GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN WATER MANAGEMENT[1]

Prof. John N. Hatzopoulos, director of RSLUA

Remote Sensing Laboratory and GIS (RSLUA), Department of Environmental Studies
University of the Aegean, Xenia Building, Mytilene, 81100, GREECE
[1] ihatz@env.aegean.gr

ABSTRACT

The use of Geographic Information Systems (GIS) in Water Management is presented in detail. New technologies in mapping sciences which are used to collect ground profile and elevation data for water management are covered. Hydrological GIS models for rainfall – runoff, continuous stream flow, flooding, and water quality are also presented. Integration of data modeling together with advances in GIS using Universal Model language (UML) programming is presented. The results of an experiment in the island of Naxos are analyzed.

1. INTRODUCTION

Water management requires a good understanding of the geographical space and related spatial information such as water sources, terrain surface, watershed, land cover, land use, rainfall, temperature, humidity, soil condition and composition, geology, conditions on the atmosphere, human activities, environmental data, etc. The accurate knowledge of the terrain surface helps to understand and model most hydrological processes. There are many hydrological models (Maidment D. R,1993) for surface and subsurface water hydrology and GIS is the way that many researchers are trying to use to manage the information. The terrain surface is the medium on which many activities of the water take place such as: Rainfall, water transport over the surface or through the surface, irrigation, flooding, plant evapotraspiration, and this work is focused on the terrain surface.

There are three basic issues on water management (Maidment D. R,1993): (a) Pollution control and mitigation for both surface water and ground water, (b) water utilization for water supply for municipalities, agriculture, industry and competing demands for insteram water use and wildlife habitat, (c) flood control and mitigation. Waters can be classified into three types: (a) atmospheric water, (b) surface water and (c) subsurface water. A water utility company deals with many aspects of the water such as: atmospheric water and rainfall, hydrology and water collection, water reservoirs, water transport through pipes and canals, water distribution to customers, maintenance of water distribution system, waste water collection and biological processing, waste water maintenance infrastructure, flood control and mitigation. The ideal way to manage all those issues is to have a data base with static and dynamic (near real time) information linked to corresponding geographic locations and have the tools to do the necessary processing or do the interface with management and planning models. Such a system is a GIS system, which is discussed bellow.

2. GIS AND HYDROLOGY.

A GIS system can be viewed as a database, which comprises all geometric elements of the geographical space with specific geometric accuracy together with information i. e. in tabular form which is related to geographic location. The GIS is associated by a set of tools, which do data management, processing, analysis and presentation of results for information and related geographic locations. The geographical space can be viewed as composed of overlaid planes of information over a wider geographical area and each plane has specific information or features. One plane may have the drainage features (see Plate 1, Hydrography of Naxos), an other plane may have the elevations, an

[1] Proceedings of the 3rd International Forum "Integrated Water Management: The key to Sustainable Water Resources", March 21 – 22, 2002.

other plane may have the rainfall, etc. Tools help among others to combine planes of information do processing with combined planes using map algebra, and create thematic maps. Plate 2 combines hydrography with digital elevation data, which were obtained from digitizing of contours of 1:50000 Army Geographical Service general purpose maps. Plates 3 and 4 combine contours hydrography and digital elevation data to produce a thematic map. Features in a GIS are considered as objects, which are used to build most models of information. There are simple geometric objects such as points or more complex objects such as lines and areas, which may be considered as composed of point objects.

GIS technology has evolved to use data from databases or warehouses which are accessed: directly in house, or through the network or Internet in remote locations and the information can be in a static or dynamic form. The example that follows illustrates such capabilities: A GIS system of a utility company uses numerical weather forecasting data from a database located at the University of Athens via Internet, the Hydrological model which is running the GIS system, runs automatically each time the weather forecasting data change, it computes the volume of the water at specific locations in the city which have an increased risk of flooding. If we assume a reliable three day forecasting system, then there is enough time for the utility company to issue a warning for the people in those areas, or to do a maintenance to the sewer system in the area of increased risk.

Further developments on GIS tools allows modeling to be performed based on object programming techniques with components ordered into classes which comprise data, methods or procedures and events. A class which may be a line segment of a river, for example, may contain data such as coordinates of points, length and profile dimensions and may have procedures to compute the flow capacity at a given moment. GIS software vendors have developed more modeling tools and capabilities into their systems and a clear modeling programming language such as the Unified Modeling Language (UML) (Booch G. et al 1999), have also evolved into a wider range of applications.

