Saline water intrusion monitoring and control at Guves Prefecture - Crete

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Abstract

This paper addresses the problem of saline water intrusion into the coastal aquifers of Guves Prefecture, Crete. First, after contacting a carefully planned geoelectric survey we mapped all regions of the aquifer possessing the highest saline water intrusion hazard. Next, a system was specially designed which continuously monitored the movement of the saline water front and automatically controlled all nearby pumping stations.

1 Introduction

This project addresses the ever increasing problem of coastal aquifer contamination due to uncontrolled movement of saline fronts within the upper geological layers. These phenomena are mainly due to the uncontrolled pumping of wells which causes (especially during periods of low rainfall) a saltwater intrusion into the coastal aquifers.
From an ecological point of view, these phenomena constitute a vivid example of how human intervention alters the natural environment causing its slow but steady degradation. The adverse effects of the salinization of coastal aquifers are apparent since they lead to a destruction of coastal ecosystems. In areas where agriculture or cattle breeding are main activities, salinization and pollution of coastal aquifers constitute a major problem, often damaging the crops or preventing the adequate watering of the cattle. Equally serious however are the

effects in regions that depend highly on tourism, such as most Mediterranean coasts.
The Guves -(Prefecture Iraklion, Crete) was selected for this pilot research because (1) its water resources have been intensively exploited in the last two decades, (2) there is an increasing antagonism between tourist development and agriculture in terms of water demands, (3) the hydrogeological regime is similar to many other areas in Greece and coastal Mediterranean regions, (4) runoff water is not used in the frame of an integrated water resources development scheme and until now most agriculturers prefer to tap groundwater in their own field through a private well instead of joining a state-owned irrigation scheme.
The objectives of this feasibility study were (a) to explore the applicability of geophysical imaging techniques in the detection and mapping of coastal saline water intrusion plumes, (b) the development of an early warning system and (c) the protection of coastal aquifers by automatically assessing the expected saline intrusion hazard and defining the optimal pumping rates and future drilling operations.

2. Hydrogeological Background

In the pilot area of Guves, Preneogene and Postalpine geological units outcrop, (Fig.1). The Preneocene formations belong the tectonic napes of the Phyllitic-Quartzitic series, Tripolis and Pindos-zone. The Postalpine series are represented by Neogene and Quaternary sediments.
The Phyllitic-Quartzitic series acts hydrogeologically as the impermeable substrate of the region, towards its southern part (not seen in Fig.1). Petrographically, this series comprises alternating chloritic schists, phyllites and quartzites. Tripolis zone, overthrusted on the phyllitic-quartzic series, comprises faulted and karstified Upper Triassic -Upper Eocene thick-bedded limestones, dolomites, calcareous dolomites, and dolomitic conglomerates -limestones acting as aquifers. These rocks are overlain by the Upper Eocene -Lower Oligocene flysch rocks (aquicludes), the extension of which is limited in a small area in the southern part.
The Pindos series, overthrusted on the previous rocks, consists of successive tectonic slices comprising thin-bedded karstified limestones alternating with impermeable radiolarites. Pindos flysch rocks (impermeable) of Middle Paleocene- Upper Eocene age overlay the limestones, thus sealing the limestones. Stratigraphy and tectonics of the Pindos series favor the formation of separated karstic reservoirs in various levels, which are discharged through springs of generally moderate yield.
Neogene series cover uncorfomably the carbonate rocks of Tripolis zone in the central part of the Guves area. Petrographically, it consists of Pleistocene compacted marls (aquicludes) with intercalations of thin beds of sandstones, marly limestones and a basal conglomerate (aquifers). Quaternary formation cover the northern part of the study area, where low altitudes prevail. They are

mainly sandy marls and red clays, with very low permeability. Hydrogeologically, quaternary rocks are no important groundwater reservoir.

