GIS database for groundwater integrated management

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Abstract: Groundwater resource represents a major component of the quantitative and qualitative integrated water resource management. In the context of the climate changes the surface water resource becomes insufficient in many times or too expensive even within complex hydrotechnical schemes. Consequently groundwater resource is extremely valuable for drinking water and other demands for clean water. In order to have an efficient management, an integrated approach is needed taking into consideration all aspects that are related to groundwater resource. GIS offers tools for such an objective like an Enterprise geodatabase unitary structure. As EU member Romania has to adopt and apply EU regulations including technology (like spatial data formats). This paper presents a standard for storage of data regarding groundwater management at national level. A case study based on this approach is presented.

Key-Words: Geodatabase, integrated groundwater resource management, GIS, SDI, conceptual data model, pollution

1 Introduction
Integrated management of water resources is one of the most important preoccupations in the context of a growing water demand. The water need for the population and the industries developed around the main urban areas cannot be covered only from one resource. Though complex water schemes are put into work for covering the water demand. Usually these schemes include groundwater as a valuable resource because of its volume of water and also of its very good quality. The exploitation of such resources must be done with great care because there is a high risk of contamination – a process which is reversible in a long period of time. An integrated management approach is needed in order to asses all components of a system that include groundwater as a resource.

In this context the building of a GIS database can be the key element for an integrated management of groundwater resource. This allows for a unitary storage and an easier way of accessing data at Enterprise level in one location and in a specified format. Almost every important institution used to have its own database, but these databases weren’t connected and data were stored in different formats according to each profile institution. At present Romania as a EU country has to adopt European legislation regarding the spatial data infrastructure(SDI)-INSPIRE [1] Directive . This means building a database structure, which should be general enough to respond to all institution needs and specialized at the same time in order to correspond to each particular institution profile activity. A unitary database structure leads to a unitary workflow. Thus analysis results can be provided in a standard form accessible by all interested stakeholders.

2 Conceptual data model
This paper will present an Enterprise GIS database structure for the Romanian context regarding groundwater resource.
This geodatabase was populated with data from Fagaras area, in Romania. The proposed database structure includes all relevant data regarding groundwater resource, exploitation and observation measurements.

Building a GIS database implies several steps to be followed. The first and the most important one is the creation of a conceptual data model which determines exactly the data that would be stored in the database, in what format (spatial or tabular data), the relationships between every component and the metadata [2].

For the spatial data, the geometrical representation and storage must be decided prior to building the geodatabase. This is done by taking into account the scale criteria and the importance of each individual object.

A conceptual data model (CDM) is a diagram organized in a logical structure. The CDM for the groundwater geodatabase was build in UML language using MS Visio software (Fig. 1) and includes modules, objects and attributes that characterize the objects.

![Fig. 1. Conceptual data model for groundwater GIS database](image)

The proposed structure database from the CDM is formed by seven modules each having interrelated object components: *Aquifers*, *Hydro geological basin*, *Measurements*, *River network*, *Pollution*, *Works* and *Settlements*. The main morphological unit for characterizing the aquifers are the groundwater bodies which are stored as polygons and represent the central object within *Aquifers* module. All other components like wells, hydro geological cross sections, lithological cross sections are connected to the *groundwater bodies* object. The *wells* are characterized by hydro geological, hydrochemical and geological parameters. In Romania there are several types of wells depending on their purpose; they are included in two monitoring programs: operation and monitoring. In order to cover this measured data properly, a *Measurement* module was included. The measured indicators were separated in two categories: quantity (water level and discharge) and quality (e.g. nitrates).

An object, *limit value* stored in this module as well. It is a tabular object which contains limit values for the quality indicators that allow different monitoring programs to assess groundwater quality [3]. Data regarding pumping tests are also included in the model in order to store the characteristic curves for each individual well. Tracer tests data are stored offering information on the hydrodispersive parameters of the aquifer.

There is usually a tight relation between the aquifers and the river network regarding flow exchange in two directions: aquifer feeds the river or the river feeds the aquifer. In order to assess these relations the *River network* module was included in the conceptual model with the following main objects: river network and cross sections (to be used in the hydraulic computations for coupling surface water and groundwater models).

The module *Hydro geological basin* includes information about the basin dimensions and is related to the *land cover* object.

As stated before the exploitation of the groundwater resource is an important task as there is a high risk of pollution. For this reason the *Pollution* module was included in the CDM containing both point and diffuse pollution sources as well as polluted areas around big industrial platforms.

The module *Works* include data about the industrial platforms, water intakes and treatment plants which are close related to the *Pollution* module.

Last but not least the social factor was introduced in the model by the *Settlement* object. The settlements can be viewed from two different perspectives:
- as pollution generator (chemical loads, accidental pollution)
- as groundwater user, possibly affected by pollution (industry or other point sources).