GIS hydrological modeling is analyzed by Jenson S. K. and J. O. Domingue. 1988, while Eli Robert N., 2000, gives a detail analysis of the current state of the art and proposes a new algorithm based on relaxation processes. The interesting of all such work is that the basic information needed to begin with is the terrain surface represented by a digital elevation model (DEM).

3. DIGITAL ELEVATIONS

In May 2000 at the ASPRS annual conference in Washington DC, the USGS National Mapping Division introduced in a Forum the “Seamless DataBases to the public”. This forum presentation was to announce the availability to the public of the “National Hydrography Dataset (NHD)”, which combines the attributes of the U. S. Environmental Protection Agency’ s (EPA) Reach files with the spatial characteristics of the USGS 1:100000 – scale hydrography data. The EPA Reach files are also reported by Plastino Michael, et. al., 2000. These datasets are designed to be ready for efficient incorporation into GIS and to be distributed by variable geographic extend as defined by the customer. The National Elevation Dataset - Hydrologic Derivatives (NED-H) and Watershed Boundary Dataset (WBDS) currently are under development in collaboration with the National Weather Service, EPA, and others. In the forum it was also reported that they were planning for water management purposes, to cover the entire USA with elevation data of accuracy of 12 cm while other plans were reported for covering the entire globe with elevation data of 35 m accuracy. Besides Photogrammetry, which was used for elevation data, new technologies were also used such as Light Detection and Ranging (LIDAR) and Interferometric Synthetic Aperture Radar (IfSAR) (Maune David F., et al, 2000). At that time 75% of the globe was covered already with IfSAR data and it was anticipated to take about 2.5 years to finish the data processing in order to produce elevation datasets of 35 m accuracy.

The important role of the elevation data in water management can be explained easily in the following example (Jenson S. K. and J. O. Domingue. 1988, Tarboton D. G., R. L. Bras, I. Rodriguez-Iturbe, 1991). Consider an area on the ground divided into raster shells (Fig. 1a) where each shell is a rectangle with elevations known in all four nodes as shown in Fig 1b. Let us examine the raster shell **X** in Fig. 1a, which is assumed to have a quantity of water and an average elevation, each of the surrounding shells have also an average elevation. Then if there is one of the surrounding shells with lower elevation, the water will flow towards that shell. If we assign codes 0 through 7 to the surrounding shells, then the flow direction may be coded as 0, 1, 2, …, 7. The maximum shell slope **S** and its direction **Az** can be computed from the elevations in the four nodes and in this way the flow direction (0, 1, 2, …, 7) can be easily determined. Those simple principles are applied to determine and analyse the watershed parameters. There are, however, some problems regarding the shell properties such as pits and flat areas, which are handled in various ways by the Hydrological models.

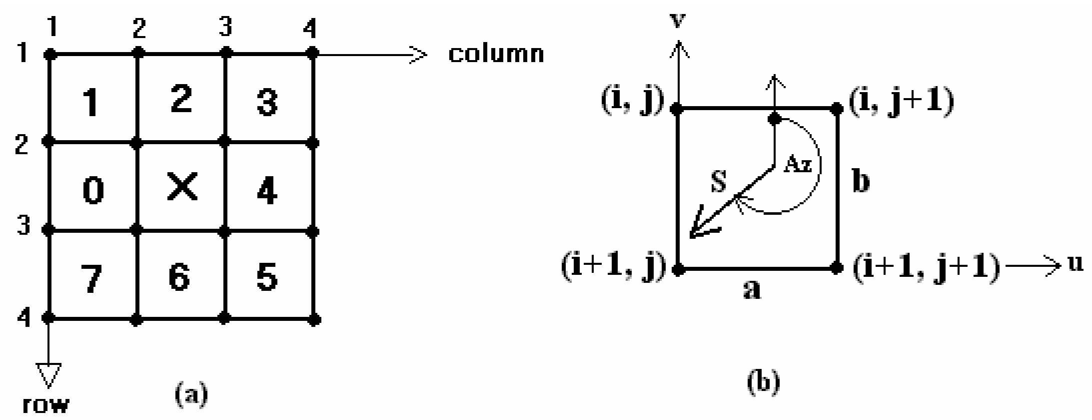


Figure 1. (a) Raster shells ordered in rows and columns, (b) maximum slope and direction in a raster shell.

