THE USE OF GIS FOR SUPPORTING THE EXPERIMENTAL REPRESENTATION OF THE SELECTED SUPPLY NETWORK IN PAFOS MUNICIPALITY: 'THE HYDROGIS LAB'

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ABSTRACT

The Project focuses on the resolution of decreased water supply as a result of continued water shortage. The water loss is the result of several causes, notably water losses in the water supply network pipes, the ineffective operation of pumping stations and design of the networks are some of the most important problems which need to be addressed to optimize the performance of the water networks and save both water and the energy consumed. The Project is innovative as it is the first time that several, state-of-the-art technologies, including Global Positioning System (GPS), Radar Scanners and Satellite Remote Sensing (SRS) will be combined to map the water networks. The data produced will be entered into a Geographic Information System (GIS), with the objective of developing a digital imprint and mapping of the network. Following, a representative section of the network will be selected and modeled in the new upgraded laboratory in order to conduct detailed experimental studies, which will be correlated with computational/mathematical studies. The main scientific challenge of the Project, which also characterizes its broader innovative aspect, lies in the possibility to optimize the design and also the operation of all the components of the network, through the combined use of hydraulic simulation models and multi-criteria evolution algorithms.

Keywords: Geo-radar, GIS, water utility

1. INTRODUCTION

The HydroGIS Lab project aims to satisfy the dire need for authorities to solve the extremely serious problem of water supply as a result of continued water shortage. The chronic problems of water losses in the water supply network pipes, the uncontrolled and non-optimum operation of pumping stations, the incorrect design of the networks because of various interventions such as town planning and erroneous mapping of existing networks, are some of the most important problems which need to be resolved in order to optimize the performance of the networks and, consequently, save water and energy. The innovative aspect of the Project is that state-of-the-art technologies are combined for the mapping of water networks through the Global Positioning System (GPS), Radar Scanners and Satellite Remote Sensing (SRS). The data is entered into a Geographic Information System (GIS), with the aim of developing a digital imprint and the mapping of the network. The study of an existing selected water supply network and the collection of the necessary information by the Cyprus University of Technology and the Water Development for the network and its systems will lead to an imaging of water pipes and their design using a radar scanner and special software and GIS. Satellite images, which have been transformed into the local reference system using specialized software, will be coupled with the digital imaging of the existing maps. This information will then be organized in such a way allowing the development of maps and their analysis at different levels (e.g. water supply network, buildings, water supply elements, geographic information, features of the network's systems, etc.).

GIS has been used to develop a comprehensive management system of the information, including text, cartographic and quantitative data. Maps from Paphos Municipality depicting existing buildings, streets and other infrastructure

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were used in creating the digital map. The ground penetrating radar (GPR) provided imaging of all required information regarding the existing water supply pipes, including altitudes, grading, location of other services, diameters, etc. Satellite images of the region of Paphos Municipality will be used to retrieve the present conditions, such as current construction development and, therefore, the immediate water supply needs in the municipality.

2. METHODOLOGY

A representative section of the water supply network in the Pafos Municipality area, including pumping stations, reservoirs, valves, and flowmeters, are recorded and the selected network is digitized. The MALA GPR is used to conduct a survey of the existing water network. After the GPR survey is concluded, the GPR data is analyzed and the water pipes are identified, according to their diameter, material and depth. Following, each survey point was inserted into a GIS system, including all the data acquired. The network was then connected from each survey point, as indicated in Figure 6.

All the retrieved information that are available through the acquired software regarding surveying, analysis, management, processing, will be inserted in the GIS database. The GIS system will be flexible, allowing the addition of any layer considered necessary for the better management of the Project information. The final structure and content of the digital imprint will depend on the results of the initial study of the networks in Paphos Municipality, in order to proceed with an accurate modeling of the representative network.

