GIS-based Hydrogeological Database and Analysis Tools

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***Abstract*—A software platform was developed to facilitate the development of 3D hydrogeological models. It is composed of a hydrogeological geospatial database and several sets of tools developed in a GIS environment. The geospatial database is used for the management of a great amount of different data types coming from different sources (geophysical, geological, hydrogeologicals, hydrological and others). The instruments enable us to create 3D geological models and allow further hydrogeological analysis. This platform offers interoperability with other external platforms.**

Keywords;GIS, geospatial database, groundwater

I. INTRODUCTION

Groundwater represents an important source of water; therefore, evaluating and predicting its availability and accessibility is one of the main tasks in Integrated Water Resources Management (IWRM) [2]. In an IWRM framework, the development of hydrogeological models is required in order to predict the impact of different land and water management. Moreover, all data required in modeling should be easily accessible to decision makers and modelers [3].

Models are a representation of the reality [6], but reality is elusive. A comprehensive hydrogeological model must use all kinds of information available such as geological, hydrometeorological, geographical, hydrochemical, hydrogeological and environmental information among other. Each aforementioned field complements the interpretation of the rest of the fields. For instance, a proper hydrochemical analysis allows us to reinterpret the geology, or a comprehensive geological analysis enables us to perform a proper hydraulic parameterization that can be complemented with pumping or tracer tests.

In practice, this interpretation task may face several difficulties: i) managing and integrating this vast amount of time and spatial data collected from diverse source and gathered in different formats [5], [25] and ii) the existence of gaps between data collection and modeling due to the necessity of a seamless integration between databases with raw data, databases with models data and models [19]. Moreover, the scarcity of comprehensive tools for the management of spatial-temporal dependent hydrogeological data, including all the information required for a wide range of groundwater modeling platforms (e.g. hydrochemical, geological and flow modeling) further complicates their interpretation.

Most common in practice software dealing with hydrogeological data are specifically designed to manage or interpret separately the different aspects involved in a groundwater analysis. For instance, GOCAD [12] is mainly used for 3D geological modeling whereas a comprehensive hydrochemical analysis can be performed by using AQUACHEM [1]. Other hydrogeological analysis such as aquifer tests interpretations can be easily managed using EPHEBO [9].

Geographical Information Systems (GIS) may serve as an efficient tool for interpreting and analyzing groundwater data [21], joining most of the aforementioned aspects in a single platform. However, some procedures are still missing refinements (e.g. detailed geological analysis, specific hydraulic tests management …).

In this context, a GIS-based platform has been developed. It is composed of a geospatial database and a set of toolbox that arranges all the available data into a coherent structure and provides support for its proper management, analysis and interpretation. Furthermore, it facilitates the pre- and post-processing of the hydrogeological data for modeling.

The presented work forms part of a wider on-going framework for the facilitation of detailed hydrogeological modeling that includes further hydrochemical and geological GIS–based analysis tools. These tools are described in [23] and [24]. Here, we describe new details of the hydrogeological database regarding to other hydrogeological data (e.g. heads measurements, hydraulic tests) and the innovative analysis tools orientated to the visualization and retrieval of these data.

These technologies were applied to some studies such as the metropolitan area of Barcelona (Spain) (e.g. [22]) and the urban area of Bucharest (Romania) (e.g. [14]).

The organization of the paper is as follows: First, Section II presents the design and functionalities of the geospatial database (subparagraph A) and the instruments developed in the GIS environment (subparagraph B). The main conclusions arising from the application of the software are presented in Section III.

II. GIS-BASED HYDROGEOLOGICAL PLATFORM

This software platform was designed taking into account the different tools and methodologies that the water managers use to evaluate, integrate and analyze the wide range of information for the construction of a hydrogeological model. Consequently, the following requirements were adopted during the design of the software platform: (1) A geospatial database with appropriate data store and management (HYDOR), (2) Data processing and analysis tools of geological and hydrogeological analysis in a GIS environment, (3) Interaction with external software for further analysis and (4) Post-processing.

A. The hydrogeological Geospatial database (HYDOR)

The geospatial database represents geospatial information based on the Personal Geodatabase structure provided by the ArcGIS (ESRI) concept. Its structure facilitates: 1) data standardization and harmonization; 2) the storage and management of large amount of spatial features and time-dependent data; and 3) the creation and the execution of simple queries.

