Spatial data infrastructure for groundwater integrated management with application in three case studies in Romania

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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 resources become scarce or too expensive even within complex hydraulic 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. Three different case studies based on this approach are presented in order to reveal the use of a common data source for different models and analysis.

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

1 Introduction

A spatial data infrastructure (SDI) is a set of spatial data, metadata, tools (hardware and software) and users which interact in order to offer an easy, flexible and efficient access to spatial data from different sources. "Metadata is a vital tool for management of spatial data and plays a key role in any spatial data infrastructure (SDI) initiative [1]. It provides users of spatial data with information about the purpose, quality, actuality and accuracy and many more of spatial datasets. Metadata performs crucial functions that make spatial data interoperable [2]. According to EU regulations each EU member state adopted INSPIRE Directive into its own legislation [3]. INSPIRE is a European Commission initiative to build a European SDI beyond national boundaries and ultimately the United Nations Spatial Data Infrastructure. Romania, as EU member state has to create a SDI for all major domains, including the management of water resources. The Ministry of Environment and Ministry of Regional Development and Housing are responsible to coordinate the creation of SDI-s in Romania. In order to achieve the goals of spatial data harmonization proposals from research institutes and universities were requested.

Integrated management of water resources is one of the most important preoccupations in the context of a growing water demand and climate changes. The water demand for the population and the industries developed around the main urban areas cannot be covered only from one source. 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 usually 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 includes groundwater as a resource.

The authors developed a SDI for groundwater data management to be used at national level. The key element of this SDI is a GIS database. Its structure was created taking into account all objects regarding groundwater resource management at national level. Thus it is destined to be used by all institutions that operate in this activity domain.

In the past years GIS developed consistently becoming very accessible and spread in many institutions [4]. The easy access to GIS determined specialists to create their own databases and workflow, which is considered a good background for the new demands. Still these databases weren’t connected and data were stored into individual sets of data and in different formats according to each profile institution.

The proposed database structure within the SDI for groundwater resource was thought to 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. Creating a SDI is in fact a process of data harmonization. This process facilitates an easy use of the data in order to reveal the groundwater dynamics and to assess and prevent further pollution of groundwater from the economical agents and settlements.

The database structure consists of a conceptual data model [5][6] which was transposed into a Geodatabase (GDB). Further three different case studies will be presented in order to reveal the use of this core SDI for different purposes. The most relevant results of the analysis are also stored into the unitary structure of GDB. What should be stressed is that this approach leads to Geodatabase enrichment with processed data. Further these data allow for more complex GIS analysis and assessments to be done based on reports and georeferenced map representations [7].

For modeling proposes the loose connection [5] between the GDB and the models are recommended because of the following reasons:

-it allows for independent choice of the modeling software

-it prevents from data blocking into already built models that cannot be updated in agreement with the new developments

-it is less expensive and less time consuming

-it allows for already developed platforms (e.g. OpenMI) to integrate results from different models created with different modeling software [8]

2 Conceptual data model

The proposed database structure includes all relevant data regarding groundwater resource monitoring and management.

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 makes an inventory of the data that would be stored in the database, the storage format (spatial or tabular data), the relationships between every component and the metadata [9].

For the spatial data, the geometrical representation and storage must be decided prior to building the geodatabse. This is done by taking into account the scale criteria and the importance of each individual object. Also an unitary data projection system has to be chosen in order to ensure the data harmonization.

A Conceptual Data Model (CDM) is a diagram organized in a logical structure. The CDM for the groundwater Geodatabase was built in UML language using MS Visio software and includes modules, objects and attributes that characterize the objects.

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*, *Water Works and Infrastructure* 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 operation and monitoring wells, hydrogeological cross sections, lithological cross sections are connected to the *groundwater bodies* object. The *wells* are characterized by hydrogeological, hydrochemical and geological parameters. In order to cover properly the measured data, a *Measurements* module was included in the CDM. The measured indicators were separated in two categories: quantity (water level and discharge) and quality (e.g. nitrates concentrations).

Limit values object was stored as tabular data in this module in order to assess the monitoring wells within different monitoring programs (e.g. quantitative monitoring, qualitative monitoring – survey and operation) [10]. 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 support information for the assessment of the hidrodispersive parameters of the aquifer.

There is usually a tight relationship between the aquifers and the river network regarding flow exchange in both senses: aquifer feeds the river or the river feeds the aquifer. In order to asses these relationships 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 *Hydrogeological basins* mo Figure1. Conceptual data model of the groundwater Geodatabase dule includes information about the basin extension and is related to the *land* use 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 *Water Works and Infrastructure* includes data objects about the industrial platforms, water intakes and treatment plants which are closely related to the *Pollution* module.

Last but not least the social factor was introduced in the model by the *Settlements* 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).

The conceptual data model diagram can be seen in Fig 1.

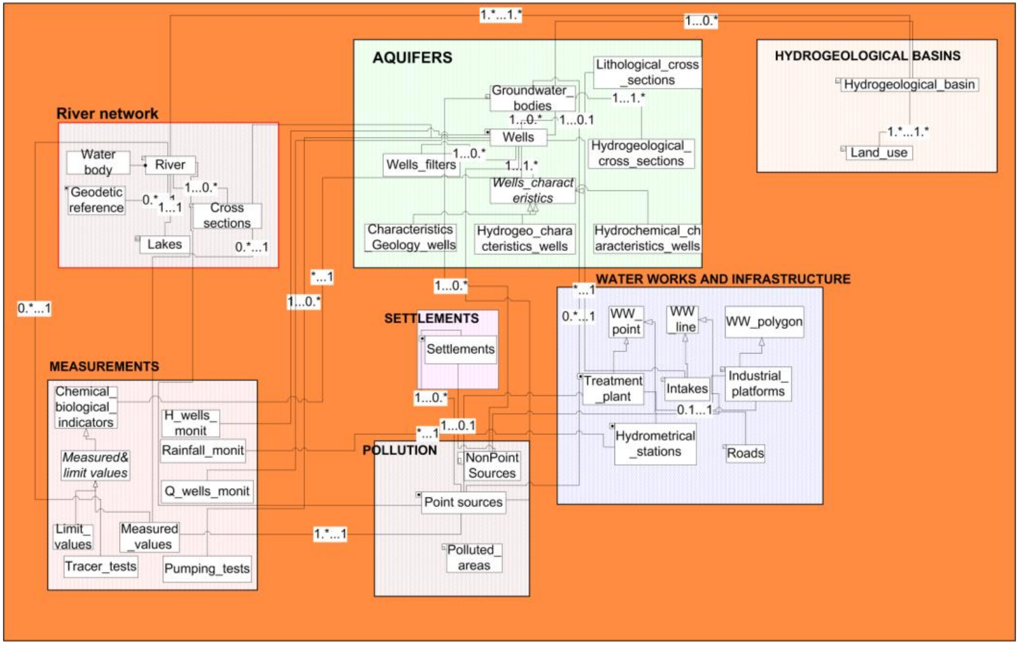
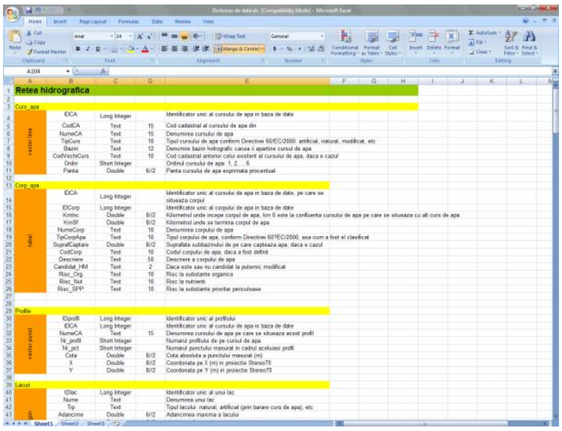