A methodology will be created for detecting and adapting critical parameters of the mathematical models (e.g. surface roughness coefficient of pipes etc), based on actual experimental measurements of the flow field in corresponding hydraulic models. As well, detailed experimental verification of the computational results and the development of knowledge for self-regulation of pumps and valves will be examined in order to satisfy the supply needs in conjunction with the uniform pressure distribution in the water supply network. In this way, guidelines will be developed which could form the basis for developing a user-friendly network simulation software, able to make up for the lack of communication between the different sciences involved in developing/designing and managing water supply networks. Figure 8 indicates similar 3D drawings of distributions networks. The experimental representation of the supply network, in combination with state-of-the-art methodologies will be used for optimizing the water supply networks, both in the design and in the operation phase, using multiple variables and criteria, which will be identified throughout the study.

A framework was created to develop specifications and relevant computational tools for the optimum analysis of supply networks, both in the design and the operation phase. An optimization framework was defined, including the identification of the problem (determination of control variables and performance criteria) and its solution, using multicriteria evolution algorithms. This methodology will be utilized in the context of an information system for the management of networks, which will include a database, a GIS and a computational code. In order to implement the computational code, existing tools and models will be used or new ones will be developed, so as to ensure compatibility with the proposed methodological framework.

The operation of the experimental model is studied in detail, with the support of specialized instruments and systems for the continuous recording of the variables (i.e. flow capacity, pressure, power etc) at different points in the network. The experimental results will be utilized for verifying the theoretical models as well as for developing a framework for the identification and optimum adaptation of critical parameters of the simulation models (e.g. surface roughness coefficients), based on the measurements in the corresponding hydraulic model. Furthermore, specialized analyses will be conducted in typical locations of the experimental model, which may prove to be problematic (e.g. cross-sections downstream and upstream of the pumping stations) in order to study flow phenomena (e.g. local losses at operational phases) and propose improvements.

2.1 Ground-penetrating radar (GPR)

Current research [3,4,5] states there is a trend is toward development of more and more sophisticated systems including the ground penetrating radar (GPR) technique, which is safe for use in urban environments and also protects the geological, environmental and archaeological integrity of subsurface settings [5]. GRP is a geophysical method that uses radar pulses to image the subsurface. It is a nondestructive method uses electromagnetic radiation in the microwave band of the radio spectrum, and detects the reflected signals from subsurface structures [6]. GPR interpretation of this reflected energy may yield information on subsurface structural variation and condition of the media, as indicated in figure 1.

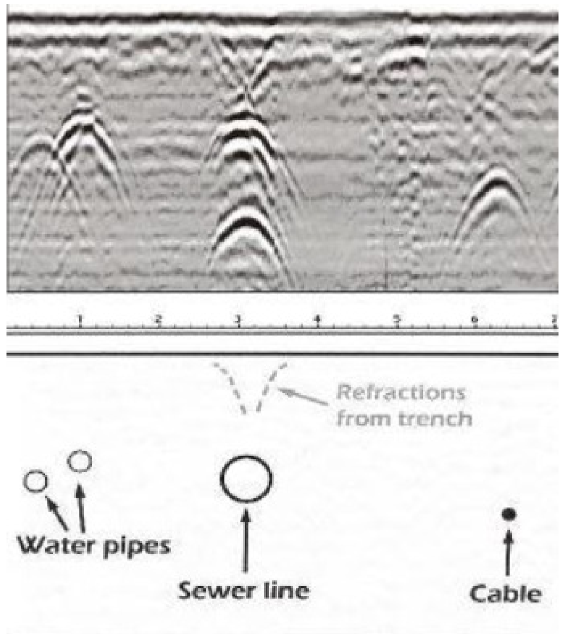

Figure 1- Reflected signals from subsurface structures

The advantages of GPR include its low cost and ease of use. Expertise is required to collect the data. Secondly, the instrumentation is easily portable (unless very low frequencies are exploited thus increasing the physical size of the antennas) and allows to survey regions also of thousands of square metres in reasonable time. Finally, the flexibility of the GPR system is ensured by the adoption of antennas (mostly portable) working at different frequencies and that can be straightforwardly changed on site [7]. GPR uses transmitting and receiving antennas or only one containing both functions. The transmitting antenna radiates short pulses of the high-frequency (usually polarized) radio waves into the ground. When the wave hits a buried object or a boundary with different dielectric constants, the receiving antenna records variations in the reflected return signal. Individual lines of GPR data represent a sectional (profile) view of the subsurface. Multiple lines of data systematically collected over an area may be used to construct three-dimensional or tomographic images. Data may be presented as three-dimensional blocks, or as horizontal or vertical slices. Horizontal slices (known as “depth slices” or “time slices”) are essentially planview maps isolating specific depths.