In order to ensure the standardization and harmonization of the data, several libraries (e.g. list of lithology, type of wells) were created, taking into account standard guidelines (e.g. INSPIRE [15]). Additionally, schemas of some features have been directly imported from others sources such as O&M [16], OGCWaterM.L2.0 [17] or WFD [11] to assure correct future data exchanges.

The main components include geographical (e.g. Digital Terrain Model) , hydrological (e.g. river, lakes, wetlands), environmental (e.g. vulnerable or protected areas, soil uses), geological (e.g., boreholes lithological description, stratigraphic units, depth to bedrock), geotechnical (e.g. laboratory tests) , hydrochemical (physic-chemical parameters), hydrogeological (e.g. well descriptions, head measurements, extraction measurements), data coming from field tests such pumping tests, tracer tests or other in situ tests (CPT, diagraphy) and administrative features (e.g. water directives, entities).

The data derived from interpretation and modeling efforts are stored separately, thus allowing further interpretation.

A sketch of some of the components related to hydrogeological points of measurements and hydraulic field tests are shown in Figure 1.

B. GIS-based tools

The set of analysis tools were developed as an extension of ArcMap environment (ArcGIS; ESRI) [10]. They were created with ArcObjects, which is a developer kit for ArcGIS, based on Component Object Model (COM), and programmed in Visual Basic using the Visual Studio (Microsoft) environment.

They have been set up to manage, visualize, analyze and interpret the data stored in the spatial database. This set of tools is separated in three main modules represented by different toolbar termed HEROS, QUIMET and HYYH.

The first module (HEROS) allows the user to exploit the geological data stored and to facilitate the geological interpretation. Detailed stratigraphic columns of the selected boreholes can be generated using customized queries. Creating automatically a geological profile is further possible by displaying the boreholes lithological columns and the geophysical and geotechnical field-tests' results together with the defined stratigraphic units. Based on an interactive analysis environment, the user is able to analyze and to define the possible existing correlation surfaces, units, and faults. The obtained information represented by the geological units can be then converted within a 3D environment. Finally, employing the resulting geological model in support of the hydraulic parameterization for hydrogeological modeling is also possible (for further information see [23]).

The second module (QUIMET) is composed of a set of instruments for analysis that cover a wide range of methodologies for querying, interpreting and comparing groundwater quality parameters. They include, among others, chemical time-series analysis, ionic balance calculations, correlation of chemical parameters, and calculation of various common hydrogeochemical diagrams (e.g. Schöeller-Berkaloff, Piper, and Stiff). The GIS platform allows the generation of maps of the spatial distribution of several hydrogeochemical parameters and of the aforementioned specific hydrogeochemical diagrams. Moreover, it is also possible to perform a complete statistical analysis of the data including descriptive statistic univariate and bivariate analysis, the generation of correlation matrices of several components, calculation of correlation graphics, and so on [24].

The last module (HYYH) has been designed to analyze and visualize different hydrogeological measurements and hydraulic field tests results (see Fig 2).

Contour maps and further spatial operations of the depth or thickness of the aquifers could be generated using customized queries. Likewise piezometric maps can be created for the selected points and for the selected period of time with another command included in this toolbar.

Finally, multi-criteria query forms enable the user to analyze and visualize different data and interpretations derived from pumping and tracer tests.

All the results obtained by using the aforementioned toolbars can be further analyzed using other inbuilt tools of ArcGIS, such as the Geostatistical Analysis toolbox or Spatial Analysis Tools.