Figure 1. Conceptual Data Model diagram

Each object in the conceptual data model is haracterized 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. A data dictionary for the CDM was built explaining each object meaning, presenting all attributes that characterize each spatial or non spatial object and the associated metadata. It also facilitates the Geodatabase population by different users with data from several locations (Fig. 2).



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	A	B	C	D	E
1	Retea hidrografica				
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5		CodCA	Text	15	Cod cadastral al cursului de apa din
6		NumeCA	Text	15	Denumirea cursului de apa
7		TipCurs	Text	10	Tipul cursului de apa conform Directivei 60/EC/2000: artificial, natural, modificat, etc
8		Bazin	Text	12	Denumire bazin hidrografic caruia ii apartine cursul de apa
9		CodVechiCurs	Text	10	Cod cadastral anterior celui existent al cursului de apa, daca e cazul
10		Ordin	Short Integer		Ordinul cursului de apa: 1, 2, ...6
11		Panta	Double	6/2	Panta cursului de apa exprimata procentual
12					
13	Corp_apa				
14	tabel	IDCA	Long Integer		Identificator unic al cursului de apa in baza de date, pe care se situeaza corpul
15		IDCorp	Long Integer		Identificator unic al corpului de apa in baza de date
16		KmInc	Double	8/2	Kilometrul unde incepe corpul de apa, km 0 este la confluenta cursului de apa pe care se situeaza cu alt curs de apa
17		KmSf	Double	8/2	Kilometrul unde se termina corpul de apa
18		NumeCorp	Text	10	Denumirea corpului de apa
19		TipCorpApa	Text	10	Tipul corpului de apa, conform Directivei 60?EC/2000, asa cum a fost el clasificat
20		SuprafCaptare	Double	8/2	Suprafata subbazinului de pe care capteaza apa, daca e cazul
21		CodCorp	Text	10	Codul corpului de apa, daca a fost definit
22		Descriere	Text	50	Descriere a corpului de apa
23		Candidat_HM	Text	2	Daca este sau nu candidat la puternic modificat
24		Risc_Org	Text	10	Risc la substante organice
25		Risc_Nut	Text	10	Risc la nutrienti
26		Risc_SPP	Text	10	Risc la substante prioritar periculoase
27					
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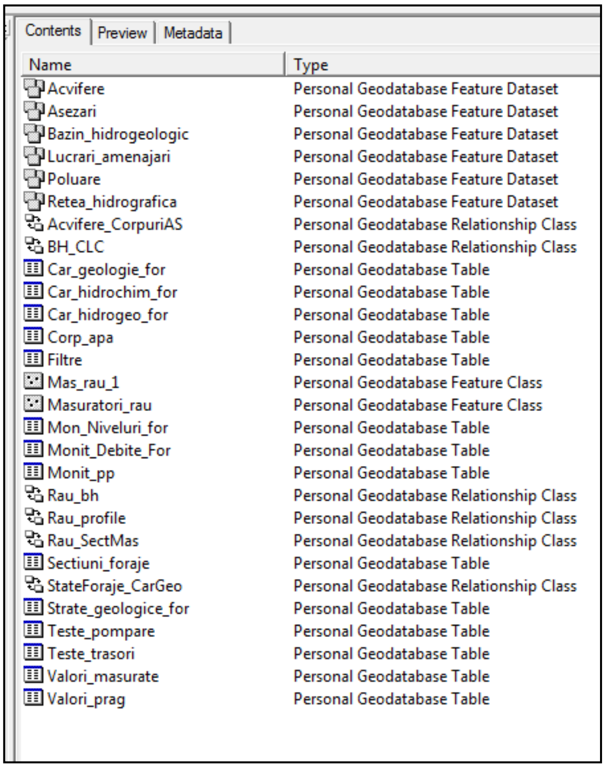
29	Profile				
30	vector punct	IDprofil	Long Integer		Identificator unic al profilului
31		IDCA	Long Integer		Identificator unic al cursului de apa in baza de date
32		NumeCA	Text	15	Denumirea cursului de apa pe care se situeaza acest profil
33		Nr_profil	Short Integer		Numarul profilului de pe cursul de apa
34		Nr_pct	Short Integer		Numarul punctului masurat in cadrul aceluiasi profil
35		Cota	Double	8/2	Cota absoluta a punctului masurat (m)
36		X	Double	8/2	Coordonata pe X (m) in proiectie Stereo70
37		Y	Double	8/2	Coordonata pe Y (m) in proiectie Stereo70
38					
39	Lacuri				
40		IDlac	Long Integer		Identificator unic al unui lac
41		Nume	Text		Denumirea unui lac
42		Tip	Text		Tipul lacului: natural, artificial (prin barare curs de apa), etc
43		Adancime	Double	6/2	Adancimea maxima a lacului