GPR is also one of the most used tools in the field of the water monitoring and management especially in the fields of the drainage pipes detection and characterization , water leaks in pipe detection and determination of the time-behavior of water content in the soil [8-11]. GPR can accurately pinpoint buried pipeline leaks without digging. The leaking substances can be identified at the source by the radar via the changes in the surrounding soil's electrical parameters. The GPR is able to generate 3D underground images of pipes, power, sewage and water mains. As well, it can identify leaks in buried water pipes either by detecting underground voids created by the leaking water as it erodes the material around the pipe, or by detecting anomalous change in the properties of the material around pipes due to water saturation. Unlike acoustic methods, application of ground penetrating radar for leak detection is independent of the pipe type (e.g., metal or plastic) [3]. The principles involved are similar to reflection seismology, except that electromagnetic energy is used instead of acoustic energy, and reflections appear at boundaries with different dielectric constants instead of acoustic impedances.

2.2 Survey and GIS

Paphos Municipality is one of the municipalities in Cyprus facing very serious problems with the water supply network, due to the age of the network, rapid town development and the urgent needs for expanding the network in an unorganized manner. One of the aims of the HYDROGIS project is the study of an existing selected water supply network in the Municipality in an effort to understand the ‘logic’ of the network and select a representative part of it that will include almost all the components (i.e. pumping station, main piping, valves, flowmeters etc) present in the networks of the Municipality in order to conduct a comprehensive study. Therefore, the mapping and development of a database using GPS and GIS technologies has the aim of developing a digital imprint of a representative water network in Paphos Municipality and the creation of scale modeling for detailed experimental studies.

Figure 2.a &b - Geo-radar Scanning of the Paphos water utility network

A representative section of the water supply network in the Pafos Municipality area, all the features and systems which compose it, including pumping stations, reservoirs, valves, and flowmeters have been recorded and the selected network was digitized (Figure 3). A survey through the use of a latest technology radar scanner has been conducted. The specific radar scanner is a MALA ground penetrated radar designed for urban areas and background noise. The shielded antenna used consists of both transmitter and receiver antenna elements in a single housing.

Figure 3. study, mapping and development of a digital imprint of an existing selected water supply network

After the GPR survey was concluded, the GPR data were analyzed using the GroundVision 2 and RadExplorer software, where the pipes were identified, according to their diameter, material and depth. Following, each survey point was inserted into a GIS system, including all the data acquired. The network was then connected from each survey point, as indicated in Figure 4.

