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A Hydrogeotechnical Integrated System for Water Resources Management of Attica – Greece

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Abstract: In this paper an information management system used in Attica Greece that combines modeling with the integrated management of water, sewerage and storm water infrastructure is presented. From this information management system there are proposed certain public works that are grouped in two categories, i.e. works that are needed for the entire Attica district and have a general character for the whole region (1st category works) and then, works that are specifically needed for every particular and individual municipality (2nd category works).

The first category consists of: Collection and Treatment of the Used Water Works, and Reuse of at least a portion of the Treated Wastewater Works, and the second category consists of: Flood Protection through Stormwater Storage Works, Artificial Recharge of Groundwater Aquifers Works, Municipal Boreholes & Wells Construction Works, Works of Water Conservation & Recycling for use for Industrial Purposes, Spring Development & Exploitation Works, and Desalination of Groundwater Resources Works. Alternative scenarios and proposals are evaluated using G.I.S. technology, and finally the greater usage of the integrated modeling and the management as well as the technical results in terms of proposed public infrastructure works for each municipality in Attica district are presented.

Key words: surface and groundwater resources sustainable management - integrated management - water conservation and recycling - decision support systems - groundwater modeling - surface water modeling - G.I.S..

1. INTRODUCTION

Water resources planning and management in Attica Greece usually involves multiple stakeholders and attempts to achieve conflicting objectives. This often addresses water supply development, consumption, discharge, and irrigation by municipal, industrial and agricultural users. Since in Attica Greece there is insufficient water available to meet projected demand, the water resources planning becomes more complicated conflictional, and often ambiguous endeavour. Between the political problems for water resources planners is to decide what infrastructure works are to be promoted In this means systems-based decision-support models can help water resources managers and planners to better identify the critical stakeholders in the water allocation process and what their goals and concerns to meet the increasing demands more sustain ably.

James (1999) examines the sustainability of water resources infrastructure investments, broadly defining “sustainability” to “require that no non-renewable energy be consumed, nor should any water or energy be imported from remote areas, and also no by-products such as chemical contaminants should be exported or accumulated locally In attempting to design more “sustainable” infrastructure, James develops an innovative proposal to radically change how our capital facilities for water supply, stormwater management, and wastewater collection and disposal are designed, repaired, monitored, and managed..” James also proposes using robotics for autonomous infrastructure inspection and repair, refocusing infrastructure planning to address population growth and waste generation, and creating new types of private-sector and public-private institutional arrangements to more efficiently address urban development objectives and to ensure better infrastructure performance and quality control. Differing also with James’ definition of “sustainability” to limit energy use and water imports.

Burke (1993) discusses an information management system used in Australia and Japan. According to Burke (1993) skilled management will be required and will emerge, if only to provide a working environment in which problems and effectiveness can be improved through these types of innovation. Infrastructure innovation is needed because it benefits both our quality of life and economic prosperity. R&D goes hand-in-hand with the provision of innovative infrastructure. Research for innovative infrastructure and development and commercialization of innovations has been discussed in three recent reports by the Civil Engineering Research Foundation (CERF, 1993, 1994, 1997). Data from U.S. federal laboratories indicates that public works (which is much more than just water) infrastructure R&D activity ranged between $1.026 and $1.386 billion in 1992, about 1.6% of total federal R&D expenditures. However no federal agency has been assigned or taken the lead role, with the result that public works infrastructure R&D lacks guidance of a comprehensive, coordinated, and integrated national policy. CERF (1993) recommended the cooperative development of a national public works research agenda by federal, state, and local entities, together with the private sector.

In a comparative study of European and American R&D, it was found that the U.S. led in high performance concrete, waste and wastewater treatment, computer-aided design, solid and hazardous waste disposal, global positioning systems (GPS) and GIS technology, and integrated databases (CERF, 1994). Europe on the other hand led in tunneling, and energy conservation (while Japan led in automation, field computer use, safety and building systems). Europeans may soon lead in innovative infrastructure because they lack the concern for liability issues that so plagues North America. In Europe new technology from R&D has a better chance of application in practice, and this encourages positive payback from R&D investment.

The aim of this study is to contribute to the problem of water Resources Management of Attica by developing a decision support system based on GIS tools for the rational selection of works of water supply development, consumption, discharge, and irrigation by municipal, industrial and agricultural users of the area.

2. DESCRIPTION OF THE INTEGRATED SYSTEM

The use of models to better understand complex relationships and thereby choose among alternative water resources decisions is a subtheme in almost all of the researchers in the area. Tarlock(1999) and Henderson (1999) both note in passing that modeling can help planners manage water resources better and develop the institutional strategies that are needed to address the forecasted impacts of proposing works or consuming such resources, while James looks to sophisticated models and distributed intelligence as a means to design and to modify infrastructure characteristics in real time to meet changing use demands.