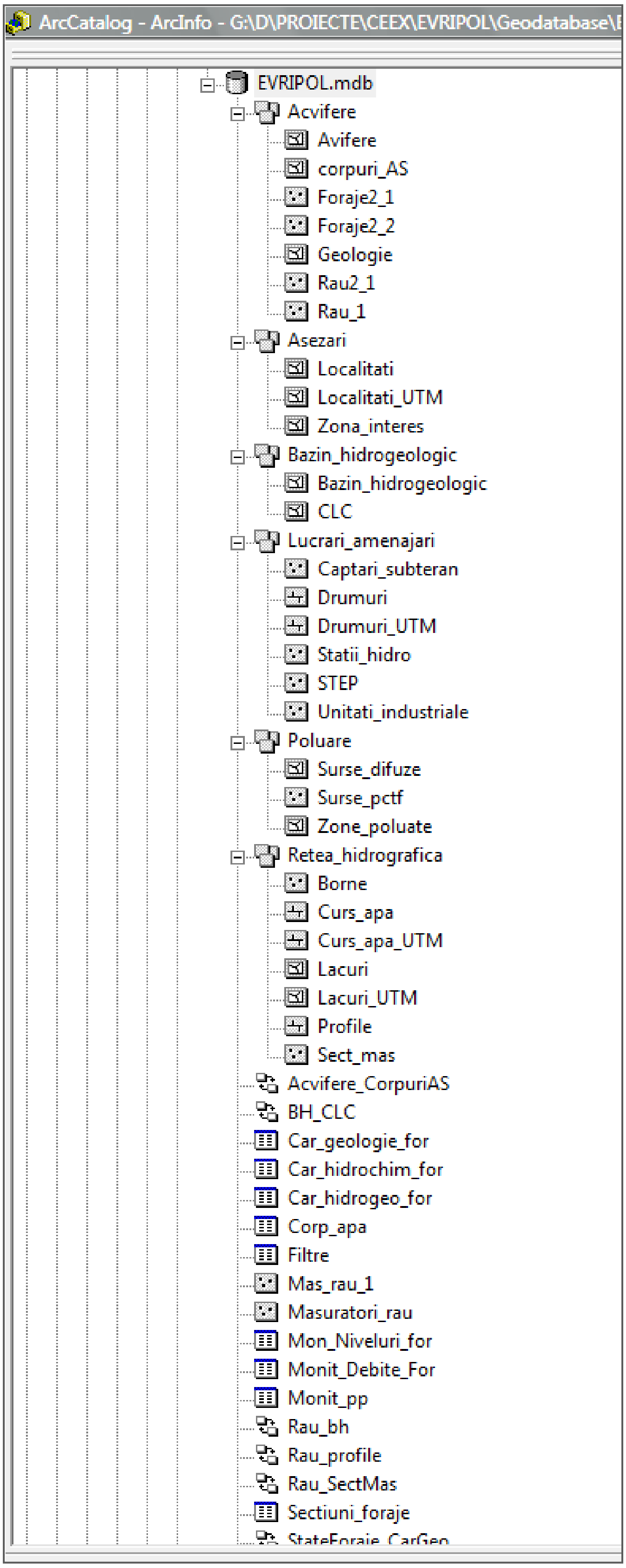
Figure 2. Data dictionary

3 Groundwater Geodatabase structure

Once built the Conceptual Data Model is transposed into an enterprise Geodatabase structure (Fig.3) and populated with data:



Name	Type
Acvifere	Personal Geodatabase Feature Dataset
Asezari	Personal Geodatabase Feature Dataset
Bazin_hidrogeologic	Personal Geodatabase Feature Dataset
Lucrari_amenajari	Personal Geodatabase Feature Dataset
Poluare	Personal Geodatabase Feature Dataset
Retea_hidrografica	Personal Geodatabase Feature Dataset
Acvifere_CorpuriAS	Personal Geodatabase Relationship Class
BH_CLC	Personal Geodatabase Relationship Class
Car_geologie_for	Personal Geodatabase Table
Car_hidrochim_for	Personal Geodatabase Table
Car_hidrogeo_for	Personal Geodatabase Table
Corp_apa	Personal Geodatabase Table
Filtre	Personal Geodatabase Table
Mas_rau_1	Personal Geodatabase Feature Class
Masuratori_rau	Personal Geodatabase Feature Class
Mon_Niveluri_for	Personal Geodatabase Table
Monit_Debite_For	Personal Geodatabase Table
Monit_pp	Personal Geodatabase Table
Rau_bh	Personal Geodatabase Relationship Class
Rau_profile	Personal Geodatabase Relationship Class
Rau_SectMas	Personal Geodatabase Relationship Class
Sectiuni_foraje	Personal Geodatabase Table
StateForaje_CarGeo	Personal Geodatabase Relationship Class
Strate_geologice_for	Personal Geodatabase Table
Teste_pompare	Personal Geodatabase Table
Teste_trasori	Personal Geodatabase Table
Valori_masurate	Personal Geodatabase Table
Valori_prag	Personal Geodatabase Table



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    - corpuri_AS
    - Foraje2_1
    - Foraje2_2
    - Geologie
    - Rau2_1
    - Rau_1
  - Asezari
    - Localitati
    - Localitati_UTM
    - Zona_interes
  - Bazin_hidrogeologic
    - Bazin_hidrogeologic
    - CLC
  - Lucrari_amenajari
    - Captari_subteran
    - Drumuri
    - Drumuri_UTM
    - Statii_hidro
    - STEP
    - Unitati_industriale
  - Poluare
    - Surse_difuze
    - Surse_pctf
    - Zone_poluate
  - Retea_hidrografica
    - Borne
    - Curs_apa
    - Curs_apa_UTM
    - Lacuri
    - Lacuri_UTM
    - Profile
    - Sect_mas
  - Acvifere_CorpuriAS
  - BH_CLC
  - Car_geologie_for
  - Car_hidrochim_for
  - Car_hidrogeo_for
  - Corp_apa
  - Filtre
  - Mas_rau_1
  - Masuratori_rau
  - Mon_Niveluri_for
  - Monit_Debite_For
  - Monit_pp
  - Rau_bh
  - Rau_profile
  - Rau_SectMas
  - Sectiuni_foraje
  - StateForaje_CarGeo

Figure. 3. Geodatabase structure for groundwater resource management

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 built in a similar way between the Geodatabase components.

4 Case studies

This Geodatabase was populated with data from several case studies, which will be described as following in the paper: Fagaras area, Constanta shore area and Pitesti area in Romania.

The mathematical modelling of groundwater flow and transport for the 3 case studies was achieved using GMS package [11][12].

