"GEOGRAPHIC INFORMATION SYSTEMS (GIS) APPLICATIONS IN VARIOUS DISCIPLINES, WITH EMPHASIS ON ENVIRONMENTAL ENGINEERING"

FINAL REPORT

CID-U-05-CU

Prepared for
National Science Foundation Gateway Coalition

By
Professor Contantine Yapijakis
Department of Civil Engineering
The Cooper Union School of Engineering
New York, NY 10003

August 31, 1998

GEOGRAPHIC INFORMATION SYSTEMS (GIS) APPLICATIONS IN VARIOUS DISCIPLINES, WITH EMPHASIS ON ENVIRONMENTAL ENGINEERING

FINAL REPORT (CID-U-05-CU)

Prof. Constantine Yapijakis
Department of Civil Engineering
The Cooper Union School of Engineering

INTRODUCTION

The present project, GIS Applications in Various Disciplines, was a new project proposal which was approved in late February, 1998 at a reduced budget. The PI, Prof. Constantine Yapijakis, was scheduled for a heart operation at the time, which subsequently led to an acute pancreatitis operation that placed him on medical leave until June. Although the basic software was purchased at the time and delivered to the co-PI, Prof. Winston Wilkerson, there was no opportunity to also purchase and utilize the required maps and database software for demonstration during the Spring semester. The additional software and some reference books on GIS applications were purchased over the summer, and several example GIS applications and demonstration modules were prepared with the help of graduate students and the participation of Architecture Prof. George Chaikin. This information will be presented in video-conferencing and will be placed on the Gateway web-page in the Fall semester.

PURCHASED SOFTWARE

The software (CD-ROM) selected and purchased, as per the project proposal, for the purpose of immediate implementation of GIS applications in various disciplines, with emphasis on environmental engineering, was the professional ArcView GIS software obtained at a discount from ESRI (Environmental Systems Research Institute), the worldwide leading developer of GIS software. Previously, Prof. C. Yapijakis had obtained from ESRI (free of charge) some CDs with GIS educational demos, sample databases and application capabilities, and proceedings of annual ESRI GIS conferences. Literature search had shown that both the USEPA in a report reviewing GIS software and experts at the US Dept. of Defense evaluating such software for all types of required applications, determined that ESRI's ARC/Info and ArcView GIS software were the best suited for their applications.

ESRI was founded in 1969 as a research group devoted to improving methods of handling geographically referenced data. Today, ESRI is the leading developer of GIS software, with more than 100,000 clients in over 70 countries, and also provides consulting, implementation, and technical support services. Many companies are currently providing CD-ROMs with maps and all types of databases compatible with

ESRI GIS software. Also, many maps and databases from various communities' and agencies' applications can be accessed and downloaded via the Internet.

The obtained ArcView GIS software and the accompanying Avenue software by ESRI, with the educational discount, cost about $1000. We were also able to obtain (at a discount) street maps of the entire New York City Metropolitan area (including Westchester County and beyond, western Connecticut, and northern New Jersey) for $400, and all types of US Census databases for $275. These are adequate for the purpose of preparing modules/examples of GIS applications in various disciplines. All software was installed and tested in the Gateway Multimedia Room and in various PCs, including the Gateway computer design center.

MAP AND SOFTWARE AVAILABILITY

The acquisition of available data is a very important aspect for the use of GIS systems. Typically, it is not feasible or desirable to create an entire map from scratch. In many cases, maps are available from local, state or federal governments. ESRI, publisher of ArcView, publishes a list of WWW sites using its products to provide geographic information in its quarterly magazine, ESRI ARC News. They also sell a CD-ROM containing every street in the US with geocoded addresses.

Additional software packages that can extend GIS software include:

- ArcView Network Analysis adds routing and drive time analysis
- PresenTable (from Applied GIS) creates easy-to-read tables automatically
- QMS Geocoder automates geocoding (from Qualitative Marketing Software, Inc.)
- ArcExplorer from ESRI is a free GIS data browser, which allows clients to easily browse the data contained within an organization's GIS without having to use a different computer.
- WaterWay, by Natural Systems, generates catchment and sub-catchment boundaries based on eight data sources for analysis in GIS.
- Paralllax Graphics markets a product which allows the integration of video into a GIS.

ARCVIEW GIS

The ArcView GIS software from ESRI brings together all types of information and data on the desktop. It is a complete system for accessing, displaying, querying, analyzing, and publishing an organization's or a community's data. ArcView links traditional data analysis tools, such as spreadsheets and business graphics, with maps for a completely integrated analysis system. Its relational capabilities allow linkage with any SQL, DBMS, ASCII, dBase or INFO databases to geographical data such as a source for descriptive information about map features. ArcView also provides extensive tabular data analysis tools to sort, query, create statistical summaries, add new fields, calculate new information based on existing attribute data, or interactively edit the contents of any field.