The Water resources Management of Attica (WARMA) is designed to serve as a GIS tool in a systematic analysis of the interactions among water resources environmental and socioeconomic dynamics of the Attica watersheds (C. Sachpazis 2004).

The Integrated System for Water Resources Management of Attica is a System of Information intended to supplement the process of decisions making. The individual objectives of this study are:

a) The estimation of available water resources potential and its geographical distribution,

b) The estimation for water needs and demand and its geographical distribution,

c) The determination of most optimal measures or works for management of exploitation of water resources,

d) The determination of most optimal measures or works for treaties of extreme circumstances or conditions (droughts, floods, etc.),

e) The evaluation of various scenarios of growth, as well as,

f) The dynamic management of water resources in a small time horizon (i.e. 1 month).

As advisable technology for the creation of the Integrated System for Water Resources Management had been decided and worked out the use of Geographical Information System Technology.

It is a GIS DSS that includes sectors for simulation of alternatives, decision analysis and assessment of alternatives. In the water resources component of this spatially explicit model, the important processes are simulated within the varying habitats distributed throughout the landscape. The principal dynamics within the model are: groundwater water resources management surface water management climate plant growth. By incorporating high spatial, temporal, and complexity resolution, the model can realistically address large-scale management issues within the heterogeneous system of the Attica watersheds.

3. THE STUDY AREA

The study area included the inner land section of Attica Region (apart from Trojzinja) and with limits, the limits of the drainage hydrologic basins that belong at least 50% in percentage in the administrative authority of the Attica Region. The study area is illustrated in Fig. 1.

The study area is divided in the prefectures of Athens, Eastern Attica, Western Attica and a part of prefecture of Piraeus. It is also further divided in 75 Municipalities and 38 Villages. The administrative limits of each Municipality or Village are shown in Fig. 1.

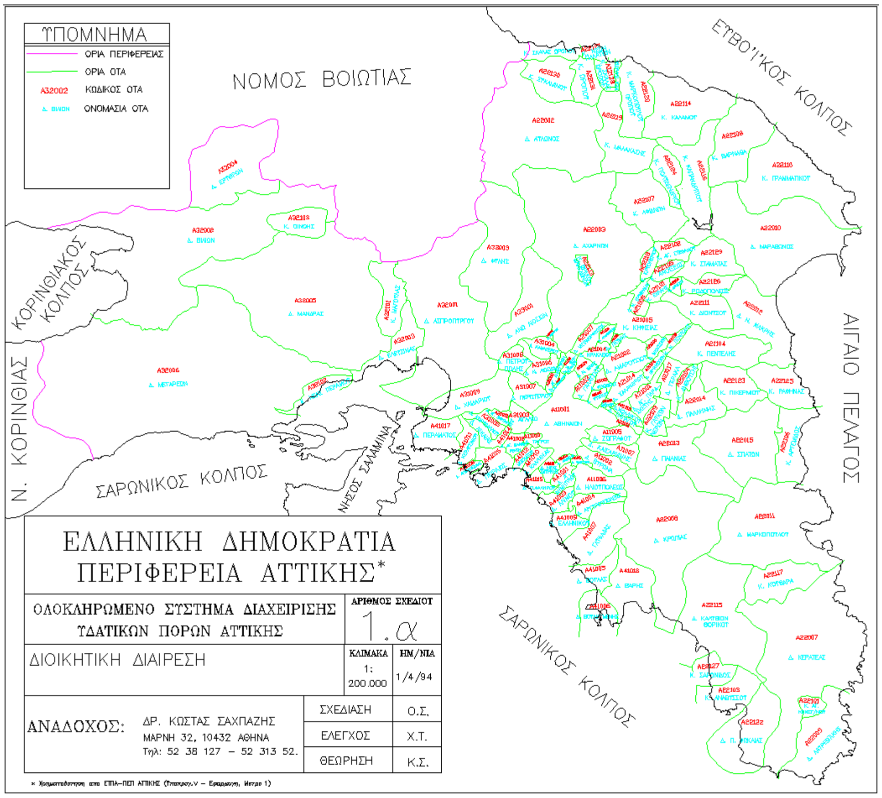

Figure 1. Study area and administrative limits.

4. PROPOSED WORKS

The works are proposed according to municipalities needs. However, there are works that apply to more than one municipality having a more general character for a region or for the entire area that lead to the conclusion that there is a need of an Organization of Water Resources Management. These works are described in the following paragraphs. Initially, the works that are needed for the entire Attica district (1^{st} category works) and then, the works that are specifically needed for every particular and individual municipality (2^{nd} category works).

1^{st} category works.

1. Collection and Treatment of the Used Water Works.

The works of Mornos, Iliki, Evinos, Trihonida, etc. Municipality can cover the water needs of 18 million cubic meters estimated for the year 2010.

2. Reuse of at least a portion of the Treated Wastewater Works.

Using of at least a portion of the treated wastewater from the Psitalia (60-90 millions m^3/year) and Metamorphosis (5-6 millions m^3/year) treatment plants for agricultural use in the municipalities of Aspropyrgos (5 millions m^3/year), Mandra (4 millions m^3/year), Nea Peramos and Megara (45 millions m^3/year) and the potential leftover treated wastewater can be used for industrial use of Aspropyrgos and Elefsis municipalities. The Metamorphosis Wastewater Treatment plant can cover reforestration works of Penteli and Parnitha and cooling in industrial plants.

2^{nd} Category works.

In the following paragraphs six types of the 2^{nd} category works are examined:

1. Flood Protection through Stormwater Storage Works.

In Fig. 2 it is shown the map of Attica district hydrologic basins and the drainage network system, indicating the needs for Flood Protection through Stormwater Storage Works.

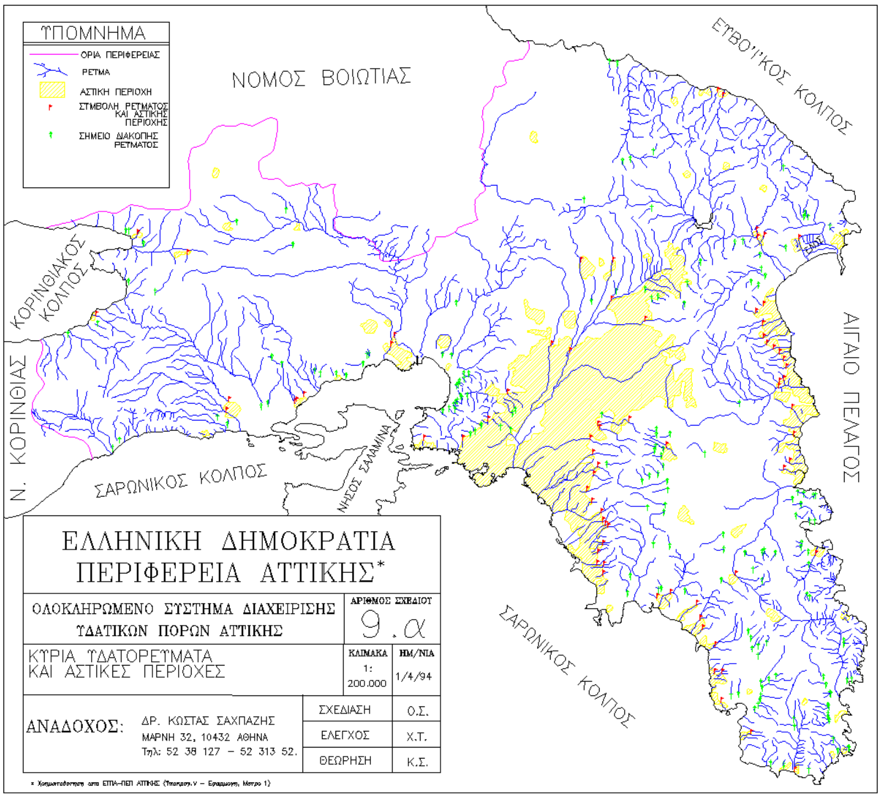

Figure 2. Map of Attica district hydrologic basins and drainage network system, showing the needs for Flood Protection through Stormwater Storage Works. Red flags ( ) indicate very high peak storm runoff (Q_p) and green crosses ( ) indicate natural recharge of aquifers. = Urban Area.

The red flags indicate very high peak storm runoff (Q_p) and the green crosses indicate natural recharge of aquifers. According to this map the proposed works are classified to:

- 1st priority works (A) representing municipalities with a considerable stormwater discharge (red flags),
- 2nd priority works (B) representing municipalities where there is an intersection of currents and inhabited areas (green crosses).

2. Artificial Recharge of Groundwater Aquifers Works.

Artificial recharge of groundwater aquifers works are proposed in areas exhibiting increased surface runoff and discharge. When there is a chance of also combining stormwater storage works with irrigation works, the area is categorized as A priority. B priority works are the ones for preserving or improving water quality for irrigation works. See Fig. 2.

3. Municipal Boreholes & Wells Construction Works.

The proposed works, presented in the following Table 1, are derived from the combination of Fig. 2, Fig. 3 and Fig. 4, which show the map of Attica district hydrologic basins and the drainage network system (Fig. 2), the map of runoff curve number or specific runoff coefficient (Fig. 3), and the map of groundwater exploitation potential (Fig. 4), according to the map of municipality irrigation needs, in Fig. 5.

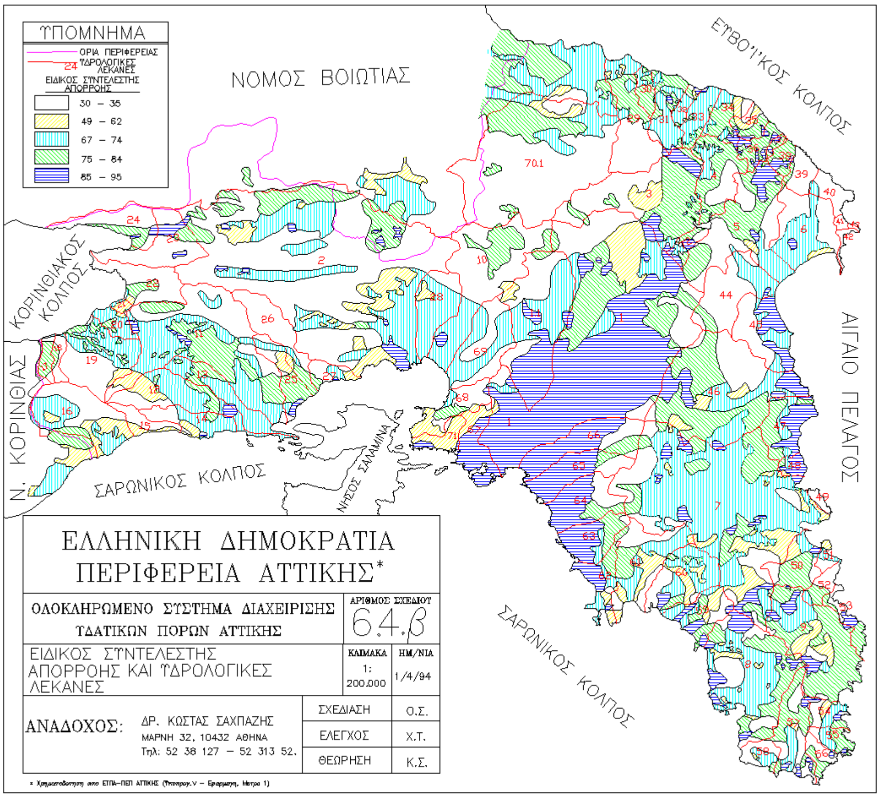

Figure 3. Map of Runoff Curve Number or Specific Runoff Coefficient. a) = 30-35, b) = 49-62, c) = 67-74, d) = 75-84, and e) = 85-95.

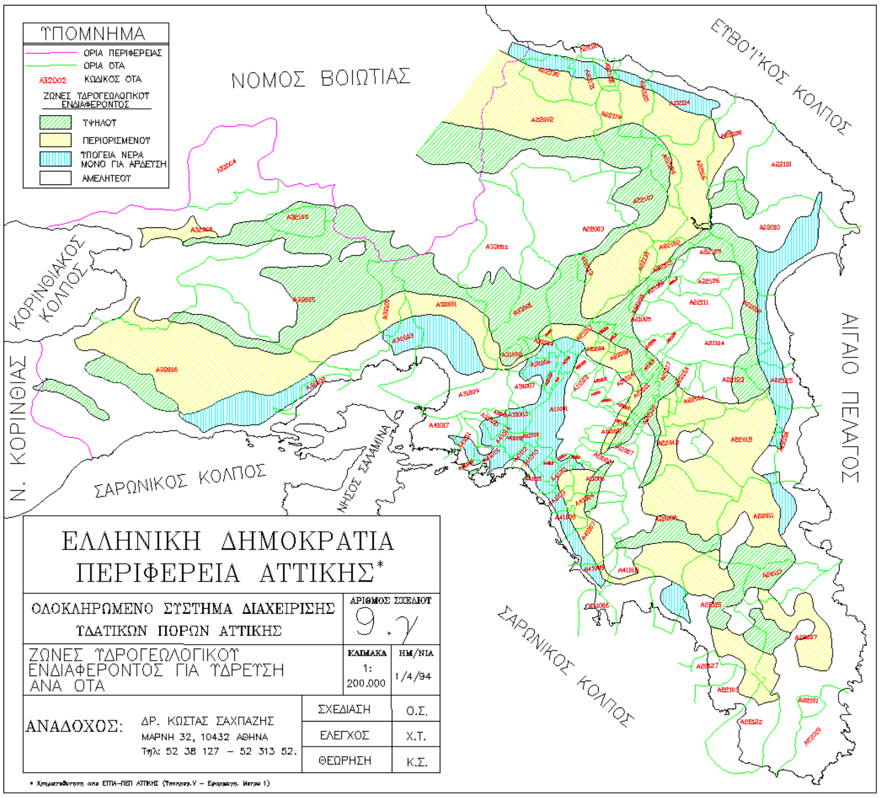

Figure 4. Map of Groundwater Exploitation Potential. a) = High, b) = Restricted, c) = Only for Irrigation purposes, d) = Negligible.

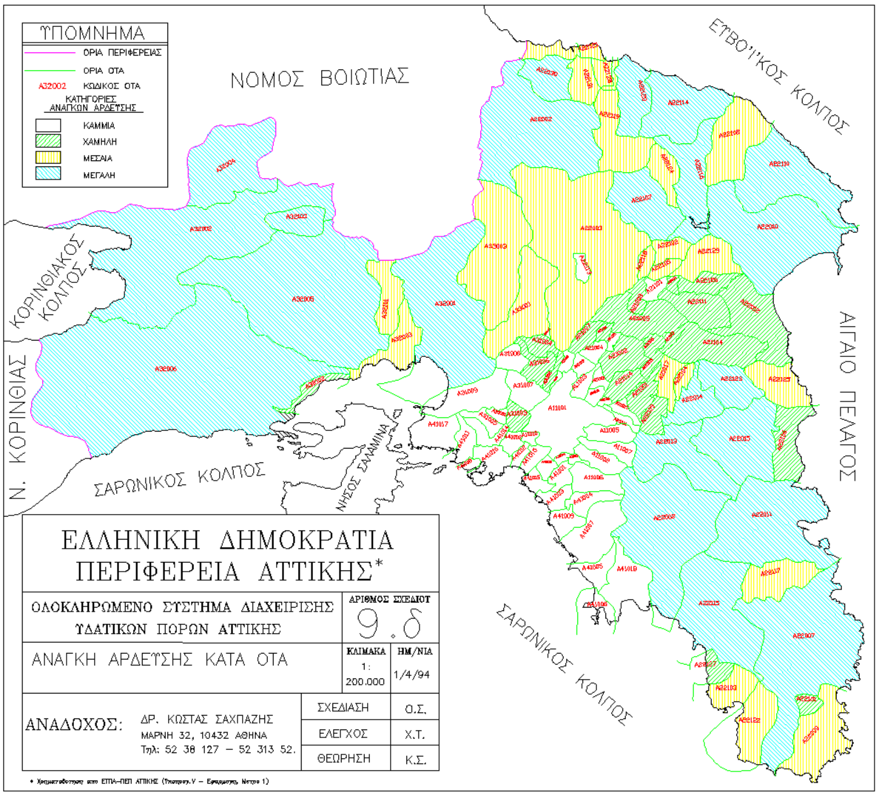

Figure 5. Map of Municipality Irrigation Needs. a) = No needs, b) = Low, c) = Moderate, d) = High

The categories in Table 1 are as follows:

A: when the proposed municipal boreholes & wells construction works are required to totally cover the irrigation needs and there is the possibility to construct three more wells within the municipality territory.
B: when the number of the additional required wells is under 10.
C: when the number of the additional required wells is over 10.

4. Works of Water Conservation & Recycling for use for Industrial Purposes.

In the municipalities marked at this column of the Table 1, there is the possibility of water conservation and use for industrial purposes. For this reason land coverage and use maps were used.

5. Spring Development & Exploitation Works.

The proposed works for spring development & exploitation concern the usage of springs, both surface and undersea, that are not in use. (See the map of surface and undersea springs in Fig. 6). Undersea springs, are totally unexploited. Furthermore the majority of the surface springs are not in use and their rate of water flow quantities can be increased with the proposed works for spring development & exploitation.

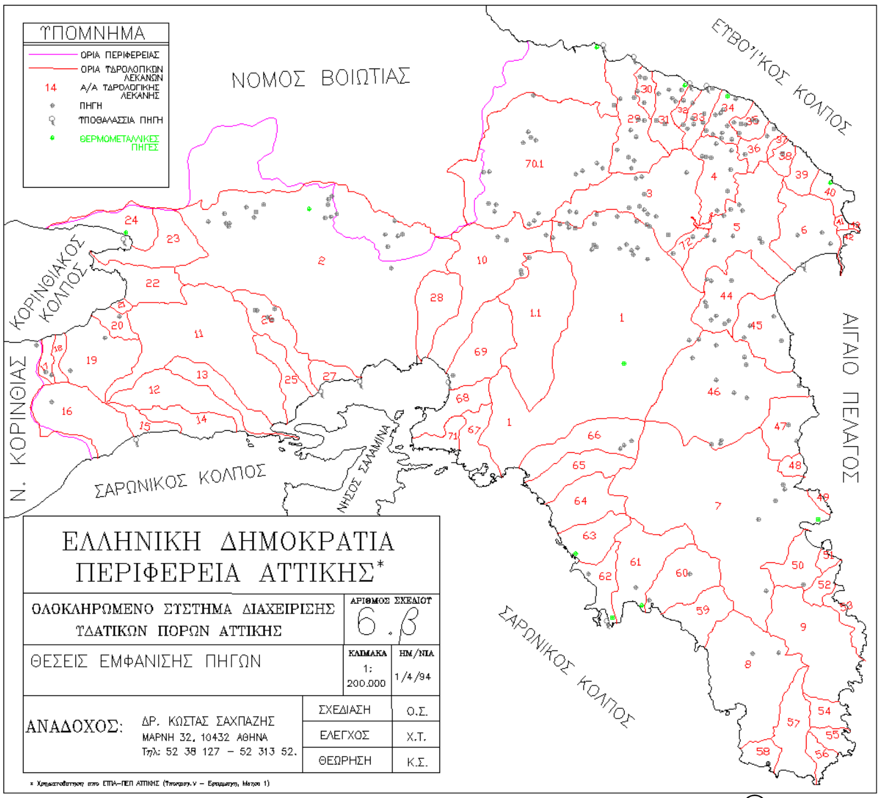

Figure 6. Map of Surface and Undersea Springs. a) ⊕ = Surface Spring, b) = Undersea Spring, ⊕ = Surface Thermometalic Spring.

6. Desalination of Groundwater Resources Works.

In Fig. 7 the map of groundwater conditions and hydrogeologic basins are shown, as well as the zones of brackish water where desalination works are required are presented. Depending on the quality of water this use can cover agricultural needs.

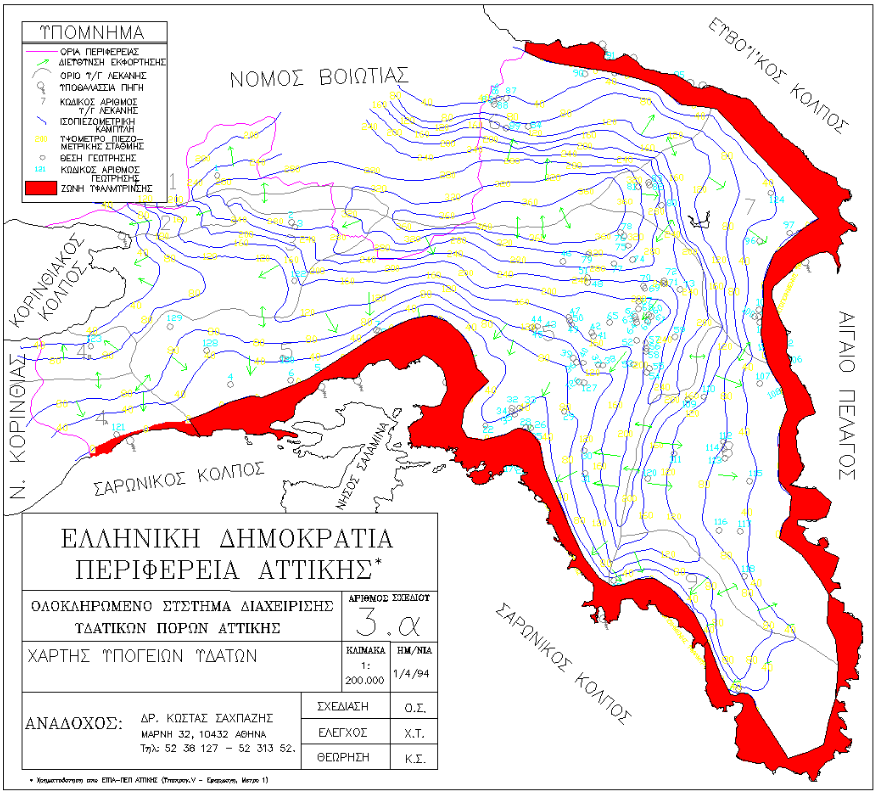

Figure 7. Map of Groundwater Conditions and Hydrogeologic basins. a) = Brackish Water where Desalination Works are required, b) = Groundwater Piezometric Contour, = Borehole Location.