The conceptual data model in GMS shows that both input data and results are stored in the GDB (Fig. 4):

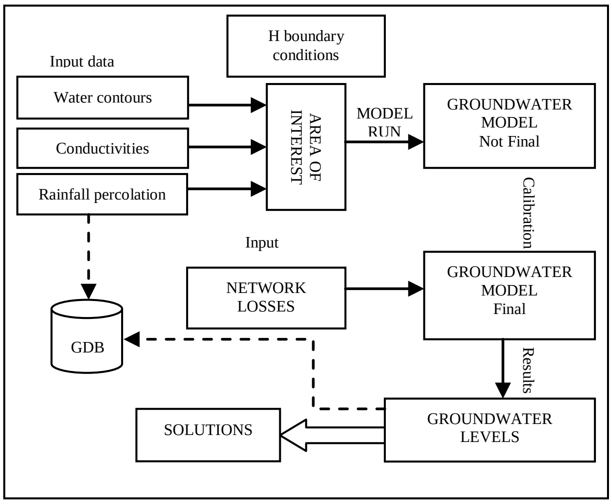


Figure 4. Conceptual data model in GMS

4.1. Industrial platforms impact

The first case study is referring to the point source pollution due to big industrial platforms and its effects upon groundwater safety use. Models for pollution assessment from different industrial platforms in Romania (Fagaras platform, Alum industrial paltform-Slatina, Oltchim industrial platform-Ramnicu Valcea), were calibrated and their results were introduced in the present Geodatabase [13].

Olt river is the main water course crossing the Fagaras area (mountainous area in central Romania). 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/km^2) (Fig. 5).

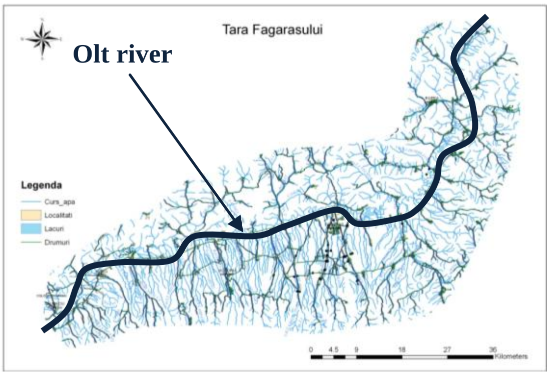


Figure 5. River network in Fagaras area

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 levels in Olt tributaries

c. a downstream area where the shallow aquifer feeds the river network

d. a drainage area close related to Olt meadow and Olt river.

Two hydrogeological cross sections that reveal these characterizations can be seen in Fig. 6, the first being along the main flow direction from South to North (I-I’) (Fig. 7) and the second partly perpendicular to the first one and partly along the main flow direction (II-II’) (Fig. 8). 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:

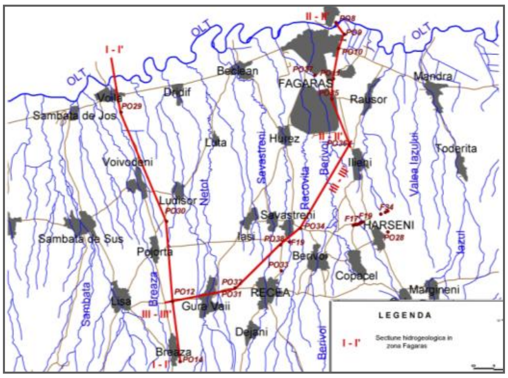


Figure 6. Position of the two hydrogeological cross sections

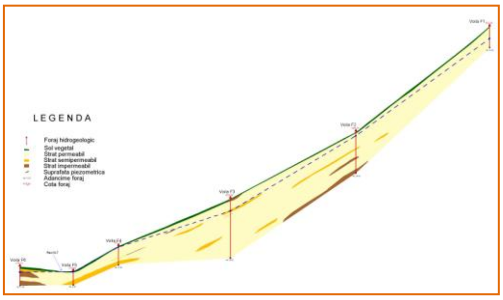


Figure 7. Cross section I-I’

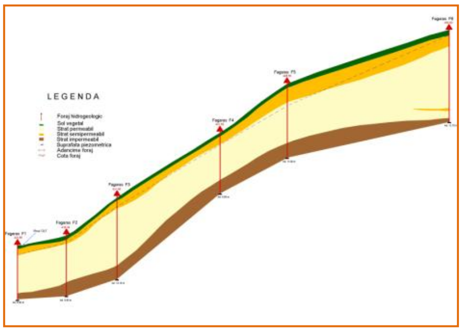


Figure 8. Cross section II-II’

The extension of GMS model for Fagaras covers an area of approximately 250 km^2 between Iazul and Sambata rivers. Input data for the model were extracted from Geodatabase structure as shapefiles and imported directly into GMS. The calibration of the hydrogeological parameters was based on the groundwater levels measured in the observation wells.

Based on the piezometric map values from the Northern part of the domain at the limit with Fagaras Mountains the boundary conditions were defined. Both Western and Eastern limits corresponding to Iazul and Sambata rivers were considered impervious boundaries, while at the Southern 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. 9 [13]:

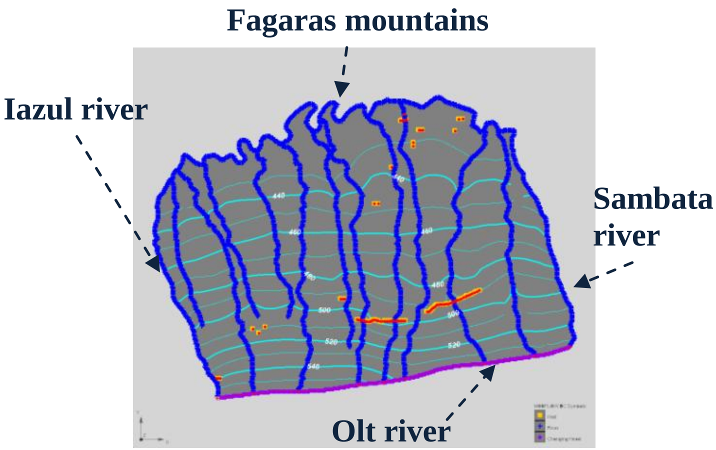


Figure 9. Piezometric surface after the calibration of the model

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

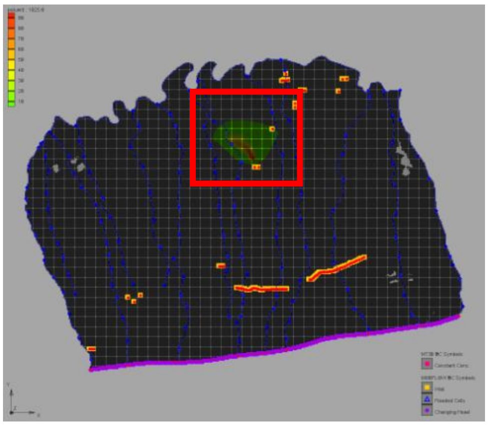


Figure 10. The evolution of the polluted area in the 10 years scenario

The pollution front evolves to the North-West because of the 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 as spatial objects and represent valuable data for further GIS analysis on Fagaras area.