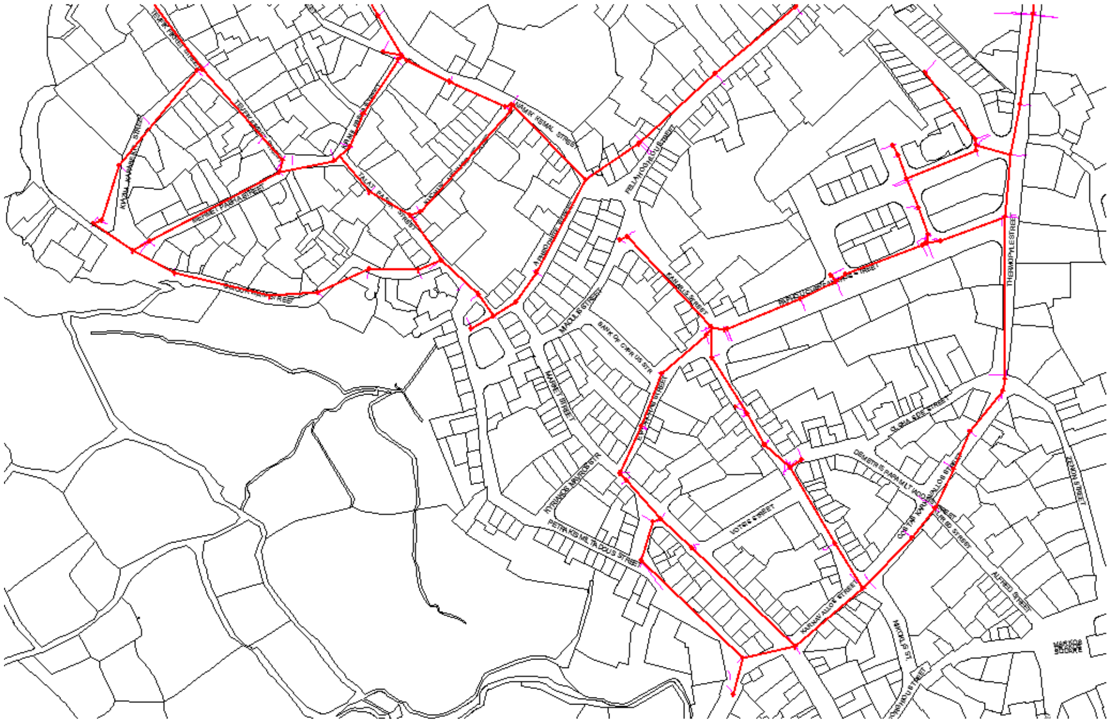

Figure 4 - The water network following the GPR survey

GIS was used to develop a comprehensive management system of the information, including cartographic and quantitative data, as well as text. Maps from Paphos Municipality depicting existing buildings, streets, etc were used in creating the digital map. The use of the radar scanner permitted the imaging of all required information regarding the existing water supply pipes, including altitudes, grading, location of other services, diameters, etc. Satellite data of the region of Paphos Municipality, including Quickbird, IKONOS, Landsat TM or SPOT satellite images, will be used to retrieve the present conditions. The capturing of satellite data at any moment in time using remote sensing techniques can provide the current construction development and, therefore, the immediate water supply needs in the municipality. In conjunction with the maps and ground measurements, it will be possible to develop an accurate digital imprint.

The acquired information will be organised in a GIS system, thereby allowing the creation of maps and their analysis at different "layers", including the water supply network, buildings, water supply elements, geographic information, features of the network's systems, etc. The basic structure of the layers is described as follows:

1. The first layer depicts the connections of the pipes to the buildings, including information relating to serviced flowmeters, the main input pipe, the relevant dimensions of the pipes, etc.
2. The second layer depicts the pipes of the network. It includes information on the geometrical elements of the excavation where the pipe is located, features of the wells, the length of the pipe, altitudes of the pipes determining their grading, etc.
3. The third layer will depict the pumping stations of the selected network and will include, in text form, all the features of the pumping station such as supplies, pressures, features of the systems comprising the pumping station such as pumps, valves, flowmeters and relief systems, etc.
4. The fourth layer will depict the reservoirs together will all the junctions/joints of the pipes and will include a description of all the features of the reservoirs.

5. The fifth layer will be the type of material of the pipe network, the diameter, the depth of the network, and the installation year. Moreover attribute table regarding water consumption, flow, water leakages records etc will be included.

6. The sixth layer will be used as a background layer from cadastral maps, elevation, etc.

7. The seventh layer will be the results of the field study of the radar measurements that will be surveyed by GPS technology.

Finally all the retrieved information that are available through the acquired software regarding surveying, analysis, management, processing, will be inserted in the GIS database (Figure 5). The GIS system will be flexible, allowing the addition of any layer considered necessary for the better management of the Project information. It must be noted that depending on the results of the initial study of the networks in Paphos Municipality, the final structure of the digital imprint as well as necessary information to be contained therein will be decided, in order to proceed with an accurate modeling of the representative network.

