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**ΠΟΙΟΤΗΤΑ ΖΩΗΣ ΚΑΙ ΟΙΚΟΔΟΜΗΣΗ ΑΞΙΩΝ
ΣΤΑ ΠΛΑΙΣΙΑ ΕΝΟΣ ΑΣΦΑΛΟΥΣ ΠΕΡΙΒΑΛΛΟΝΤΟΣ**

GroundWater Information System. A digital tool for GroundWater resources protection and management.

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ABSTRACT
Potable water and in general fresh water resources should be protected from pollution coming either from industrial sources, sewage systems, chemicals in use at farms, or other anthropogenic or natural source.
An early warning system for groundwater level fluctuations due to climatic condition changes or human activities as well as for water quality changes can greatly help in decision-making on water-takings, drought management and land use planning thus providing support for groundwater sustainable management. The above, necessitate the design of an integrated GroundWater Information System (GWIS), by use of contemporary spatial information technology, including Geographic Information Systems (GIS) along with other related spatial technologies like Linear Referencing Systems (LRS).
The GWIS presented, comprises a set of sub-systems (web server, map server and database server) serving custom applications, either for data storage and maintenance or for data retrieval and visualisation purposes. The internet subsystems represented by a web and a map server are charged with satisfying external requests for cartographic information, by servicing map images. The database subsystem provides the geospatial data needed through a geographic database, along with a series of tables containing geological events. The database is developed by adopting proven ground water data models (e.g. ESRI Ground Water ArcGIS Data Model). The geographic database model provides the framework for establishing a Linear Referencing System (LRS) through which, traffic geological events are referenced over the geological linear network as point or linear route events. Finally, custom web-based applications provide the ability to manage the involved parameters by accessing the appropriate tables of the geodatabase, while at the same time, they provide a real time cartographic representation of the relevant geological and groundwater related feature classes.

1. Introduction

Issues concerning groundwater management arise when the use of land or water adversely affects groundwater attributes to the extent that its use as an asset is threatened.

The most common concern about groundwater management is related with its demand parameters for human use including **amount** and demand over time. The issues regarding that matter usually concern depletion of spring-fed surface water flow, sea-water intrusion, well interference, sustainable well levels and yield of aquifers / over-use of the resource, bore construction standards, lack of knowledge as regards, water abstraction.

The main concerns about groundwater **quality** are primarily related with land-uses that are considered to adversely affect groundwater quality or are potentially expected to do so. Problems include contamination of groundwater as a result of disposing wastes from municipalities and industry to land, nitrate, pesticide and microbial contamination as well as nitrate contamination of groundwater by agricultural activities. Most of these sources are identifiable, localised sources for which everyone realises the need for monitoring and managing their environmental impact.

On the other hand, assets that depend on groundwater quantity and quality regime are the affordable access to potable water at the quantity and rate required, the life supporting capacity of groundwater-fed surface waters, the life supporting capacity of groundwater and the stability of land.

During the last decades the continuously increasing demand in groundwater uses, resulted to the necessity for groundwater resources management. Efficient groundwater management will protect the quantity of groundwater and ensure a dependable and affordable supply of this resource. It will also protect the water quality to ensure that the groundwater remains suitable for domestic, industrial, agricultural and environmental uses and it will help to prevent land subsidence that may damage public and private infrastructure.

The tools used to support and manage groundwater include hygrogeological surveys, vulnerability and source protection zone maps, software and methods of numerical analyses. The essential issue in such a case is **groundwater monitoring** because it can provide, in real time, quantitative and qualitative information regarding changes in groundwater storage as well as in its physical, chemical and biological characteristics.

2. GIS as a tool for groundwater management

A GIS package can help display data spatially and can also be used to track contaminants or other types of concentration over area maps. It offers a powerful means for evaluating and interpreting many types of data associated with a site as it offers a broad spectrum of capabilities including visualization, analysis, and querying of electronic data.

Designing groundwater monitoring networks is not a simple task and various approaches have been proposed and adopted for that matter (Rouhani ang Hall, 1987; Srpuill and Candella, 1990; Woldt and Bogardi, 1992, Dutta D. et al, 1998). Each one of them proved not to be equally suitable and reliable for any particular region, as the design of such a system strongly depends on site specific conditions. Any approach used, must depend on the objective of the groundwater monitoring system as well as on the parameters affecting groundwater quantity and quality over the entire study area. A groundwater monitoring system will be effective only if these factors are taken into consideration simultaneously.

In the present study the development of a flexible web based prototype Ground Water Information System (GWIS) aiming to become adaptable to any site is presented.

3. Key points and Background of GWIS

Designing the Ground Water Information System was a twofold issue because it should balance between data and result credibility and costs. For that reason, the system's optimization is essential in order to adapt to site specific conditions and to maximise cost-effectiveness without compromising program and data quality.

The five general tasks that ensure a cost effective monitoring program include the ability of reducing the number of monitoring points, of reducing monitoring duration and/or frequency, of simplifying analytical protocols, of ensuring efficient field procedures and streamlining data management and reporting.

In order to reduce monitoring costs without compromising program quality or effectiveness, the optimization process focuses on collecting relevant data of the appropriate quality to achieve program goals. This is done by evaluating the number of monitoring points, the frequency and duration of monitoring, the analyte list and assurance/quality control samples, the sampling procedures and the data evaluation, management, and reporting procedures.

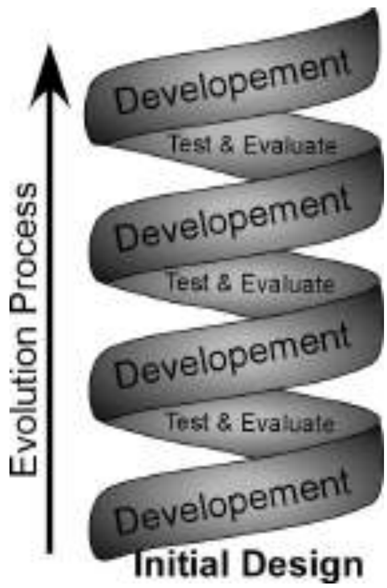

Fig. 1. GroundWater Information System (GWIS) design. Adaptation to local conditions.

The proposed system is designed so that selected parameters regarding groundwater quantity and/or quality can be constantly (or selectively) measured and data can be instantly transferred and stored in a server. This can be achieved either by direct input or by using telecommunication technology (i.e. commercial GPRS network). In this way, sampling costs can be significantly reduced.

Sampling points selection is based on the conceptual site model, the data quality objectives, the regulatory framework and the performance monitoring.
The **conceptual model** focuses in understanding the existing problems. Factors to be considered include, the scope of the monitoring procedure, the geological and hydrogeological regime of the area, the biological and geochemical conditions, potential transport contamination pathways , historical data and monitoring points. All parameters to be measured or measures to be taken depend on state and local **regulations** which aim to provide protection to human health and the environment.

Performance monitoring aims to provide the quantity and quality of data necessary to verify progress towards the overall monitoring program goals and to make informed decisions regarding environmental issues as well as groundwater monitoring system enhancements (fig.1).
Sustainability and improvement of the GWIS is achieved through periodic evaluation on a regular basis. Evaluation should include a review of all the analytical data generated during the last period. A comparison with historical data could help validation. Reviewing any hydrogeologic data collected during the last year can help detect major changes in the hygrogeological regime of the area and also to verify that the assumptions made are still valid. A data review can also help in evaluating the impact of the measures taken on groundwater quantity and quality.