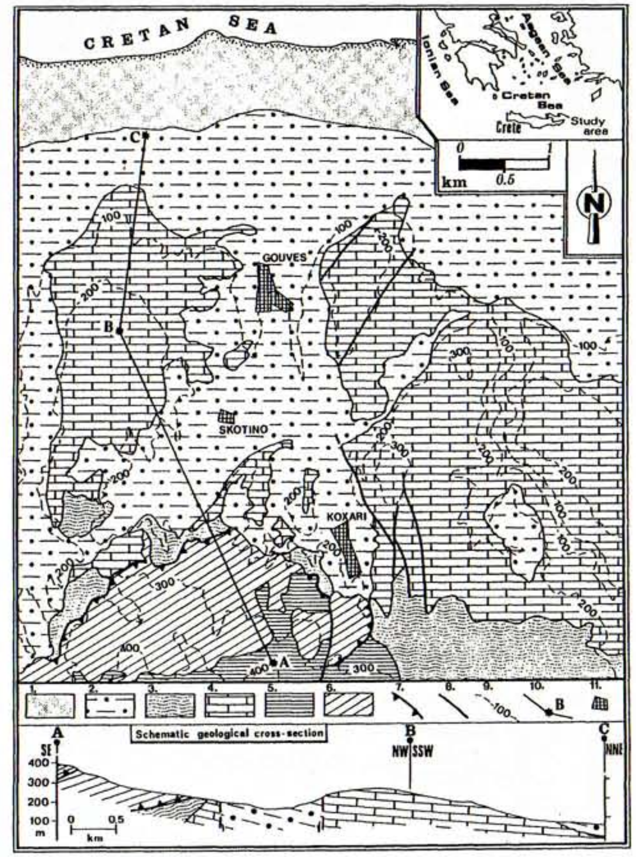

Figure 1: Geological map of Guves area. 1: Quarternary deposits. 2:Neogene formations. 3-4: Tectonic nappe of Tripolis Zone. 3: Flysch of Upper Eocene- Oligocene. 4: Limestones, dolomitic limestones, dolomites, of Upper Triassic-Upper Eocene. 5-6: Tectonic nappe of Pindos zone. 5: First flysch. 6: Limestones with radiolaritic intercalations. 7: Overthrust. 8: Fault . 9 Contour interval 100m. 10: Geological cross section . 11: Villages. (Kallergis & Lambrakis[1]).

In the Guves area, two main types of rocks are hydrogeologically important: the karstified carbonates of Tripolis zone and the Neogene series. The karstified and faulted reservoir with a mean permeability of 2.5 x10 $^{-2}$ m/sec forms a piezometric surface in the sea level. The direct contact of the karst to the sea implies a degradation of groundwater quality; overpumping caused a severe seawater enrichment and a moving of the sea- freshwater interface towards the interior. The sandy- marly limestones and conglomerates of Neogene with a mean total permeability of 5x 10^{-3} m/sec, act as successive confined aquifers; their groundwater charge takes place mainly through seepage from preneogene carbonates as well as from direct infiltration of rainwater.

3 Hydrochemical Background

Groundwater samples were collected from the study area. In the field, temperature, electrical conductivity and pH were measured, while laboratory analyses of main parameters were conducted just after collection. Calcite and dolomite saturation indexes, as well as ionic ratios rSO_4/rCl and rMg/rCa were also calculated. From these data a map of chloride isolines (Fig.2) and the expanded Durov -diagram (Lloyd and Heathcote [2]) were drawn.