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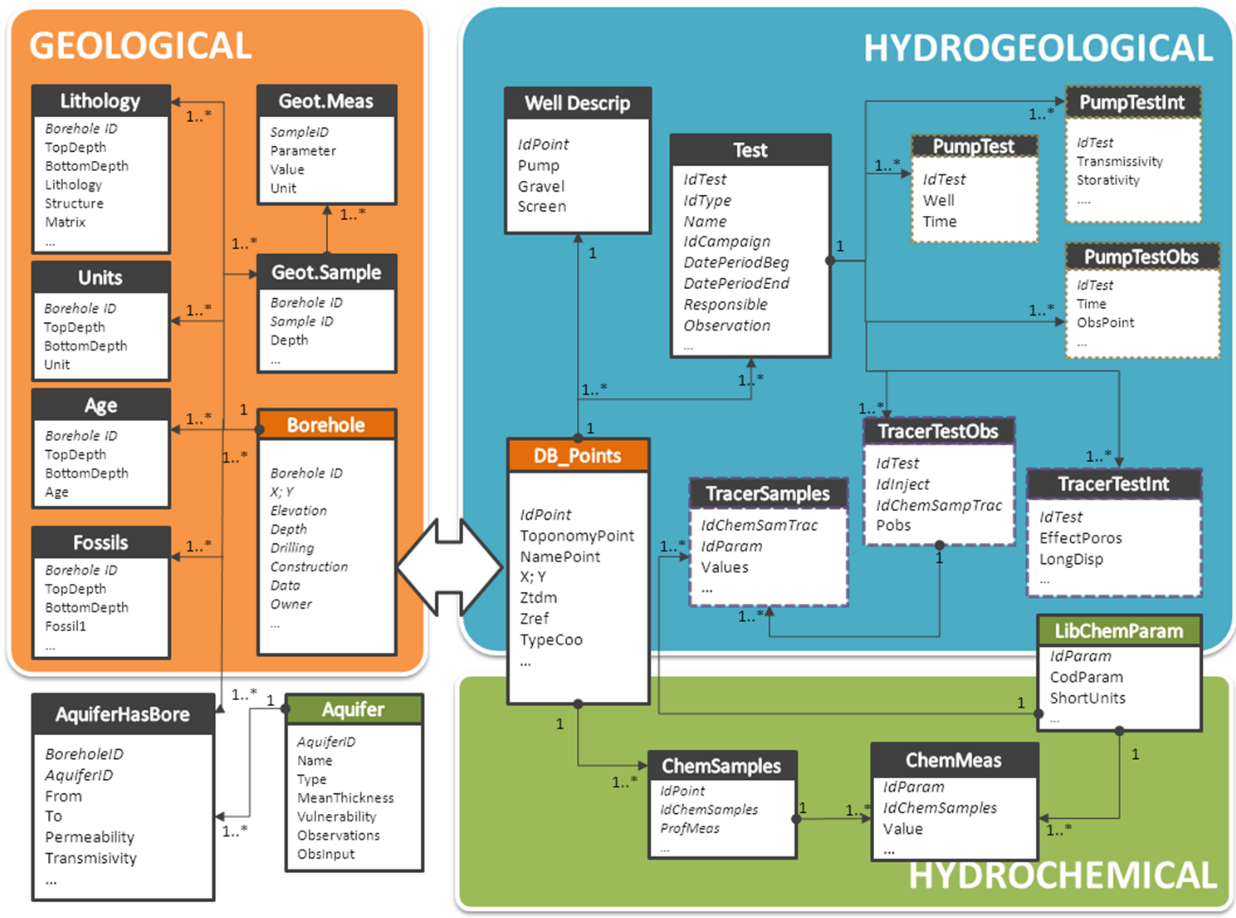

Figure 1: Simplified conceptual diagram representing the main contents in the hydrogeological database. The 1 and 1*.. represents the cardinality of the relationship between tables (further information of the database can be seen in [23]and [24]).

This software platform offers interoperability with external software for further analysis of the hydrogeological data, such as Hydrochemical modeling packages (e.g. EASYQUIM ; [8] and MIX; [4]), or codes designed to facilitate the hydraulic test interpretation (e.g. EPHEBO).Thus, the user pre-process the required spatial-temporal data in the same GIS environment and through the use of the export commands integrated in the different toolbars aforementioned, the results are transferred automatically through input/output predefined files.

III. CONCLUSION

The GIS-base software platform presented in this paper offers a user friendly GIS environment with a large variety of automatic tools developed specifically for the management and analysis of hydrogeological data to facilitate their integration and interpretation.

Despite the complexity of the internal structure of the database, the consultation and the introduction of the data is simple using the different query forms and instruments.

This software platform enables us to set up an updatable model database for further interpretations. Thus, each model study does not have to start from scratch.

The tools developed add a spatio-temporal analysis required to complete the analysis to other external platforms such as EASYQUIM or MIX. Moreover, with adequate adjustments this software platform could be readily linked to other programs such as PHREEQC [18], SGeMs [20], MODFLOW, and EASYBAL [7] considerably increasing the variety of hydrogeological calculations.