4.2 Instability of the terrace slope in Constanta harbor area

The second case study refers to analyzing the causes of instability of the terrace along the shoreline in Constanta harbor area and proposing solutions for remediation. The lack of rehabilitation works of the water supply network led to increasing leakage in the shallow aquifer. This phenomenon determined the increase of groundwater level causing instabilities of the terrace slope. Additionally it is assumed that the extension and modernization of Constanta harbor caused several processes of soil compaction and the drainage towards the sea was diminished. The long term effects of these causes led to an artificial increase of the groundwater level on the terrace producing landslides (Fig. 11).

Figure 11. Landslide along the shoreline in Constanta port area

Due to the soil type (red lime), the vegetation with developed root system cannot be found in the area. Only small bushes grow from place to place having no role of stabilizing the slopes. As a result of the groundwater level increase wet areas can be identified along the slopes; also reed is growing proving that the groundwater level is high (Fig. 12).

Figure 12. Reed along the slopes indicating high groundwater level

The above pictures were stored as hyperlinks to different points of interest along the slopes together with other collected data concerning previous sliding and wet areas.

The losses from the water supply network are the main cause of the compaction of tens of centimeters in an area with blocks of flats on the terrace. As a consequence, the safety of the inhabitants might be put into danger.

In the analyzed area the rainfall is reduced (350-400 mm/year), having little influence on the hydrogeological regime in comparison with the quantity of water from the network losses.

The needed data for building the model are the following: wells, location of the water supply network in the terrace, topographic data (contours and elevation points) including Digital Terrain Model, initial groundwater levels, hydraulic conductivities, groundwater level on the boundary of the domain, average multiannual rainfall data.

The GMS model was calibrated using a set of data from 1996 and after calibration it was run with data from 2007. The latter set of data included also the losses from the network into the aquifer. Two scenarios were proposed, supposing 20% respectively 50% losses from the total flow in the water supply network.

The model geometry in GIS was imported directly in GMS; the extension of the model is 20.6 km^2 (Fig. 13). On the Western and Eastern limits of the domain groundwater levels of 40 m, respectively 0.2 m have been introduced as boundary conditions. Groundwater level boundary condition was entered at the intersection of the terrace slope with the beach.

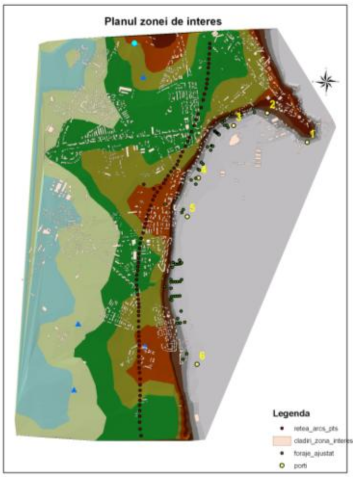
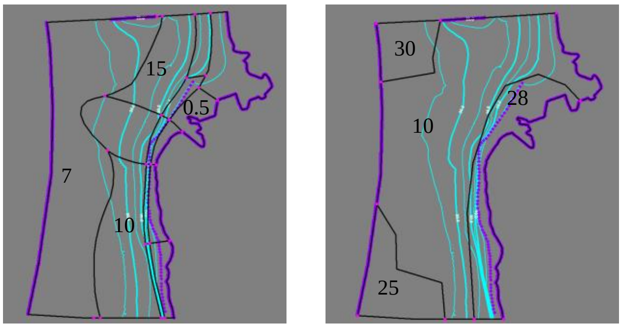


Figure 13. Model geometry in GMS imported from the Geodatabase

13 different areas with values for conductivity between 0.5 and 15 m/day (Fig. 14. a) and 4 areas for percolation with values between 10 mm/day (in the area with block of flats) and 30 mm/day (in the shore area) (Fig. 14 b.) were obtained through the process of calibration.



a. b.

Figure 14. a Conductivity areas after calibration
b. Recharge areas after calibration

Comparing final computed results with measured values differences between 7 cm and 1.22 m (Table 1and Fig. 15) were obtained.

Table 1

	X	Y	Np_Obs	Np_Calc	dH
1	789940.10	301024.10	30.00	29.93	-0.07
2	790323.63	300084.24	25.50	24.28	-1.22
3	790127.00	304367.00	33.20	33.53	0.33
4	791176.40	303759.90	19.10	18.40	-0.70

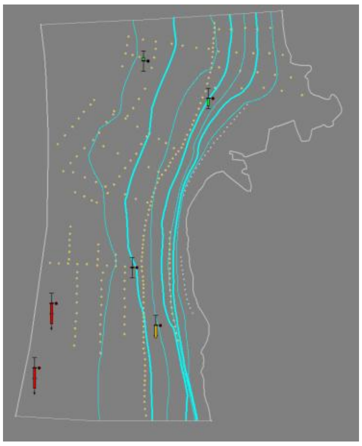


Figure 15. The piezometric errors of the calibrated model

Comparing the results from 1997 with the ones from 2007 it can be seen that the groundwater level has severely increased, fact which confirms the observations made along the terrace slope concerning vegetation and wet areas (Fig. 16).