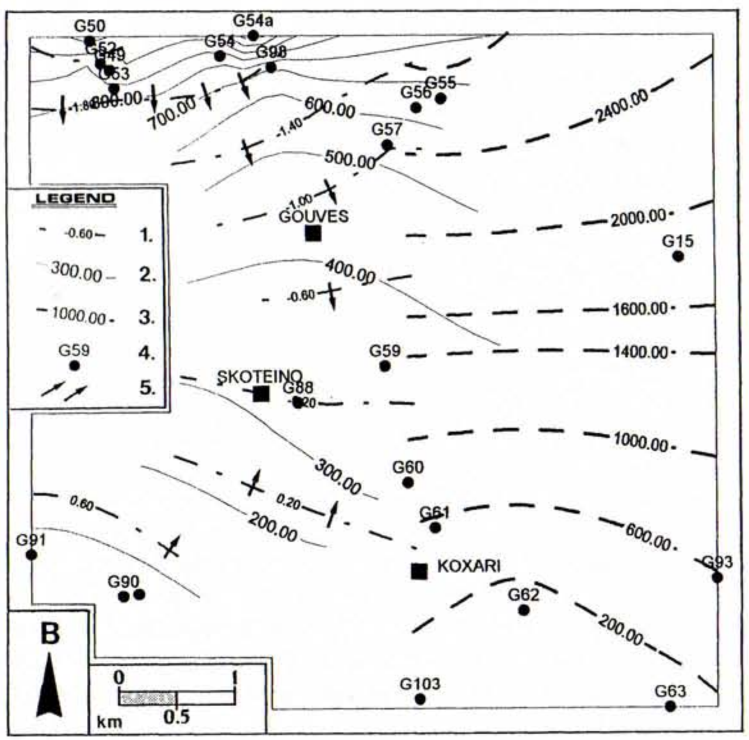

Figure 2: Groundwater potential distribution (1) and flow net map of the Neogene aquifers. Chloride distribution of the Neogene (2) and the Preneogene (3) aquifers of the Guves area. (25 October 1993), (Kallergis & Lambrakis[1]).

Groundwater and the Neogene reservoirs are classified into three hydrochemical types (Fig.3) : a) Ca^{+2} -HCO_3 -water, b) Mg^{+2} - HCO_3 -water and c) Na^+ -Cl^- -

water types (Kallergis and Lambrakis[1]). The change from the type (a) to type (b) can be attributed to the mixing of the Neogene-aquifer groundwater with the water of the dolomitic aquifers while the change from types (a) and (b) to (c) may be explained as a result of sea intrusion According to the same diagram the ground water of the Tripolis limestones aquifer is classified in two types: The (b) Mg^{+2} - HCO_3 and the (c) Na^+ -Cl^- -water types. The change from type (b) to type (c) may be explained by the sea intrusion

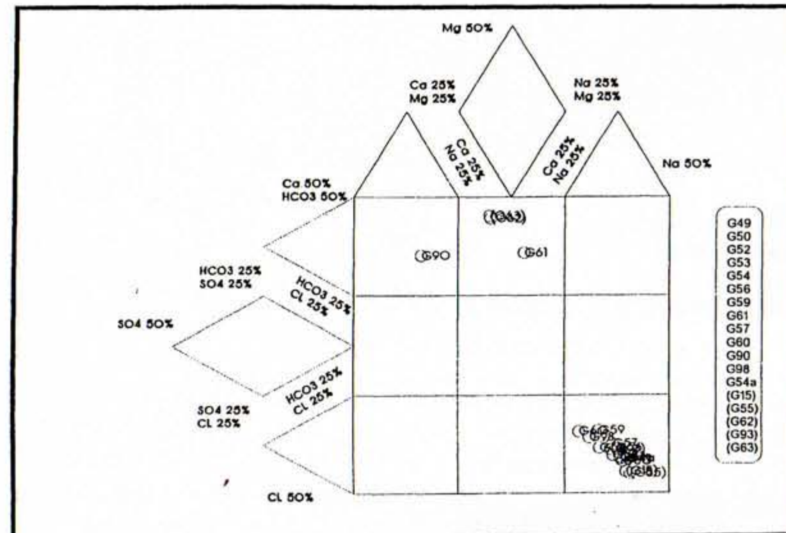

Figure 3: Water types grouped using an expanded Durov diagram. (Kallergis & Lambrakis, 1994).

The chloride isoline map of the study area (Fig.2) is very indicative of the relative sea intrusion into the interior of the aquifers. The hydrogeological characteristics of the aquifers are clearly shown in this map. So in the Neogene aquifers which have a lower permeability than those of the Preneogene, the sea - fresh water interface is more limited. The sea's influence appears to reach to a distance of 7Km from the coast.

4. Geophysical Investigations

Electrical prospecting methods have been used successfully in solving various groundwater exploration problems for some time now. They became popular owing to the relatively low price of the geophysical survey as compared with the cost of drilling observation wells and also to their ability to provide information which can be directly connected with water quality.

Assuming that the distribution of the electrical resistivity of coastal formations represents the extend of saline water intrusion we contacted forty five geoelectric (Shlumberger) soundings which can be grouped in seven traverses (Fig.4).

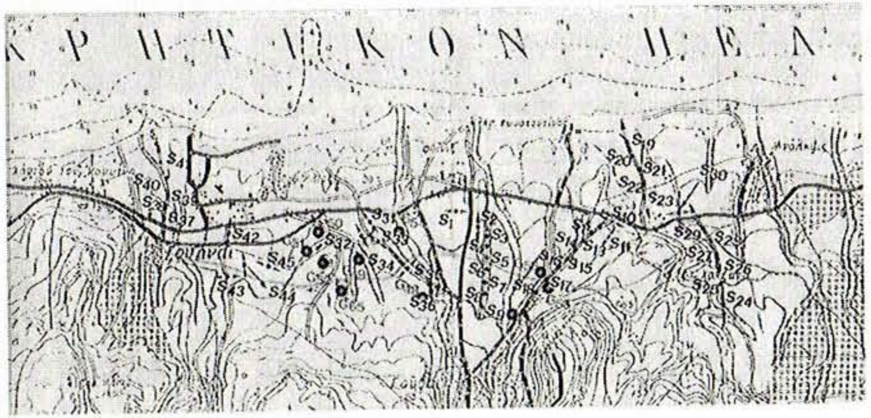

Figure 4: Topographic map showing geoelectric soundings and boreholes.

An example of the measured apparent resistivity curves along Traverse T1 (soundings S19-S23) and their corresponding geoelectric models is depicted in Fig.5. Regions with resistivities less than 10 Ohmm depict salinization. A 2D geoelectric section along the whole traverse is presented in Fig.6 and shows clearly the intrusion of saline water.

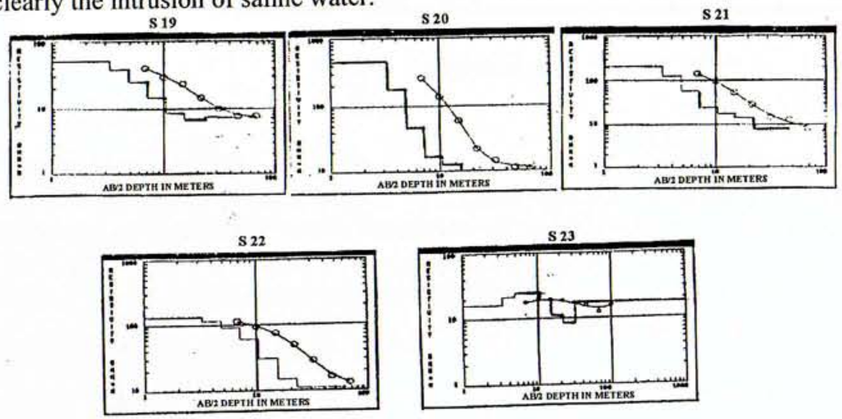

Figure 5: Measured apparent resistivity curves and corresponding geoelectric models for traverse T1.