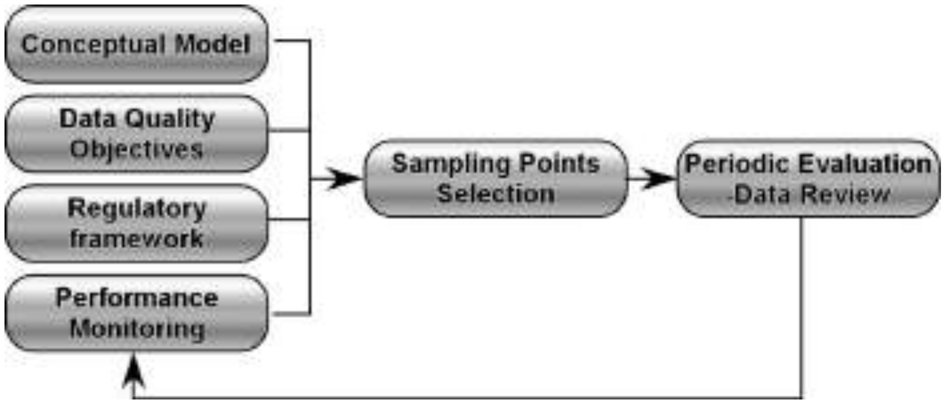

Fig. 2. GroundWater Information System (GWIS) concept design. Sustainability and improvement through evaluation on a regular basis.

Monitoring points are chosen based on the geological and hydrogeological regime of the area, in the context of the overall scope.
Monitoring Network Optimization is based on tracking ion concentrations that are above a set threshold, identify contaminant trends and to evaluate remedial measure performance.

Analytical costs make up a significant portion of monitoring program expenses. Streamlining the analytical approach is a viable way to cut overall monitoring program costs. The proposed GWI System can help in this matter by reducing time and economic costs through its ability to get remote measurements of the appropriate parameters and also by the sampling points performance monitoring which can lead to sampling point number reduction, without compromising data quality or credibility.

4. GWI System Architecture

In order to manage the Ground Water data collection and exploitation system, through a real time web-based GWIS, the system architecture, illustrated in figure 3, is proposed. It should be stressed that the schematic, the terminology and components analysis following, is mainly based on proven commercial products.

The adopted System Architecture is a typical multi-tier architecture customised to meet the proposed system requirements and is introduced through three major tiers (layers) which are described in detail in the following paragraphs.

Data Collection Layer

The Data Collection Layer comprises any kind of field equipment device that is used to perform measurements related to Ground Water critical factors. Raw data extracted from these devices are transferred to the data layer on a real-time basis through typical TCP/IP over GSM communication infrastructure.

Data / Services / Application Layer

The Data / Services / Application Layer groups the typical data and application (business logic) layers of the 3 – tier architecture along with a layer comprising the required services provided by standard software components (Web Server, Map Server and Database Sever).

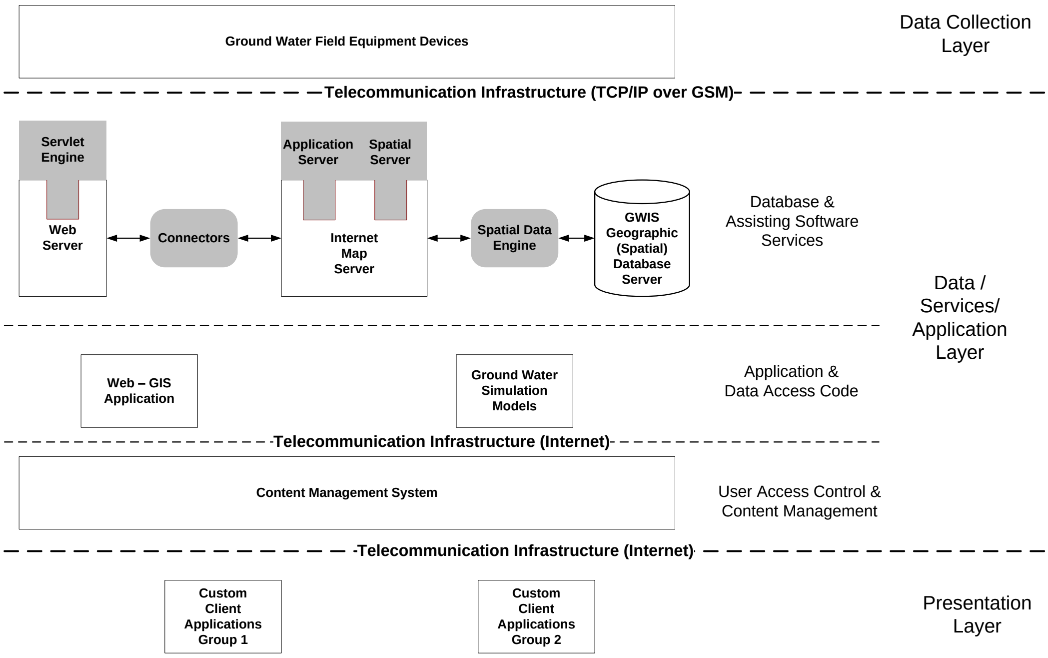

Fig. 3. GroundWater Information System (GWIS) Indicative Architecture**.**

Database and Assisting Services

The following services and utility software components compose the Database and Assisting Services sub layer:

<u>Internet Map Sever</u>

The Internet Map Server receives client requests for cartographic information and returns the final map images. Its principal components are:

- **Spatial Server:** performs the core GIS services (spatial processing, data retrieval and extraction etc.) and it actually, executes client’s request by producing the final map image, to be published by the Web Server.

- **Application Server:** distributes requests to Spatial Server acting as an intermediate for these requests and it also performs other critical information management tasks.

Web Server

The Web Server receives web client requests for data, locates the requested data and sends it back to the client application.

Servlet Engine

Some client requests require special programs (Servlets) to be executed on the server's side. A Servlet Engine provides support for Servlets running within the Web Server environment, through a Servlet Application Programming Interface (API).

Connectors

Connectors provide a communication link between the Web Server and the Internet Map Server, which is achieved through the Servlet Engine. Connectors may also include special Java components for developing client and server applications, custom Servlets and JavaServer Pages (JSP) applications.

Spatial Data Engine

The Spatial Data Engine provides communication between a spatial DBMS and any other GIS-related data request activity. It supports, beyond others, concurrent multi-user editing, many concurrent network user serving and unlimited spatial data.

Spatial Database Server

A spatial Database Server is a DBMS, maintaining spatial data. Recent developments include special GIS data models for a wide range of human activities to be transformed in relational spatial databases during physical design.

Application and Data Access Code

The Application and Data Access Code layer consists of two major application software componenets:

Web-GIS Applications

They are responsible for accessing the database sevice in order to retrieve, modify and delete data to and from the database and send the results to the presentation tier. This sub layer is also responsible for processing the data retrieved and sent to the presentation layer. In addition it executes user requests with regard to core GIS geoprocessing functions.

Ground Water Simulation Models

This assisting software component includes simulation models used by ground water experts in order to perform forecasts with regard to critical factors affecting ground water quality. Ground water data collected on a real time basis may be consequently used to test and calibrate the algorithms adopted by these simulation models.

User Access Control and Content Management

The User Access Control and Content Management sub layer ensures authorized user access and provides strong capabilities of building user profiles according to roles and responsibilities as well as configuring special data accessibility levels. A significant functionality of this sub layer provides easy to use interfaces for managing the content of the GWIS web portal.

Presentation Layer

The Presentation Layer is the topmost layer of GWIS architecture providing custom browser-based applications to satisfy user interaction. Such applications may also be programmed in a variety of programming languages (scripting, visual etc.), and may be installed in a variety of devices (PC, PDA etc.). Communication with the upper architecture layer containing the geographic (spatial) database service, may be achieved via the appropriate protocols (TCP/IP, GPRS/3G). Client applications are divided into two main categories depending on whether they are used for reviewing or managing spatial information:

- **Group 1:** Applications used for navigating inside the ground water related cartographic information. They are also used for extracting data through simple or complicated queries.
- **Group 2:** Applications used for storing and managing data into the geographic ground water database, through SDE.

5. GroundWater Information System Development

Adopted Software Products

A pilot implementation of the proposed architecture made use of the software products presented in table 1. ESRI's Internet Map Server (ArcGIS 9.3) cooperates with specific combinations of Web Server and Servlet Engine versions of the Apache products. Alternativelly, IIS built-in MS Windows Server 2003 operating system may succesfully satisfy web-GIS services. On the other hand MS SQL Server responded perfectly during geographic data base creation through SDE. Finally, pilot java applications accessed the DBMS, through JDBC connectivity, without problems. The same succesfull development was achieved by use of visual programming languages, provided by .NET framework.

Table 1. Adopted Software Products

System Component	Software Product
Operating System	Linux, Windows XP / Windows Server 2003
Web Server	Apache HTTP Server 2.0.48 / Internet Information Server
Servlet Engine	Apache Tomcat 4.1.29
Internet Map Server	ArcGIS 9.3
Spatial Data Engine	ArcSDE 9.3
Connectors	ArcGIS Servlet Connector, Java Connector
Spatial Database Server	MS SQL Server 2003
Custom Applications	Java Developer Kit / .NET Framework

System Implementation

An efford has been made to use the GWI system proposed in order to identify it's abilities and/or limitations.

The test area selected was a part from Thessaly plain (the part between Trikala and Kalambaka cities) where data from a total number of 300 sampling points were available. Data included water levels measured temporarily as well as hydro-chemical data regarding the physical and chemical parameters of groundwater in the area.

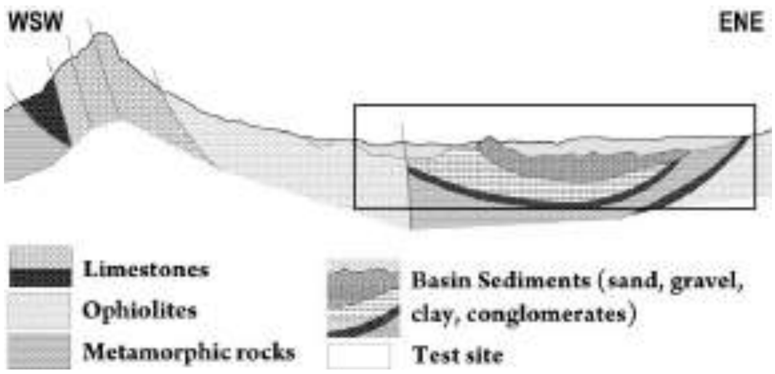

Fig. 4. Schematic representation of the test site's geologic structure.

The pilot implementation of GWIS comprises two custom client application groups as depicted in the System Architecture Diagram (fig.3).

Custom Client Applications Group 1

As the data used were already available, they were imported in the GWIS as standard tabular data files (Excel worksheets, comma and/or tab delimited etc) and were used to create various types of spatial information including groundwater level maps as well as physical properties and chemical ion distribution maps. Data retrieval and manipulation is done through a Web application (fig. 5) so authorized users can have access to the system remotely, through a web service.

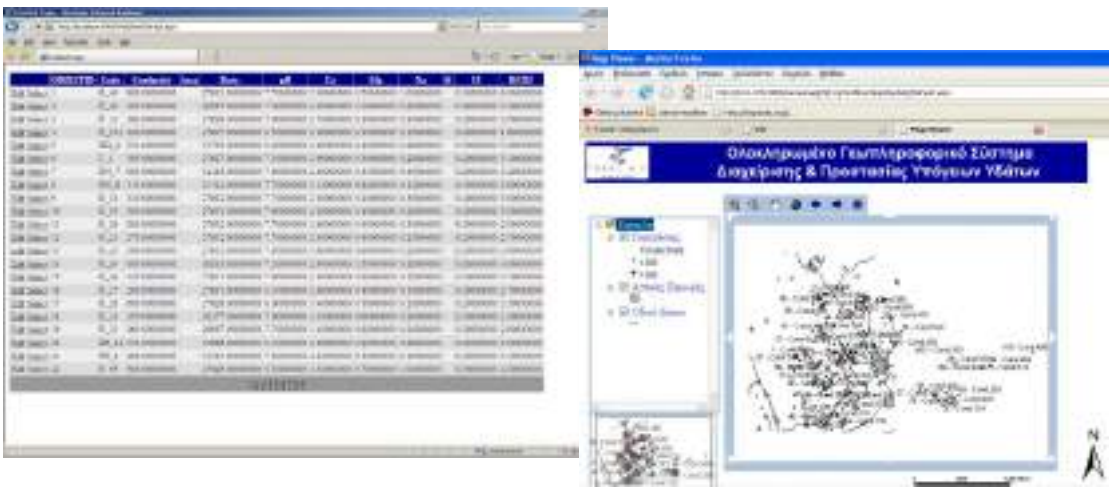

Fig. 5. Data input through Web services and Data (information) layers shown.