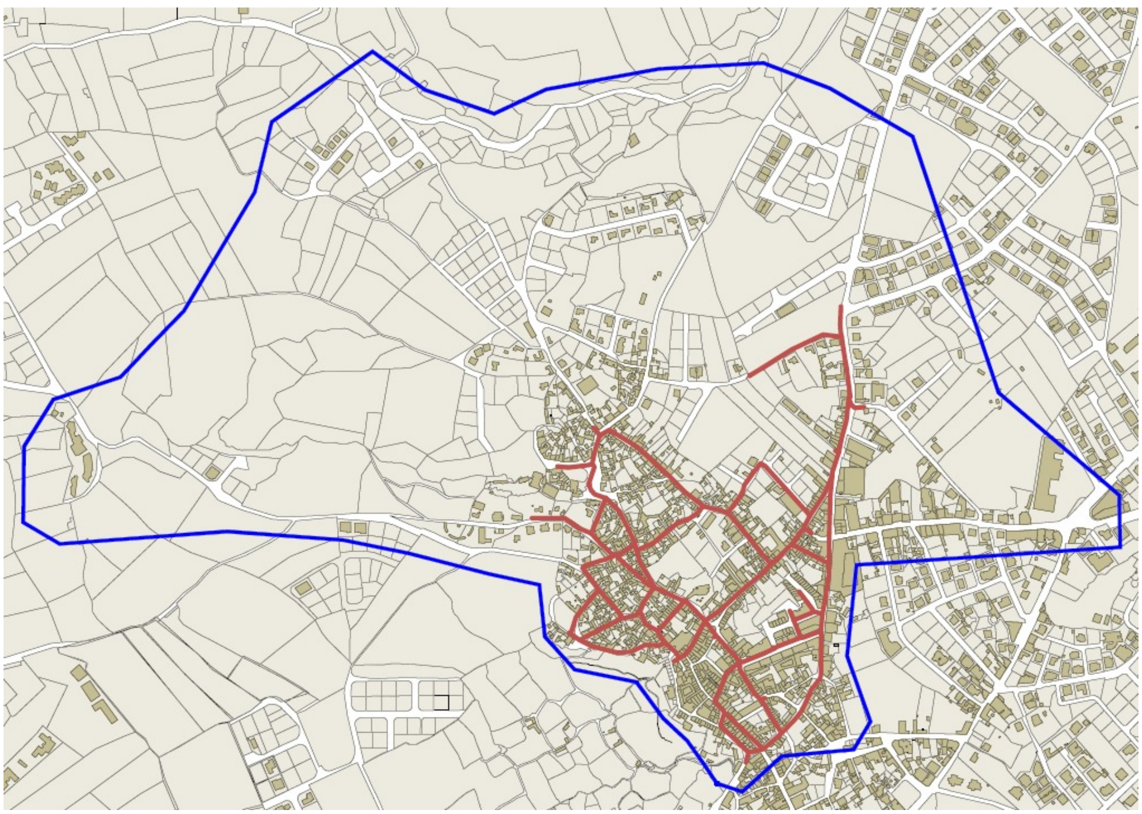

Figure 5 - Area of interest, including the GPR water pipe network survey

3. GIS

Worrall and Bond (1997) define the GIS as a computer system (software) that collects, stores, manages, analyzes and visualizes spatial information and upgrades to other information systems. The power of a GIS comes from the ability to correlate different information in a spatial context and to reach a conclusion about this relationship. Therefore GIS is a tool for modelling and analysis of complex research, a system that supports decision making, proposing possible solutions to users.

Some important advantages of GIS are listed below:

a) The data are stored in a small space,

b) Both the storage and the recovery can be achieved with lower costs than traditional ways

c) Analysis can be carried out much faster,

d) The spatial and attributes data can be correlated simultaneously

e) GIS allow synthetic analysis of data without any particular problems and

f) GIS offers the digital environment for an integrated process, where the collection, analysis and decision process are in a continuous flow (Koutsopoulos, 2000).