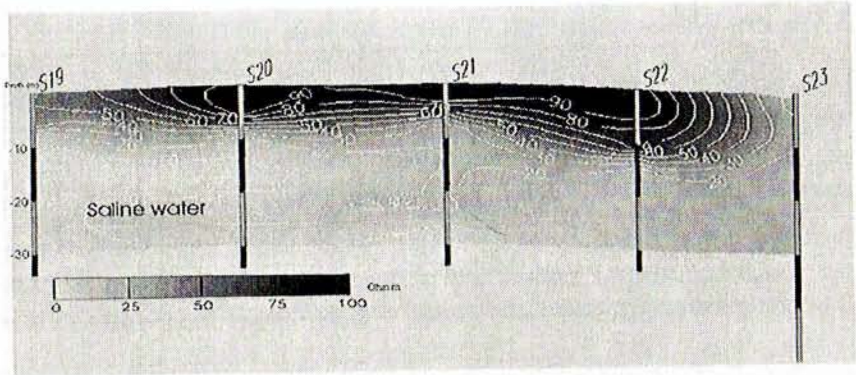

Figure 6: Geoelectric section T1.

By combining the geoelectric data from all traverses we constructed a 3D geoelectric model of the coastal region of Guves (Fig.7) which depicts the extend of the salinity problem in the region. Judging from this diagram we can deduce two major saline water intrusion plumes separated by a fresh water region. The later can be explained by the existence of a stream discharging at the sea. The outskirts of the two plumes were selected as the installation sites of the permanent monitoring units which are described in the following paragraphs.

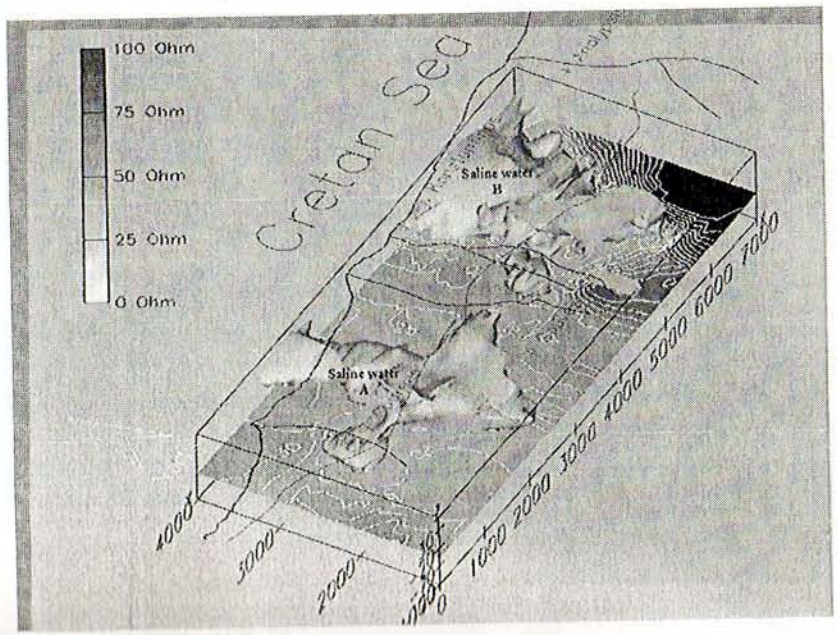

Figure 7: 3D model of seawater intrusion.

5. Saline Water Intrusion Control System

The general structure of the salinity control system which has been specifically designed for the project is depicted in Fig.8. It consists of four local measuring stations (LS1-4) which are located at points were the geophysical investigation showed that possess a high saline water intrusion risk.

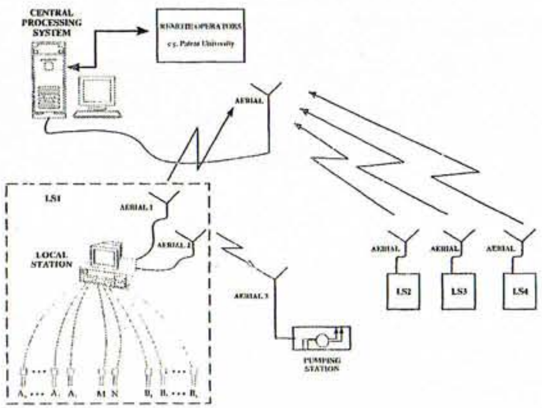

Figure 8: Structure of the system.