Custom Client Applications Group 1, provides the capability of modifying sampling points attributes. By specifying threshold values for the above parameters it is possible to activate alarms as soon as the parameter values exceed the specified thresholds. Figure 5 presents the web-based user interface for manually modifying the drill attribute values.

Custom Client Applications Group 2

Custom Client Applications Group 2 provides the capability of monitoring the status of critical drilling parameters. The system provides alarms and special information when a set threshold in one or more selected parameters is exceeded. It can also provide information in real time if the spatial database is connected to remote sampling points through GPRS or other means.

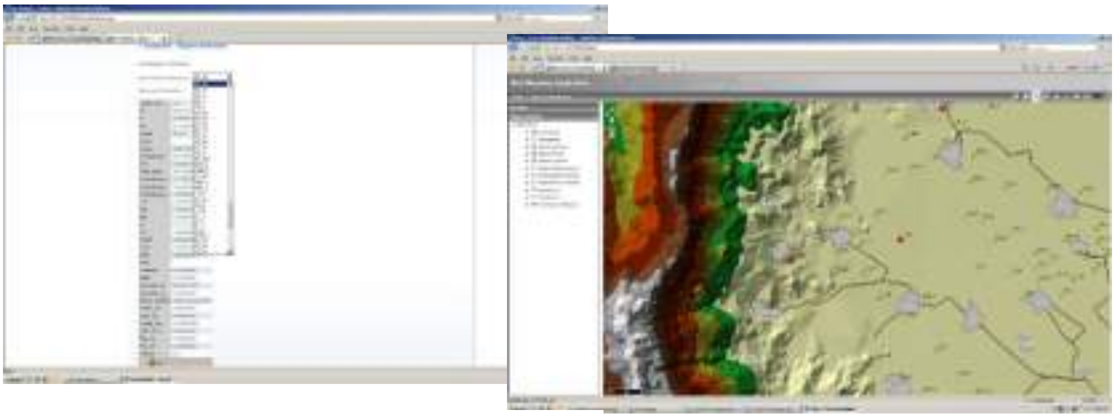

Fig. 6. Data input through Web services.

Figure 6 depicts in red color the the sampling points where the specified threshold value for a specified parameter was exceeded. As all parameter values change over time, appropriate feature symbology facilitates sampling point performance control and “surveillance” capabilities.

Conclusions

The GroundWater Information System proposed is mainly based on proven commercial products and it comprises of a set of sub-systems (web server, map server and database server) that cooperate in order to serve custom applications, either for data storage and maintenance or for data retrieval and visualisation purposes. The internet subsystems consist of a web and a map server that are provided with the required cartographic information, by servicing map images. The database subsystem provides the geospatial data needed through a geographic database, along with a series of tables containing hydro-geological events. Data input can be direct, through the keyboard or imported tabular data files or remote through GPRS services.

The proposed system is designed so that selected parameters regarding groundwater quantity and/or quality, can be constantly (or selectively) measured and data can be instantly transferred and stored in a server. The system’s optimization ability permits it to adapt to site specific conditions and to maximise cost-effectiveness without compromising program and data quality.

The GWI System developed was tested using data from 300 sampling sites from a part of the Thessaly plain (central Greece). As it was shown, the system is able to handle large amount of data and to provide spatial distribution information in real time over the Web thus helping identify, at an early stage, groundwater contamination, locate the potential sources and make decisions in order to prevent contaminants from being spread. Fed with data in real time through GPRS services, *a feature already implemented*, the system can help take measures at a very early stage thus preserving the quantity and the quality of groundwater resources of the implementation area.

Spatial distribution of groundwater quality parameters can also help identify the most representative sampling positions thus reducing the sampling points (and the overall cost) without compromising results and credibility.

Additionally, decisions can be made regarding a certain monitoring point by tracking it over time and by querying several rounds of data.

Provided that they are measured, contaminant concentrations that are above a set threshold can be tracked, contaminant trends can be identified and if taken, remedial measure performance can be evaluated.

Presentations to regulators and the community can be greatly enhanced by using the GWI system so that decisions based on data can be made and also public environmental awareness can be improved.