GIS technology operates easily on raster layers through the map algebra operators and helps to easily access data from various sources, manage intermediate results and make necessary interfaces with water management models and produces well documented outputs.

4. CONCLUSIONS

The priorities in water management start with basic information, which, as stated in the USGS forum, is the creation of National Hydrography Dataset (NHD) and digital elevation datasets of 12 cm accuracy. Hydrologic Derivatives and Watershed Boundary Dataset can also be planned to be the next priority. Already Greece is facing many problems related to water shortage and it is necessary to start taking actions on that direction. The Athens Utility Company EYDAP can play a very important role to make initiatives on those priorities so that other Utility companies can benefit as well. Parallel to that other Government services such as OKXE (Organization for Cadastre and Mapping of Greece) must get government support and also be staffed with qualified personnel to develop and deliver to the public the necessary mapping products which are necessary for any essential planning for development and which are so important for water management.

The production of basic data such as digital elevations and the access to the public will also help to develop know how on using the GIS technology in water management. The Laboratory of Remote Sensing and GIS (RSLUA) at the University of the Aegean has all necessary infrastructure to provide education (seminars, short courses, summer school, workshops), and to do research on those areas and already cooperates with municipality of Drymalias of Naxos on a SEAM project.

5. REFERENCES

Booch G., J. Rumbaugh, and I. Jacobson [three amigos], 1999, "The Unified Modeling Language Used Guide. Addison – Wesley.

Eli Robert N., 2000, "Distributed Watershed Modeling within Geographic Information Systems", Proceedings (on CD) of the ASPRS 2000 Annual Conference, Washington DC.

Jenson S. K. and J. O. Domingue. 1988. Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis, Photogrammetric Engineering and Remote Sensing. Vol. 54, No. 11, November 1988, pp. 1593-1600.

Maidment D. R. 1993, « GIS and Hydrologic Modeling », Environmental Modeling with GIS, M. F. Goodchild editor, Oxford University Press, pp.147 – 167.

Maune David F., Carlton Daniel, James Damron, 2000, "LIDAR and IfSAR: pitfalls and opportunities for our future", Proceedings (on CD) of the ASPRS 2000 Annual Conference, Washington DC.

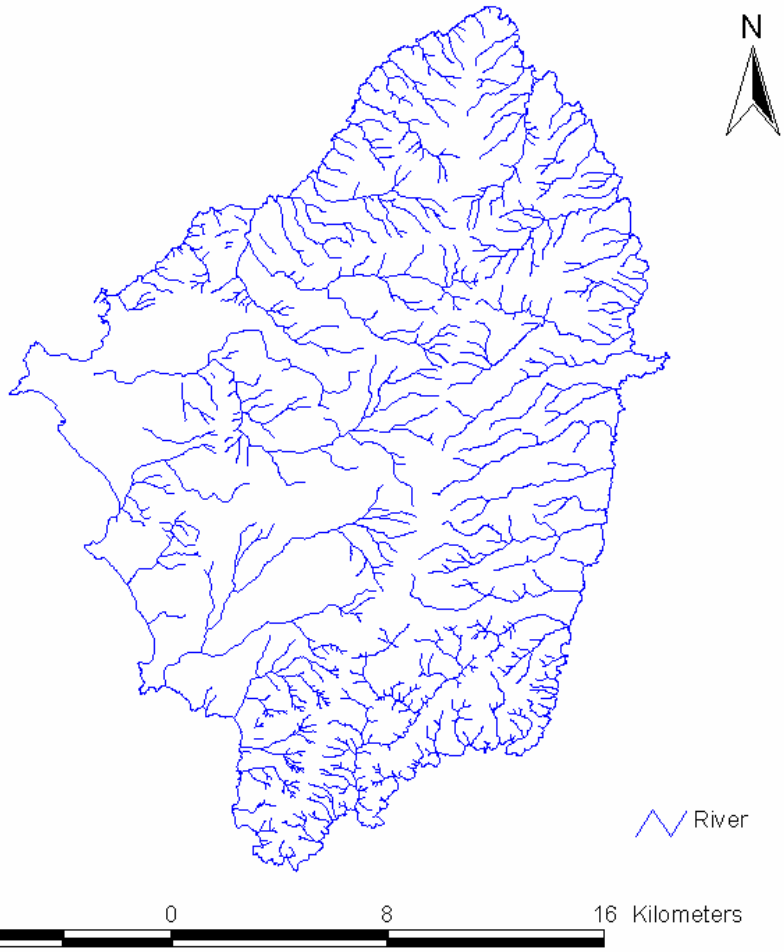
Plastino Michael, T. Dewald, T. Dabolt, 2000, "Towards a more Integrated EPA Information Framework: Office of Water Reach and Watershed Geo-Referencing Initiatives", Proceedings (on CD) of the ASPRS 2000 Annual Conference, Washington DC.