Each object in the conceptual data model is characterized by a unique identifier. This allows the exact identification of the object in the geodatabase and the creation of different types of relationships between them: one to one, one to many or many to many.
3 Groundwater geodatabase creation

Once build the conceptual data model is transposed in a ESRI geodatabase structure (Fig.2):

![Fig. 2. Part of geodatabase structure for groundwater resource management](image)

The modules from the CDM correspond to Feature Datasets in the GDB, each individual object is transposed into Feature Classes or tables and relationships between the objects inside a module or between different modules are build in a similar way between the geodatabase components.

A geodatabase dictionary was created for facilitating the geodatabase population.

The purpose of this geodatabase is data harmonization process within SDI for groundwater resource management. This process facilitates an easy use of the data for mathematical modeling of the aquifer in order to reveal the groundwater dynamics and to assess the pollution of groundwater from the industrial platforms. Mathematical models require different data and sometimes different geometry or time scale formats. It is not convenient to store individual sets of data compliant to each modeling program, but to use needed data from one single database. Most of the numerical models for groundwater simulation use spatial data through direct import functionalities or by making simple data conversions from GIS format. The results of the modeling can be also stored in the geodatabase, which allows for georeferenced maprepresentations and reports.

Data regarding groundwater characteristics from the industrial platform of Chemical Plant in Fagaras area (Romania) were entered in the geodatabase.

4 Case study

Olt river is the main water course crossing the Fagaras area. From Fagaras mountains there are lots of springs which are drained by Olt river and which form a very dense river network (0.7 – 1 km/km²) (Fig.3).

![Fig.3. River network in Fagaras area](image)

From the hydrogeological point of view Fagaras hydrostructure is characterized by four different areas:

a. a recharge area at the boundary of the mountain area, where massive infiltrations from the river or precipitation are taking place
b. an area where the water levels in the shallow aquifer are lower than the water level in Olt tributaries
c. a downstream area where the shallow aquifer feeds the river network
d. a drainage area close related to Olt meadow.

Two hydrogeological cross sections can be seen (Fig.4), the first being along the main flow direction from South to North (I-I’) (Fig.5) and the second partly perpendicular to the first one and partly along the main flow direction (II-II’) (Fig.6). Both cross sections are situated in the central part of the area of interest where the shallow aquifer reaches 40-50 m depth and a hydraulic conductivity of 25m/day.

![Fig.4. Position of the two hydrogeological cross sections](image)
A GMS model was created for an area of approximately 250 km$^2$ situated between Iazul and Sambata rivers. For the calibration of the hydrogeological parameters the piezometric surface was generated using the groundwater levels measured in the observation wells.

The boundary conditions were introduced based on the piezometric surface in the North of the domain at the limit with Fagaras Mountains. Both West and East limits corresponding to Iazul and Sambata rivers were considered impervious, while at the South limit measured water levels in Olt river were introduced. Olt tributaries inside the modeled area have the channel bottom formed of sands and gravel, which leads to very high discharge exchanges with the aquifer. Consequently the water level along these tributaries was introduced as boundary conditions as well. The percolation was evaluated at about 100 mm/year, which corresponds to an input discharge of 790 l/s. The piezometric surface after calibration can be seen in Fig. 7 [4].

The hydraulic conductivities after calibration have values between 10-15 m/day in the North and South areas and between 60-80 m/day in the central and North-West part of the domain. Based on these results the effects of the diffuse pollution from Fagaras industrial platform were simulated. The GMS model was run for 1 year, respectively 10 years (Fig.8) scenarios.

The pollution front evolves to the North-West and not to the North according to flow lines because of a strong drainage of Racovita river. It was estimated that the pollutant transport time through the aquifer before reaching Racovita river is about 50 years. Thus, the pollutant reaches Olt river not by the direct transport through the aquifer but mainly by Racovita river.

All these results were introduced in the geodatabase and represent valuable data for further GIS analysis on Fagaras area. In a similar way data from other industrial platforms in Romania were introduced in the present geodatabase.

### 4 Conclusions

At present, the spatial information is divided into subsets according to the institutions profile and it has different sources and formats. Spatial databases are duplicated by each of the major institutions through partial overlap of the data. These problems prevent from an easy identification, access and use of spatial data that still are available. EU established a law regarding spatial data infrastructure which has to be applied by the member states. Prior to applying any regulation each country has to provide its own SDI for different domains. This paper described a SDI for integrated groundwater resource management.
The proposed Enterprise geodatabase structure contains physical data (e.g. groundwater bodies, wells, river network, settlements) and measured data (e.g. water levels, intake discharge, quality indicators) related through different types of relationships. The modeling results are also stored in the same geodatabase in order to maintain the SDI in a unique location.

As a case study, simulation results regarding the groundwater pollution from the industrial platform in Fagaras area were introduced in the geodatabase.

The information related to existing data (metadata) is also introduced in the geodatabase in a unitary format according to SDI regulations. Additionally a data dictionary was created as a guide for geodatabase population.

A unitary storage of data has many advantages when creating mathematical models: no need for complicated preprocessing of data and use of spatial data import functionalities. The modeling programs can use and access data easier from one geodatabase source that provides all needed information.

References: