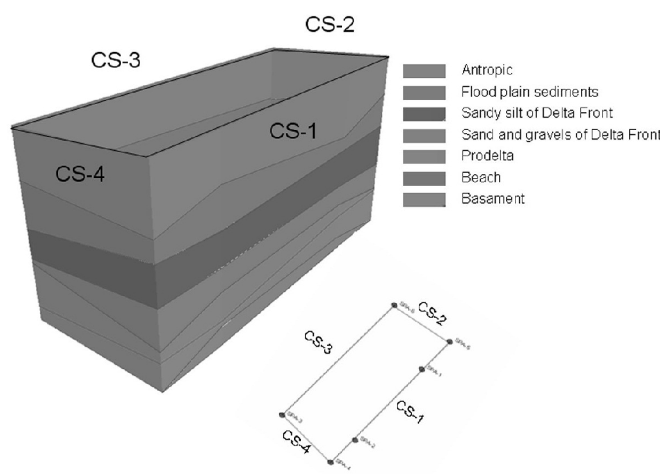

Figure 4. Fence diagram showing the obtained stratigraphic information visualized within a 3D environment.

Tool for the hydraulic conductivity initial estimation

Several steps have been made in quantifying hydraulic conductivity hydrogeological strata in boreholes, on the basis of the grain size distribution. For each lithological stratum or for the user defined hydrogeologic units, the hydraulic conductivity can be computed by using empiric formulas on the basis of the existing lithological description.

This procedure could provide for the hydrogeologic models, hydraulic conductivity values closer to the reality. To date this procedure is on its way to be studied and improved.

Discussion

The final target for the performed work focuses especially the characterisation of groundwater, as well as the dynamics of water systems and their standard distribution in space. In this sense, the presented set of instruments represents a working environment for integrating the 3D sedimentary media spatial distribution standards of the different

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hydraulic parameters, in the regular hydrogeology modelling methodologies. The final goal is to explain the relationship between the computed hydraulic conductivity values and the effective-type values, which are the ones that in reality define the dynamics of the aquifers. This help improving the conceptual model to build-up a hydrogeological model.

The developed database structure allows storing data for most of the hydrogeological studies. The integration of detailed core stratigraphical and lithological description with hydrogeological local and regional parameters, hydrogeological tests as pumping and tracer tests, surface hydrology features, information related to different observations and measurements, give the user a consistent image on the studied aquifer behavior.

As the described software allows performing detailed geological analysis, it also represents an excellent tool for managing and obtaining geotechnical information. This will help in studying the current geotechnical conditions and in recommending infrastructure development methods taking into account the environmental requirements.

To date the presented software platform offers tools and methodologies that allow the representation in three dimensions of the geological record heterogeneity and its spatial distribution. The current research work focuses on the interaction of the groundwater with the urban infrastructure in terms of water supply and sewer systems, drainage systems of basements, subway network, and others.

Conclusions

The design of the described instruments is following the geologist classical way of working when they characterize geologically a study area. The instruments have been thought to be applied for hydrogeological analysis but they could be applied to other kinds of geological, geotechnical, or environmental studies.

The presented work support the development of 3D geological characterization methods in sedimentary media, to carry out the development of hydraulic parametrization techniques for hydrogeological modeling. This represents the base for developing a reliable groundwater model facing urban aspects. The analysis of the geotechnical aspects in relationship to different ground and underground infrastructure elements as well as their interaction with groundwater will represent the next step of using the 3D geological software platform.

Acknowledgements

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