Smith A. Y., R. J. Blackwell, 1987, "Development of an information system data base for watershed monitoring", GIS for Resource Management a Compedium, Ripple W. J. Editor, Published by ASPRS & ACSM.

Tarboton D. G., R. L. Bras, I. Rodriguez-Iturbe. 1991. On the Extraction of Channel Networks from Digital Elevation Data, Hydrological Processes. Vol. 5, pp. 81-100.

6. PLATES

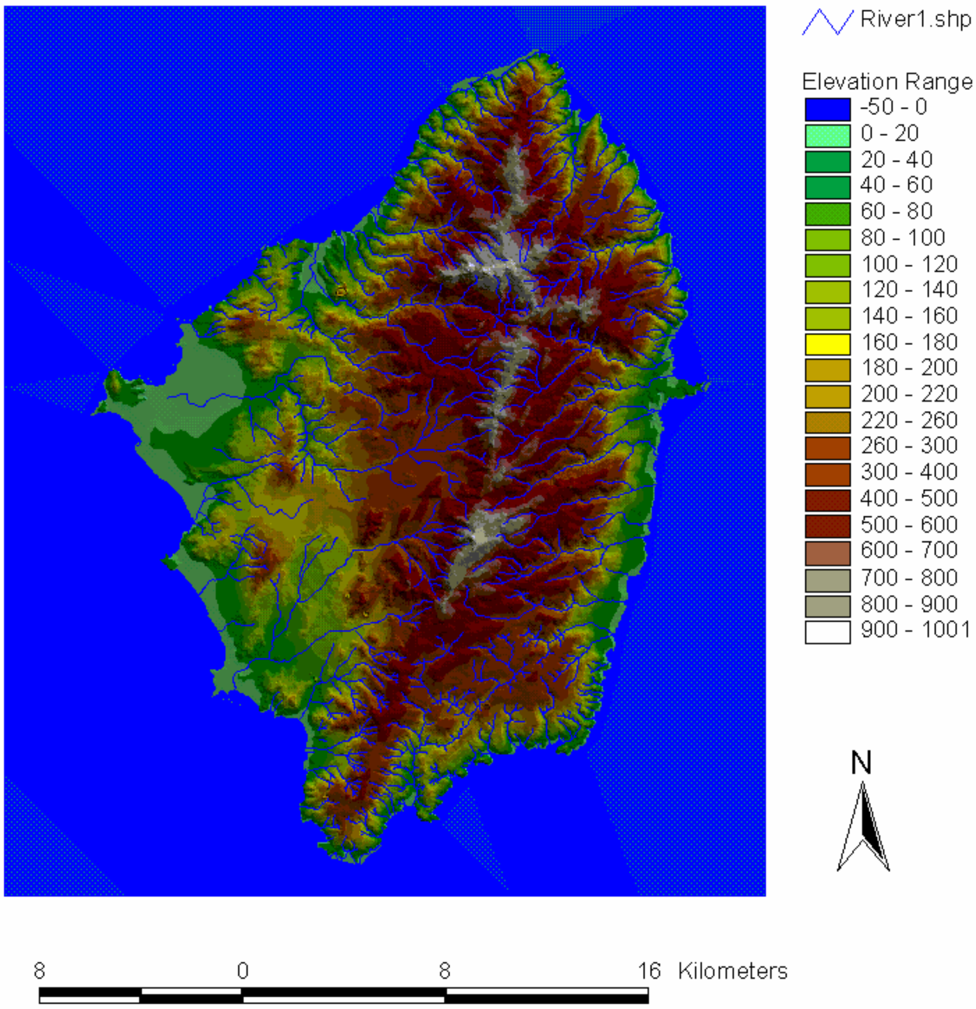
Hydrography of NAXOS



UNIVERSITY OF THE AEGEAN
DEPERTMENT OF ENVIRONMENTAL STUDIES
REMOTE SENSING AND GIS LABORATORY
Director: Professor John N. Hatzopoulos