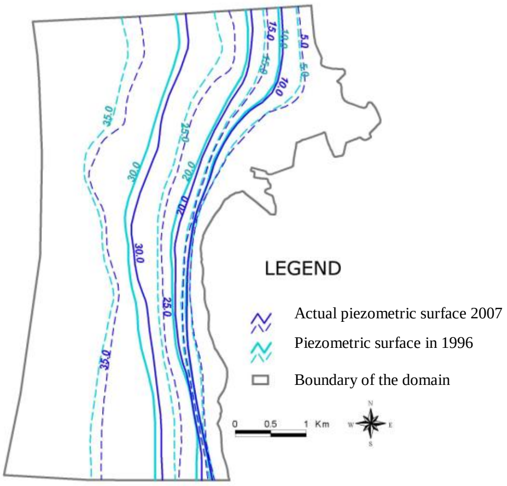


Figure 16. Groundwater levels in 1996 and 2007

As control measures for stabilizing the terrace slope the construction of 20 drainage wells was proposed in order to lower the groundwater level. The maximum discharge was set to 0.5 l/s for each well. This limited value is due to the fact that the lime loess soil can easily lead to pumps blockings and clogging of the wells. The drainage wells were constructed along the piezometric lines. The differences between groundwater levels before and after drainage system introduction are visible in Fig. 17.

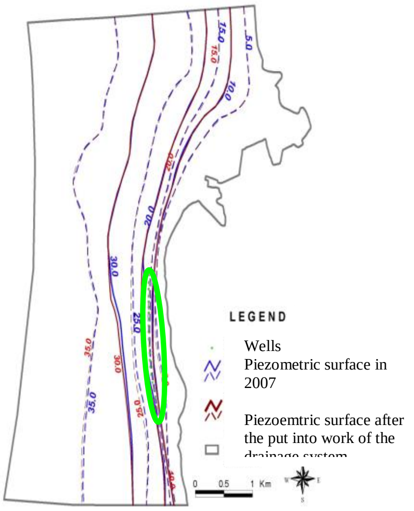


Figure 17. Groundwater levels in 2007 and after introducing the drainage system

4.3 Assessment of wells protection zone extensions in Pitesti area

The last example of case study is represented by the delineation of the protection area around the production wells of Pitesti water works (in the South of Romania – 60 km far from Bucharest capital). The drinking water quality is becoming a major challenge concern in the last years all over the world. [14]

Pitesti town is supplied with water not only from surface sources (Arges river – Budeasa reservoir, treated at Budeasa treatment plant), but also from the shallow aquifer located between the junction of the rivers Doamnei and Arges. Three batteries of production wells (Fig. 18) are able to provide a maximum discharge of about 145 l/s:

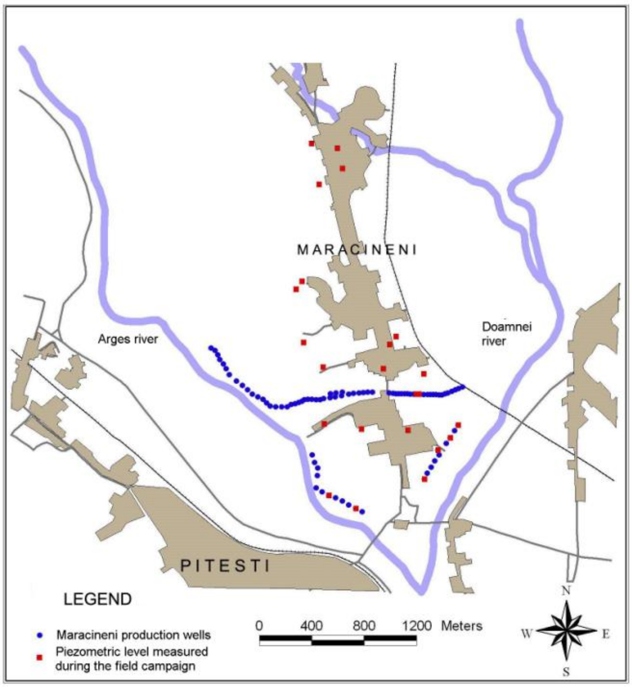


Figure 18. The distribution of the production wells batteries in Pitesti area

Presently, a discharge of only 53.35 l/s is continuously exploited from the aquifer. Graves and boulders, within sand mass, which appear frequently on the land surface, compose the shallow aquifer from the flood plain of the Arges and Doamnei rivers. Locally, a complex of clayey and sandy dusts covers these strata.

The hydrodynamic situation of the aquifer (Fig.19) was obtained after a field campaign when groundwater levels both in the domestic wells and in the water works of Maracineni were measured.

At the same time, the water levels in different locations of both Arges River and Doamnei River were determined using topographical landmarks. The shape of the piezometric lines shows the strong influence of the pumping wells of the water works:

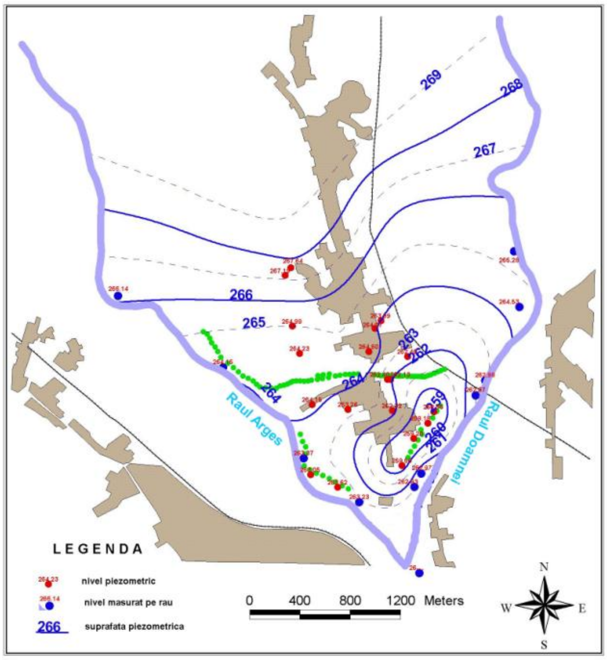


Figure 19. The hydrodynamics of the aquifer in the area of interest

The main problem at Maracineni water works is the lack of a protection zone properly defined. After 1990, houses were built in the close proximity of the production wells. Due to the lack of the sewerage system in the area, the danger of organic and bacteriologic pollution is very high.

The purpose of the mathematical modelling is the delineation of the protection area around the production wells. The computation was made in agreement with the principles stated in the “Special norms for the delineation of the protection areas” in force in Romania [15]. The protection areas thus determined, correspond to a transit time of 20 days (severe protection area), respectively 50 days (restricted protection area).

The model calibration was difficult because of the uncertainties concerning the input values (piezometric levels and water levels in the rivers); some of these values were measured in an additional field campaign, while others, inconsistent with the rest of the values, were eliminated.