The Study Results.

Based on alternatives-proposals studied, as well as the actions and the public works proposals that will contribute in the resolution of this problems are concisely and precisely presented in the conclusion Table 1.

Table 1: Proposed municipality public infrastructure works, related to water resources management, flood protection and exploitation.

Municipality Code	Municipality Name	Flood Protection through Stormwater Storage Works	Works of Artificial Recharge of Groundwater	Municipal Boreholes & Wells Construction	Water Conservation & Recycling for use for industrial purposes	Spring Development & exploitation	Desalination of Groundwater Resources
A11001	Athinaion				**X**		
A11002	Vironos	**B**					
A11003	Galatsi						
A11004	Daphni						
A11005	Zoogrrafos						
A11006	Ilioupoli	**B**					
A11007	Kaisariani	**B**				**X**	
A11008	Nea Filadelphia				**X**		
A11009	Nea Chalkidona						
A11010	Tavros				**X**		
A11011	Imittos				**X**		
A21001	Agia Paraskevi			**A**			
A21002	Amarousio			**A**			
A21003	Vrilissia			**A**			

Municipality Code	Municipality Name	Flood Protection through Stormwater Storage Works	Works of Artificial Recharge of Groundwater	Municipal Boreholes & Wells Construction	Water Conservation & Recycling for use for industrial purposes	Spring Development & exploitation	Desalination of Groundwater Resources
A21004	Iraklio						
A21005	Kifisia			**A**	**X**		
A21006	Melissia			**A**			
A21007	Metamorphosi			**A**	**X**		
A21008	Nea Erythrea			**A**			
A21009	Nea Ionia				**X**		
A21010	Neo Psichiko						
A21011	Papagos						
A21012	Pefki						
A21013	Philothei						
A21014	Chalandri			**A**			
A21015	Cholargos						
A21016	Psichiko						
A21017	Gearakas			**B**	**X**		

Municipality Code	**Municipality Name**	**Flood Protection through Stormwater Storage Works**	**Works of Artificial Recharge of Groundwater**	**Municipal Boreholes & Wells Construction**	**Water Conservation & Recycling for use for industrial purposes**	**Spring Development & exploitation**	**Desalination of Groundwater Resources**
A21101	Ekali						
A21102	Likovrisi			**A**	**X**		
A21103	Nea Penteli						
A21104	Penteli			**A**		**X**	
A22002	Avlon			**C**	**X**	**X**	
A22003	Acharnai	**B**		**B**	**X**	**X**	
A22007	Keratea			**C**			
A22008	Kropia			**C**			**X**
A22009	Lavreotiki				**X**		
A22010	Marathonas			**C**		**X**	**X**
A22011	Markopoulo Mesogeas			**C**		**X**	**X**
A22012	Nea Makri	**B**		**A**			
A22013	Paiania			**C**	**X**		
A22014	Pallini				**X**		

Municipality Code	Municipality Name	Flood Protection through Stormwater Storage Works	Works of Artificial Recharge of Groundwater	Municipal Boreholes & Wells Construction	Water Conservation & Recycling for use for industrial purposes	Spring Development & exploitation	Desalination of Groundwater Resources
A22015	Spata						
A22101	Agios Konstantinos						
A22102	Agios Stefanos	**A**	**A**	**B**	**X**		
A22103	Anavisos			**B**			**X**
A22104	Anthousa			**B**			
A22105	Anoixi			**B**			
A22106	Artemida	**A**	**A**	**A**			
A22107	Afidnai			**C**	**X**	**X**	
A22108	Varnava			**B**			
A22109	Glika Nera			**A**			
A22110	Grammatiko			**C**		**X**	**X**
A22111	Dyonisos					**X**	
A22112	Drosia						
A22113	Thracomakendonon	**B**					

Municipality Code	Municipality Name	Flood Protection through Stormwater Storage Works	Works of Artificial Recharge of Groundwater	Municipal Boreholes & Wells Construction	Water Conservation & Recycling for use for industrial purposes	Spring Development & exploitation	Desalination of Groundwater Resources
A22114	Kalamos	**A**	**A**	**C**			**X**
A22115	Kalyvia Thorikou			**C**			**X**
A22116	Kapandriti			**C**			
A22117	Kouvaras			**B**			
A22118	Kryoneri			**B**	**X**		
A22119	Malakasa			**B**	**X**	**X**	
A22120	Markopoulou Oropou			**C**			**X**
A22121	Neon Palation			**B**			**X**
A22122	Palaias Fokaias			**B**		**X**	
A22123	Pikermiou			**C**			
A22124	Poludendriou			**B**			
A22125	Pafina	**B**		**B**			
A22126	Rodopolis			**A**		**X**	
A22127	Saronida						**X**