Plate 1

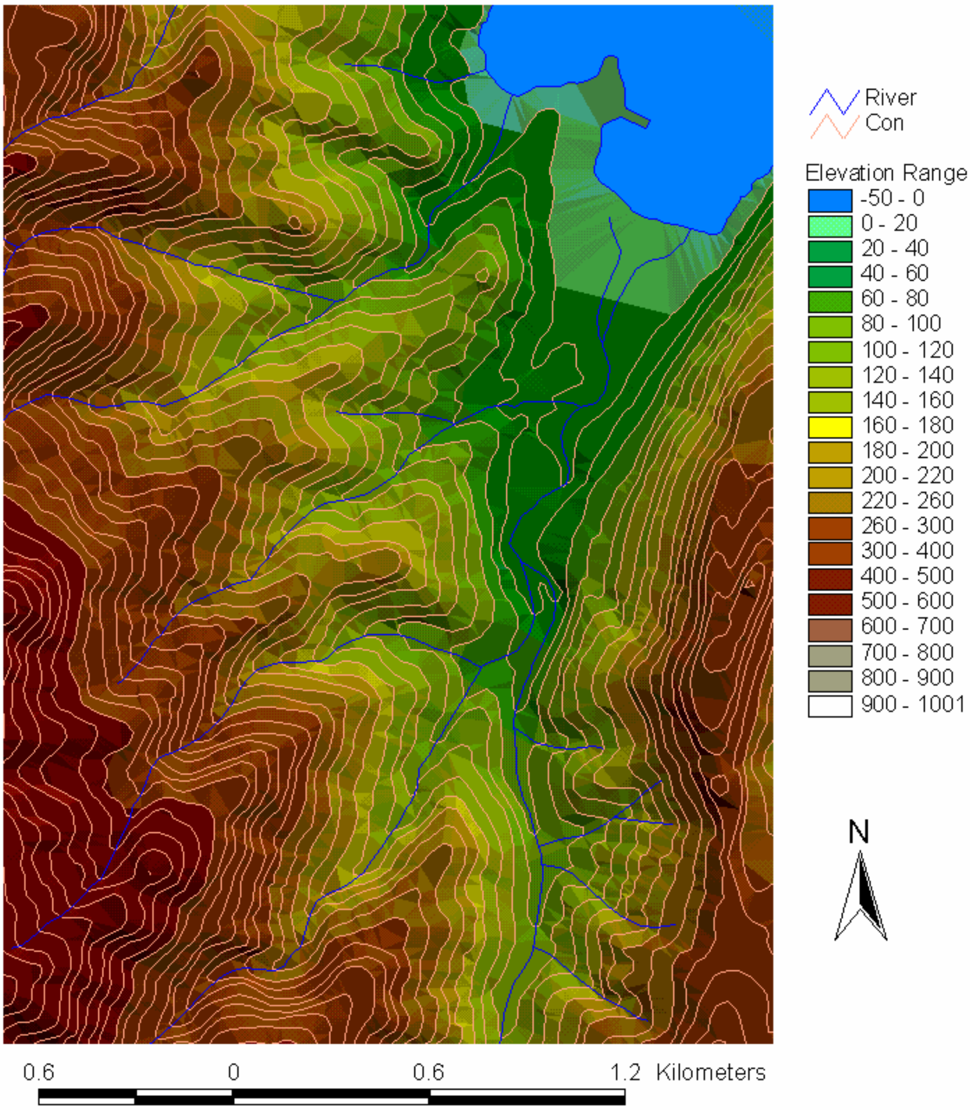
Elevations and Hydrography of NAXOS



UNIVERSITY OF THE AEGEAN
DEPERTMENT OF ENVIRONMENTAL STUDIES
REMOTE SENSING AND GIS LABORATORY
Director: Professor John N. Hatzopoulos