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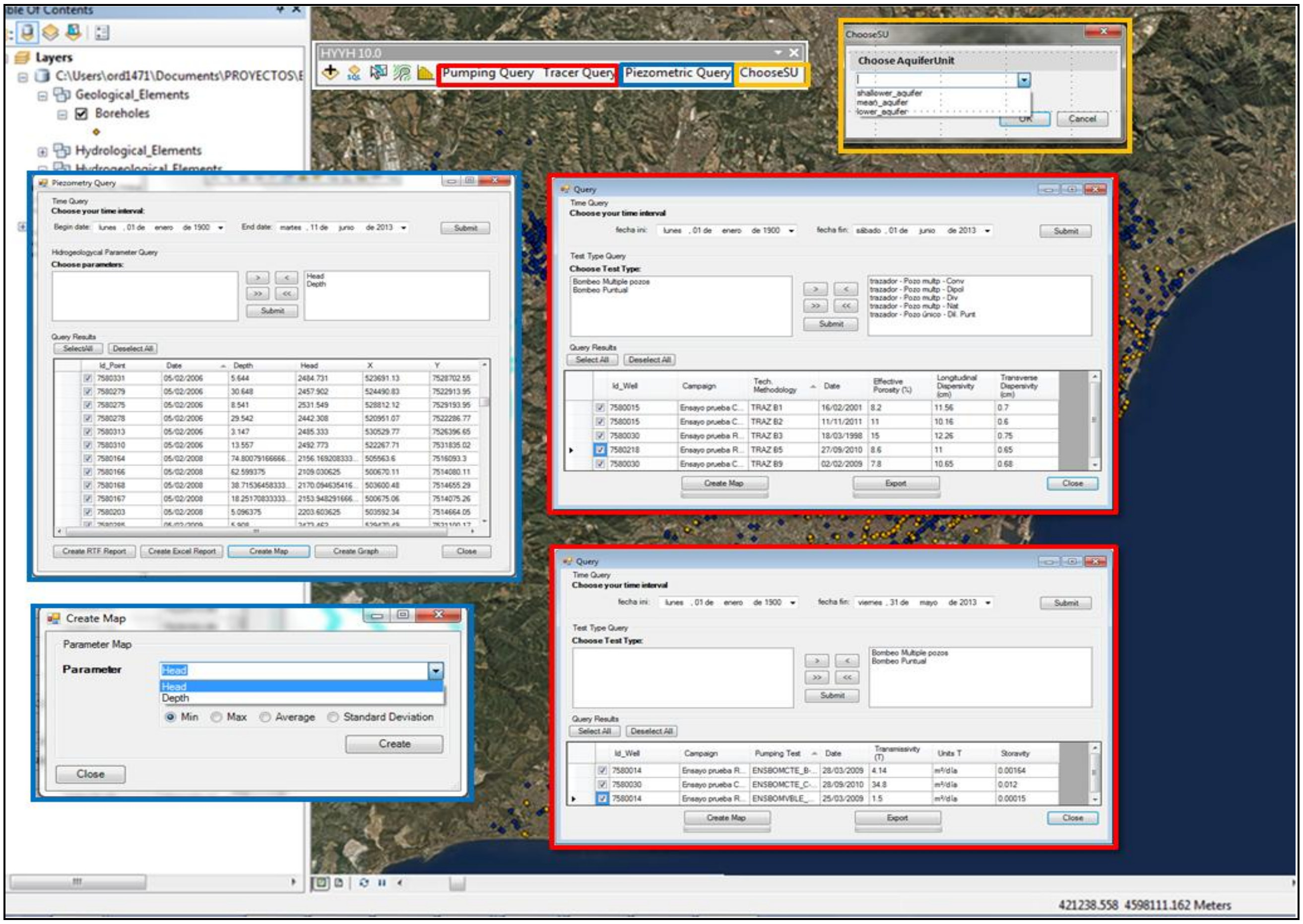

Figure 2: Toolbar HYYH integrated as an extension in ArcMap. It is composed of several commands: 1) inbuilt tools of ArcGIS (select, add data, statistical tools, etc) and three different multi-criteria query forms for interpreting hydrogeological analysis.

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