Municipality Code	Municipality Name	Flood Protection through Stormwater Storage Works	Works of Artificial Recharge of Groundwater	Municipal Boreholes & Wells Construction	Water Conservation & Recycling for use for industrial purposes	Spring Development & exploitation	Desalination of Groundwater Resources
A22128	Skala Oropou						**X**
A22129	Stamata			**B**		**X**	
A22130	Sikaminou			**C**			
A22131	Oropos			**B**			
A31001	Agia Varvara	**A**	**B**				
A31002	Agioi Anargyroi			**A**			
A31003	Egaleo			**A**	**X**		
A31004	Kamatero			**A**			
A31005	Korydalos	**A**	**B**				
A31006	Ilion - Nea Liosia			**A**			
A31007	Peristeri				**X**		
A31008	Peroupoli						
A31009	Haidari	**B**			**X**		
A32001	Aspropyrgos	**B**		**C**	**X**		

Municipality Code	Municipality Name	Flood Protection through Stormwater Storage Works	Works of Artificial Recharge of Groundwater	Municipal Boreholes & Wells Construction	Water Conservation & Recycling for use for industrial purposes	Spring Development & exploitation	Desalination of Groundwater Resources
A32002	Vilia	**B**		**C**		**X**	
A32003	Elefsina	**B**		**B**	**X**		
A32004	Erithres						
A32005	Mandra			**C**		**X**	
A32006	Megara	**A**	**A**	**C**		**X**	
A32101	Magoula			**B**			
A32102	Nea Peramos	**B**		**A**		**X**	**X**
A32103	Oinoi			**C**		**X**	
A33001	Ano Liosia	**B**		**B**			
A33002	Zefyri						
A33003	Fyli			**B**		**X**	
A41001	Agios Dimitrios						
A41002	Agios Ioannis Rentis				**X**		
A41003	Alimos						

Municipality Code	Municipality Name	Flood Protection through Stormwater Storage Works	Works of Artificial Recharge of Groundwater	Municipal Boreholes & Wells Construction	Water Conservation & Recycling for use for industrial purposes	Spring Development & exploitation	Desalination of Groundwater Resources
A41004	Argyroupoli	**A**	**B**				
A41005	Voula	**A**	**B**				
A41006	Vouliagmeni					**X**	
A41007	Glyfada	**A**	**B**				
A41008	Drapetsona				**X**		
A41009	Elliniko	**A**	**B**				
A41010	Kallithea						
A41011	Keratsini	**A**	**B**		**X**		
A41012	Moschato				**X**		
A41013	Nea Smyrni						
A41014	Nikaia	**A**	**B**				
A41015	Palaio Faliro						
A41016	Piraeus				**X**		
A41017	Perama	**B**			**X**		
A41018	Vari	**B**				**X**	

5. CONCLUSIONS

A decision support system based on G.I.S. tools designed as an hydrogeotechnical information management system that combines modeling with the integrated management of water supply development, consumption, discharge, hydrologic water cycle and irrigation by municipal, industrial and agricultural users of the study area is presented. The system was used in Attica district - Greece and specifically in the prefectures of Athens, Eastern Attica, Western Attica and a part of prefecture of Piraeus.

The system proved very useful for the rational selection of proposed works such as Collection and Treatment of the Used Water Works, Reuse of at least a portion of the Treated Wastewater Works, Flood Protection through Stormwater Storage Works, Artificial Recharge of Groundwater Aquifers Works, Municipal Boreholes & Wells Construction Works, Works of Water Conservation & Recycling for use for Industrial Purposes, Spring Development & Exploitation Works, and Desalination of Groundwater Resources Works.

Alternative scenarios and proposals may be evaluated, using G.I.S. technology, for each municipality and the greater use of the integrated modeling and the management, as well as technical results in terms of proposed public infrastructure works can be rationally derived. Out of this study one hundred and fifty nine (159) public infrastructure works related to water resources management, flood protection and exploitation, were proposed in one hundred and thirteen (113) municipalities of prefectures of Athens, Eastern Attica, Western Attica and a part of prefecture of Piraeus.

It is believed that a future computer-based support systems tool will provide a more comprehensive information management system, combining: engineering input-output data, hydrogeotechnical input-output data, maintenance requirements schedules, automatic data collection, and impact assessments scenarios, related to water resources management, flood protection and rational exploitation.

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