Plate 2

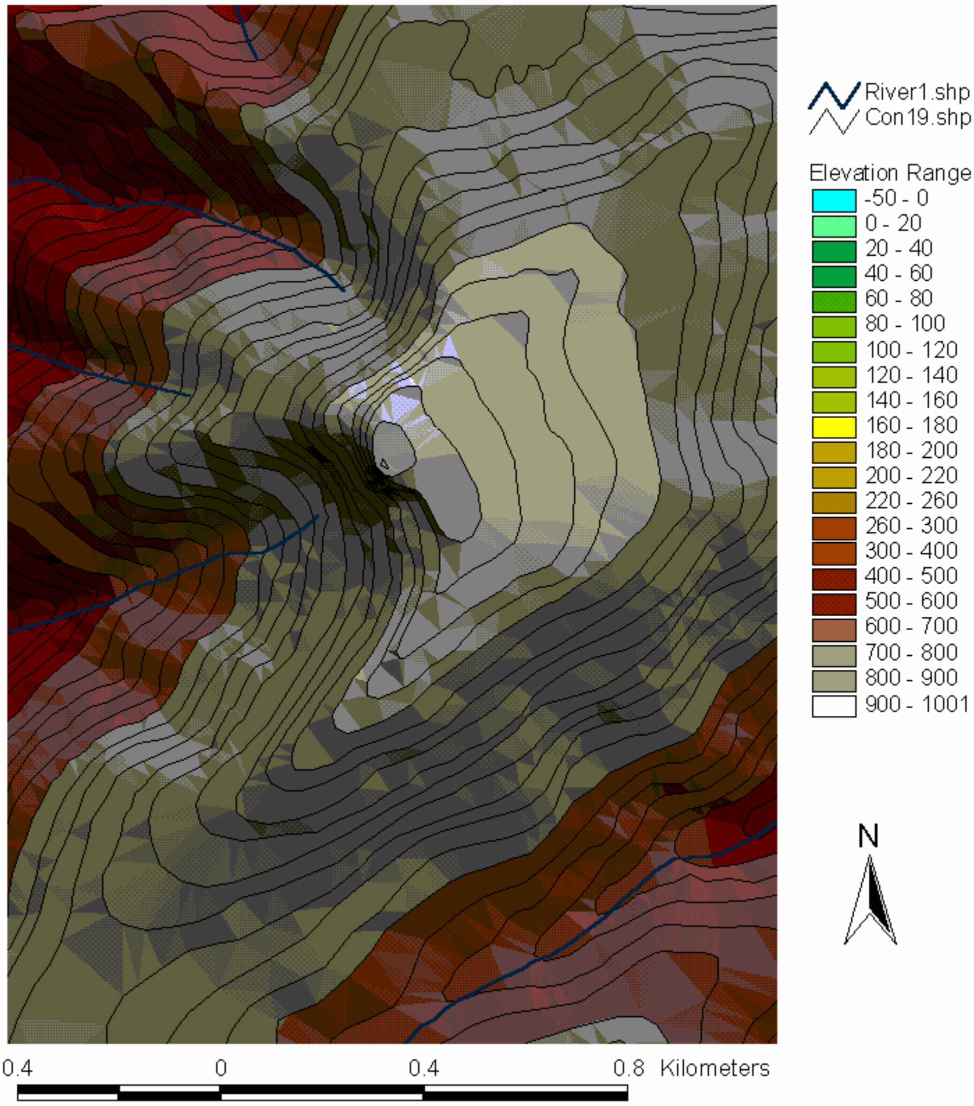
Contours, Elevations and Hydrography of the area of Komiaki and Apollonas of NAXOS



UNIVERSITY OF THE AEGEAN
DEPERTMENT OF ENVIRONMENTAL STUDIES
REMOTE SENSING AND GIS LABORATORY
Director: Professor John N. Hatzopoulos

Plate 3

Contours, Elevations and Hydrography of mount Zeus of NAXOS



UNIVERSITY OF THE AEGEAN
DEPERTMENT OF ENVIRONMENTAL STUDIES
REMOTE SENSING AND GIS LABORATORY
Director: Professor John N. Hatzopoulos

Plate 4