All local stations communicate with a central controlling computer throughout radiolink communication and have the following possibilities:

- Definition of their working parameters automatically or manually (also via remote control).
- Automatic measurements at predetermined time intervals.
- Communication and control with pumping stations.
- Communication and data transfer with the central computer control system.

The central computer control system is located at the Municipality of Guves and has the following possibilities:

- Collection and storage of data from all four local stations.
- Data processing and decision on the optimum use of pumping rates.
- Communication with remote operation centers (e.g. the University of Patras with the ability to define / change the operation parameters throughout modem lines).

5.1 Local Station Layout

The construction details of a local station are depicted in Fig.9. The system consists of six main sections (sub-units), the characteristics of each one are described below:

Unit A - Computer System. This is the main platform of the local station through which we can define the operation of the various sub-units. It consists of a computer (Pentium 133MHz) responsible for the data processing of the collected data, communication with the central station and the pumping stations.

UNIT B - A/D Converter. The operation of this unit is controlled from unit A and it is responsible for the digitization of all analogue data incoming into the system such as electric current to electrodes Ai,Bi, electric potential at electrodes Mi,Ni and output from the conductivity meter. The resolution of unit B is 16-bit and it has 16 data input channels.

Unit C - Digital I/O. This unit supplies all the required digital outputs for controlling the operation of units D and E (fig. 9). It controls the operation of Hydroton, that is it selects the current and potential electrodes, level of driving voltage etc. It is also responsible for the addressing of the pumping stations.

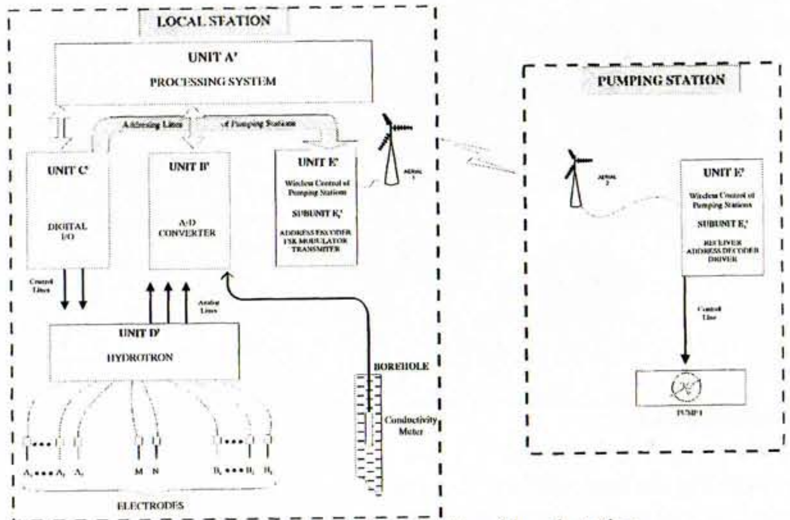

Figure 9: Construction details of local station.

Unit D - Hydroton. This unit consists mainly of all the analogue electronics which will supply the required current to electrodes [Ai,Bi], and measures the induced electric potential along the electrodes [Mi,Ni].

Unit E - Radiolink Control. This unit is responsible for the radio-control of the operation of the pumping stations and consists of two sub-units. Sub-unit E1 (Fig.9) is located inside unit A and its purpose is, in collaboration with unit C, to address the implemented pumping stations, transfer to FSK (Frequency Shift Keying) and emit the signal in the VHF band. Sub-unit E2 is located close to each one of the controlled pumping stations and its role is to receive the FSK codes, translate them and after following specific instructions switch on or off the pumping.