Figure 6: GIS Components

GIS can reveal important new information that leads to better understanding and decisions. Furthermore GIS can be used to emphasize the spatial relationships among the objects being mapped. The core of a complete GIS system consists of three basic components that are in constant balance and interdependence. These are machines (hardware), algorithms (software) and available data (resources) (Figure 6)

In order to design a GIS some basic steps must be followed. These steps are: (1) exterior design of the model, describing the real world (depending on the needs of users), (2) conceptual design, where a generalization of the real world is performed and final 3) the logical design where the implementation is made at a computer (Kavouras, 1998). The customized GIS developed will be able to monitor changes regarding the pipelines both in space and time. The continuous updating and monitoring of water pipelines can help the public authorities to examine changes over time based on a continuously feedback of the GIS database. All GIS data are imported into common ArcGIS files extensions. A personal geodatabase is built into the ArcGIS. The geodatabase is the common data storage and management framework for ArcGIS. It combines "geo" (spatial data) with "database" (data repository) to create a central data repository for spatial data storage and management. Moreover the geodatabase supports all the different elements of GIS data used by ArcGIS. The structural elements of a geodatabase, listed below, are some of the elements used to develop a rich GIS, such as: (a) Attribute data, (b) Geographic features, (c) Satellite and aerial images (raster data), (d) CAD data, (e) Surface modelling or 3D data, (f) Utility and transportation systems, (g) GPS coordinates, (h) Survey measurements and (i) digital photographs.

4. RESULTS

The preliminary underground survey conducted for the HYDROGIS project shows positive results in using ground penetrated radar to identify the underground pipe network in the Municipality of Paphos[11,12,13]. GPR scanning is a useful tool for modeling the water supply network, design and operation, with the goal of minimizing water loss. The aim of the project is to utilize scanning and 3D spatial representation to develop a GIS platform for managing all information required, including maps, satellite imaging, 3D scans, network system components and others. A methodology will be developed to regarding the critical parameters required for hydraulic models. Because of the nature and importance of the Project, there will be immediate dissemination of the results to all government authorities, including Water Boards, Municipalities, the Ministry of Agriculture and Natural Resources, the Ministry of Communications and Works, Associations of Civil & Mechanical Engineers, etc. The results will be of immediate interest and use, since they can be used to resolve some of the most pressing water supply problems in Cyprus.

Based on the digital imprint of the selected network, CUT will develop constructional drawings of the part of the network to be modeled. These drawings will include all necessary information of the piping and locations of all components to be installed. It is important to note that all parameters included in all four layers of the GIS System will be used for the accurate modeling of the network (i.e. altitude and gradients of piping, etc). Using the existing workshop facility, the piping will be constructed and will assemble the network together with all its necessary components. Figure 7 indicates similar 3D drawings of distributions networks. The experimental representation of the supply network, in combination with state-of-the-art methodologies will be used for optimizing the water supply networks, both in the design and in the operation phase, using multiple variables and criteria, which will be identified throughout the study.

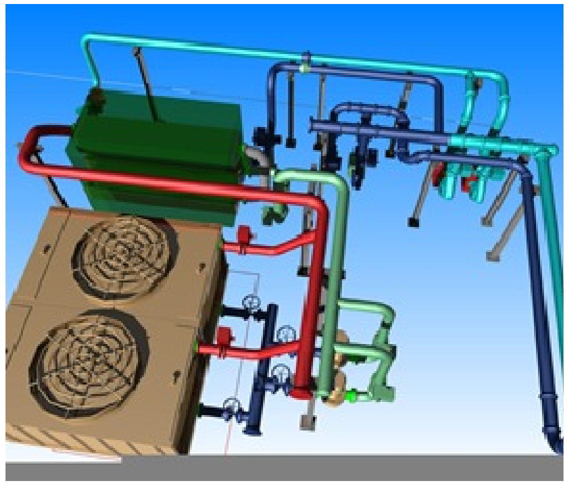

Figure 7 - Typical 3D drawing of a distribution network

A methodology will also be created for detecting and adapting critical parameters of the mathematical models (e.g. surface roughness coefficient of pipes etc), based on actual experimental measurements of the flow field in corresponding hydraulic models. As well, detailed experimental verification of the computational results and the development of knowledge for self-regulation of pumps and valves will be examined in order to satisfy the supply needs in conjunction with the uniform pressure distribution in the water supply network. In this way, guidelines will be developed which could form the basis for developing a user-friendly network simulation software, able to make up for the lack of communication between the different sciences involved in developing/designing and managing water supply networks.

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