The boundary conditions are as following:

- Dirichlet conditions (imposed head) on the upper limit of the flow domain
- Cauchy conditions (discharge dependent on hydraulic head) at the contact of the aquifer with Arges River
- Impervious limit in the upstream part of Doamnei River

- Cauchy conditions in the downstream part of Doamnei River
- Newman conditions (prescribed discharge) for each well of the water works.

During the calibration process, the hydrogeological parameters (Fig. 20) as well as the natural recharge values (Fig. 21) were derived. The model calibration was stopped when the difference between the computed and the measured piezometric values was less than 0.5 m.

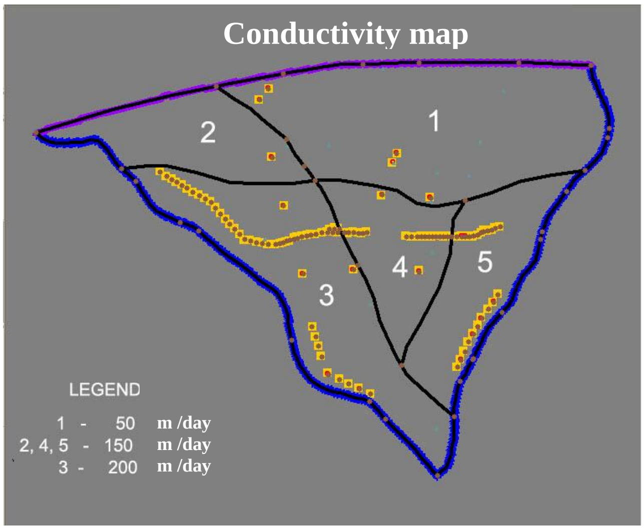


Figure 20. Areas with different hydraulic conductivities resulted after model calibration

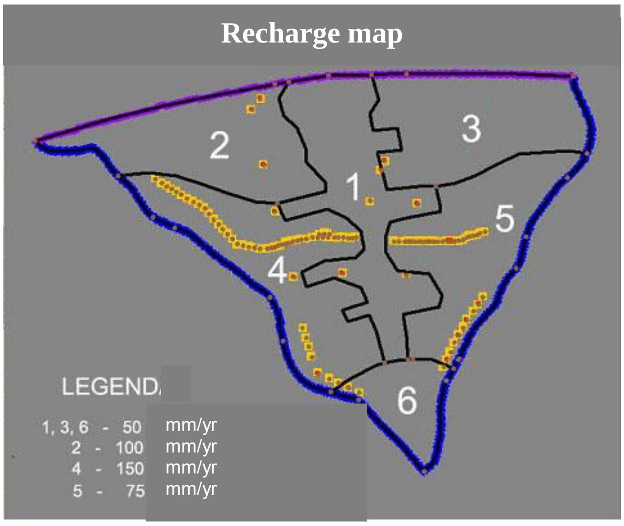


Figure 21. Areas with different natural recharge resulted after model calibration

The water balance scheme is presented in Fig. 22. The total discharge entered in the domain is equal with the output (118 l/s); the aquifer is supplied with water mostly from the upstream part of the domain (89 l/s).

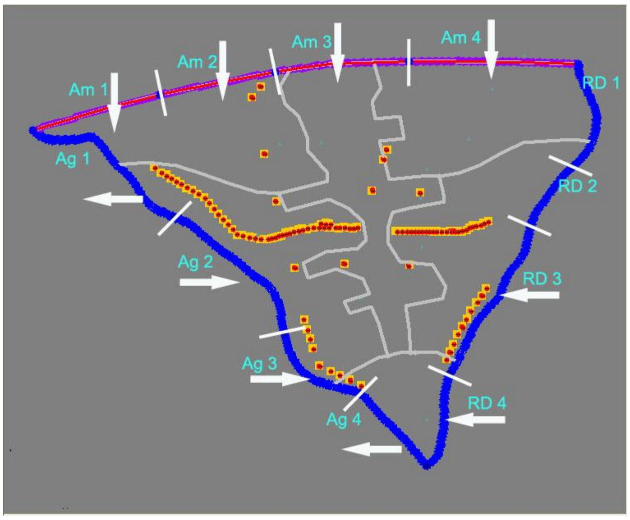


Figure 22. The water balance scheme in the area of interest

Once a calibrated hydrogeological model of the area of interest was obtained a transport model was built in order to assess the extension of the protection areas around the wells. Two hypotheses were taken into account [16]:

- considering of only the advection component of transport
- considering advection, dispersion and retardation processes

In the first hypothesis, the effective porosity determined through pumping tests (0.05) is quite small because of the local influence of very fine sediments. Using "Backtracking" procedure of GMS, simulations for 20 days and 50 days transit were performed. The protection areas can be seen in Fig. 23 and Fig. 24 [17].

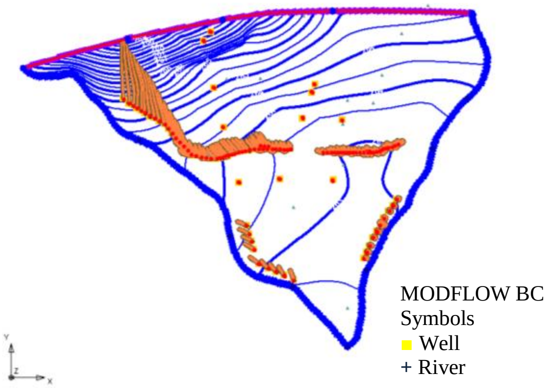


Figure 23. Severe protection area (20 days)

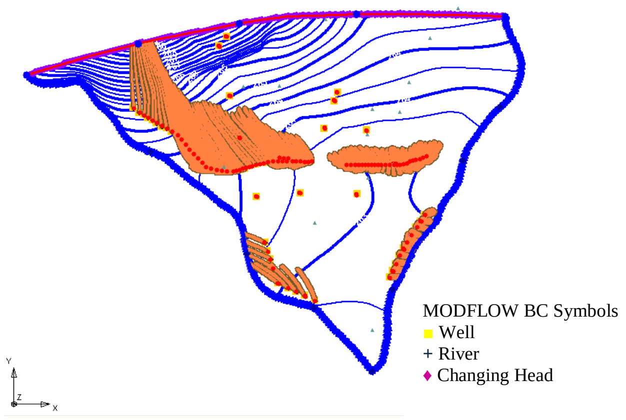


Figure 24. Restricted protection area (50 days)

In the second hypothesis a tracer test using fluoresceine was undertaken at the Doamnei river branch of Maracineni I water works in order to calibrate the transport parameters.