Unit F - Radiolink Network. This unit is responsible for the operation of the radiolink computer network which connects all the computers together via a NOS operating system.

5.2 Software

The developed Software collaborates with the Hardware and is responsible for the monitoring and follow up of the saline water intrusion at the territory of each local station. The drivers designed can be separated into the following two categories:
Low Level drivers. These drivers control the configuration of the various sub-units of the system and recognize various error codes. The operator communicates with the system through a friendly graphics user interface which automatically calls the low level drivers.
Presentation and Control Software. This Software is responsible for 1)the control (by using the low level drivers) of the configuration and the operation of the programmable Hardware of the local station, 2) perform at regular intervals all required measurements, 3) process the geoelectric data in order to derive the physical parameters determining the extent of saline water intrusion, 4)decide on the operation or not of the controlled pumping stations and transmit the required coded signals, 4) Collect, organize and present in a graphical format all collected data. For the implementation of this part of the Software we used the Labview graphical programming environment by National Instruments. An example of a control screen of one of the modules designed and the corresponding graphics user interface are presented in figures 10 and 11 respectively.

6 Conclusions

After mapping the extend of saline water intrusion at the coastal region of Guves a prototype automatic monitoring and control system has been designed. This system is currently under further development by implementing neural algorithms in order to increase its sensitivity to minor variations of the salinity of the coastal aquifers.

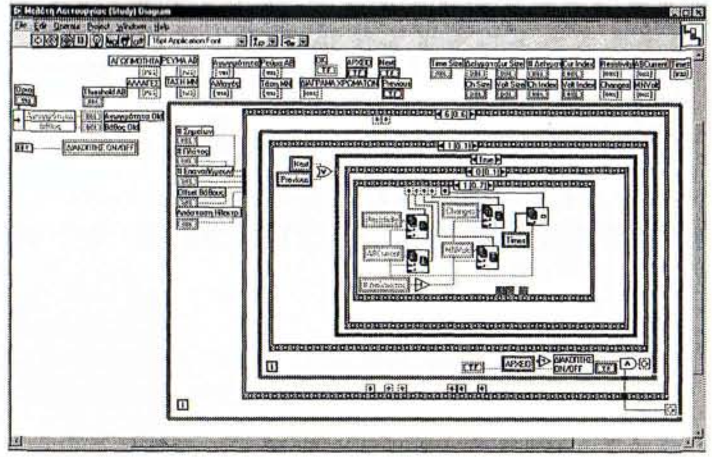

Figure 10: Module designed to generate the graphics user interface of fig.11.

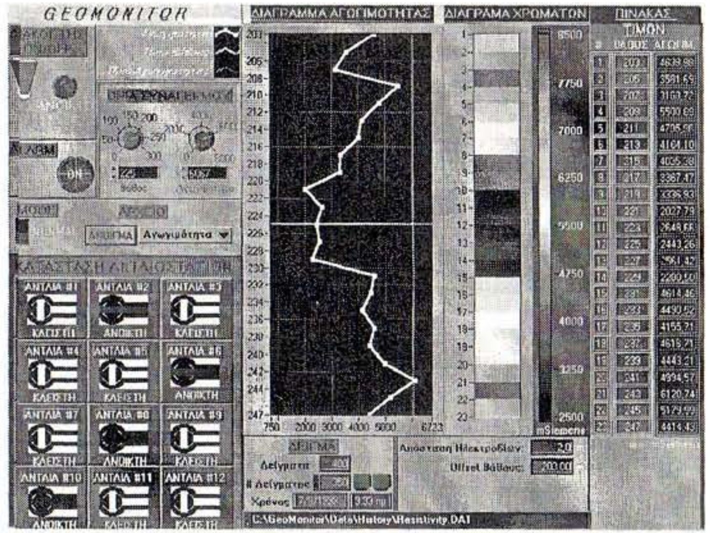

Figure 11: Example of graphic user interface for the control of 12 pumping stations corresponding to fig. 10.

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