A local model with a refined mesh discretization was used for the transport simulations. As boundary conditions for the flow model, the imposed heads derived from the global model were used. Concentrations measured in the injection well represents the boundary conditions for the transport simulations. During the calibration process, it became obvious that not only advection and dispersion processes have to be modelled, but also retardation and molecular diffusion. The explanation is related to the presence of small particles in the solid matrix, formed by gravels and course sands, creating a double porosity medium.

The isochrones corresponding to the standard travel times (20 days and 50 days) can be visualized in Fig. 25.

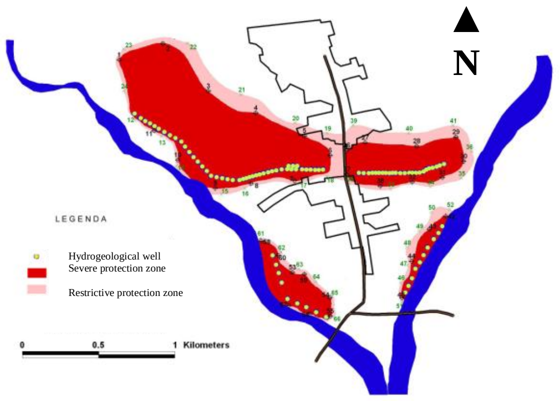


Figure 25. Delineation of the protection zones for 20 and 50 days

Due to the high gradients of the groundwater surface and the small values of the effective porosity, the protection zones are very extended, covering areas where houses (without sewerage system) are already built. Under these circumstances, the shallow aquifer is threatened by organic and bacteriological pollution in the near future. Quite soon, the water from this aquifer can no longer be used for water supply, and another water source must be found

4 Conclusions

The development of GIS and spatial data development, exchange and analysis in the last years created the need for standardization [18]. The SDIs represent the answer to this increasing need.

The proposed Geodatabase structure is the main component of a SDI for groundwater resource management. This SDI can solve the problem of spatial data standardization consisting of spatial information divided into subsets according to the institutions profile, having different sources and formats, and the information redundancy (spatial databases are duplicated by each of the major institutions through partial overlap of the data). This problem prevent from an easy identification, access and use of spatial data that are available.

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 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.

The three case studies which were presented have different purpose and have the areas of interest located in different parts of Romania. Although the stakeholders belong to different institutions, the use of a unique data source was possible and easier than before because of the harmonization of the data through a Geodatabase structure.

Processed data was stored in the same Geodatabase as the raw data, opening a new direction for further analysis and sharing information within hydrogeology specialists.

References:

[1] J. Irigoyen, E. Coll, J.C. Martinez, undamental Cartography Production On SDI Framework, WSEAS Conferences, Buenos Aires, Argentina March 1-3, 2005, Paper 503-174.pdf

[2] Abbas Rajabifard, Mohsen Kalantari and Andrew Binns, SDI and Metadata Entry and Updating Tools, *Global Spatial Data Infrastructure Association Conference*,2009

[3]Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007

[4] Pantelis Soupios, Apostolos Sarris, Giorgos Papadakis, Michalis Papazoglou, Filippos Vallianatos, John P. Makris, Compilation of a Relational Digital Database for Monitoring and Management of Geo-Environmental Data in Crete Region, WSEAS International Conference on Engineering Education Athens, Greece, July 8-10, 2005, Paper 507-122.pdf

[5] Radu Gogu, Guy Carabin, Vincent Hallet, Valerie Peters and Alain Dassargues, GIS-based hydrogeological databases and groundwater modelling, *Hydrogeology Journal*, Volume 9, Number 6 / December, 2001

[6] Philippe Orban, Ileana_Cristina Popescu, Ingrid Ruthy, Serge Brouyere, Database and general modeling concepts for groundwater modeling in the Squash Project, Hidrotehnica, volume 49, Nr. 9-10, 2004, Pages 51-57

[7] Bill Thoen, Internet resources for the geosciences, with an emphasis on GIS and mapping, *Computer&Geosciences*, Volume 21, Issue 6, july 1995, Pages 779-786

[8] Roger Moore, Peter Gijsbers, David Fortune, Jan Gregersen, Michiel Blind, RIZA, OpenMI Document Series: Part A - Scope for the OpenMI (version 1.4), V1.4, 2007, *Final © The OpenMI Association*

[9]David Maidment, ArcHydro – GIS for Water Resources, ESRI 2002, USA

[10] Groundwater directive 2006/118/EC

[11] 2002. Groundwater Modeling System TUTORIALS - Vol. 2. MODFLOW, MODPATH, MT3D, SEAM3D. *Environmental Modeling Research Laboratory*, Brigham Young University.

[12] Harbaugh, A. W., Banta, E. R., Hill, M. C and McDonald M. G., 2000. *Modflow-2000, The U.S. Geological Survey Modular Ground-Water Model. User guide to modularisation concepts and the ground-water flow process* - Open-File Report 00-92. Reston, Virginia.

[13] Radu Drobot, Minciuna Marin-Nelu, Alexandrescu Maria Ilinca, Cheveresan Bogdan, Galie Andreea, Laurentiu Ichim, Vasile Alexandru, The evaluation of the pollution risk related to the industrial platforms from Olt river basin focusing on surface waters, groundwaters and sediments, *EVRIPOL project*, Technical University of Civil Engineering Bucharest2007

[14]T.C. Young, C.M. Kao, T.Y.Yeh, C.E.Lin, Y.C. Lai, Non-Point Source Pollution Investigation in Drinking Water Protection Area of Kaoping River Basin, Taiwan, 4th WSEAS Int. Conf. on HEAT TRANSFER, THERMAL ENGINEERING and ENVIRONMENT, Elounda, Greece, August 21-23, 2006 (pp34-40)

[15] Normative regarding wells protection zone in Romania (H.G.930/2005)

[16] Zheng, C. and Wang P. P., 1999. *MT3DMS:* A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guid, University of Alabama - *Contract Report SERDP-99-1*.

[17] R. Drobot, M. Bretotean, M.N. Minciuna, E. Radu, D. Dragusin, L. Coarna, Delineation of the Protectiona Area around the Production Wells of Pitesti waterworks. Conferinţa "Excelence Research Conference", 2007, Braşov, Romania

[18] Jandirk Bulens, Wies Vullings, Joep Crompvoets, Marcel Reuvers, *The framework of standards for the Dutch SDI*, 10th AGILE International Conference on Geographic Information Science 2007 Aalborg University, Denmark