ArcView accesses all types of spatial data. It supports vector and raster data formats including the ARC/INFO and PC ARC/INFO software's basic vector feature types (e.g., points, lines, and polygons) and ARC/INFO software's advanced feature types (e.g., routes and regions, images, and grids). Geographic images, such as satellite images and aerial photographs, can be referenced and displayed with vector themes for visual reference, or as a background source for data entry. Geographic Hot Links is a hypertext-like capability that allows for various kinds of data sets and software objects to be attached to geographic features and queried or initiated on request. For example, photographs can be retrieved or a video clip can be run by pointing at features on the map.

ArcView is developed on top of a new object-oriented programming language and development environment known as Avenue. Avenue is a full-function, object-oriented development environment with a scripting language designed specifically for GIS. With Avenue, one may completely customize ArcView to address specific user requirements. Most data in an organization of discipline area have some type of an address, ZIP code, census tract, sales territory, or some other geography. ArcView helps you take advantage of this with a powerful, flexible address-matching tool, which can be used to match addresses to streets; ZIP Codes to points; or city, county, state and country names to geographic features on the map. Finally, ArcView software's layout document provides a complete set of graphical editing and drawing tools to help compose high-quality hard-copy maps.

The ESRI ArcView GIS offers a framework for implementing solutions in various areas, such as:

- Publication of and access to data on the Information Superhighway
- Use GIS as an educational tools for visualization of information
- A CAD drawing and image browser
- Analysis tool for business planning and as an executive information system
- Real-time visualization and project management
- Evaluating alternatives for building a new road
- Respond to natural disasters, or to crime and fire incidents
- Plan a cellular network
- Monitor and plan urban growth and infrastructure
- Measure a crop potential and plan irrigation schedules
- Identify, manage, and protect wetlands and plan their use
- Insert maps in a report and disseminate them over the Internet
- Visualize a project and alternative solutions in 3-D
- Display and enhance an image
- Create water/wastewater facility inventories and automated mapping, necessary for expansion of existing infrastructure and the cartographic basis to support operation and maintenance activities
- Maintain and analyze storm and sanitary sewers more efficiently and perform flow modeling

- Map water distribution systems and link them to a database defining each element, including reservoirs, pumping stations, valves, etc.
- Carry out water distribution network pressure and flow analysis
- Use regional information to investigate the implications of long-term urban growth within a watershed as it relates to increased flooding and time of concentration dynamics, impacts to groundwater levels and water quality, and other hydrologic factors (slope, land use, vegetation, etc.)

The following sections of this report present summarized examples of actual ArcView and ARC/INFO GIS applications. Detailed descriptions of these and many more example applications can be found in the Appendix of this report, or in the References section.

GIS can be and is employed in various capacities. A large portion of the GIS market are government agencies. They use GIS for a variety of reasons, including tracking facility locations, providing public information and responding to residents needs. For example, the Irvine Ranch Water District (IRWD), which supplies water, sewer service and wastewater treatment in south-central Orange County, CA is using GIS for demand forecasting. Using GIS software, IRWD created an automated water demand forecasting model based on land use and associated known water demands. The Southeastern Anatolia Project in Turkey is also using GIS for planning development. The Regional Development Agency, GAP-RDA, is using GIS to analyze socioeconomic factors, land development potential and other factors to plan the locations of communications, housing, industrial, education and health care infrastructures. The UN is developing a GIS to aid in the allocation of food caravans in needy countries. The LA Metropolitan Transportation Authority is using GIS to analyze traffic data in real time, aiding in the short term goal of reporting delays and the long term goal of planning to reduce such delays.

GIS is also being used to provide the standardized geographic information which is necessary for some agencies to perform their duties. Nassau County in New York State has established a wide-ranging and highly detailed GIS to aid its various departments and agencies in providing their services. One GIS is shared between eight different county departments, allowing them to share data effectively. The County provides its users with geographic data over an intranet through a Web-browser application. The system provides its users with news and information about the system, documentation (including the dates on which various objects were updated and user guides on how to operate the system), technical support, script libraries (so that if one county worker has already solved a particular problem, another who encounters it later separately doesn't have to redo all of the work) and various other services. Columbus, Ohio is also implementing a similar, far reaching system. In addition, the Los Angeles Department of Water and Power is using GIS to combine two existing sets of base maps previously maintained by hand into a computerized version which can be easily updated and modified to show only relevant features.

The Defense Mapping Agency has begun consolidating data about the ocean floor from various sources with the goal of identifying areas that have never been mapped or are inadequately mapped. The DMA will accomplish this through the combination of four separate agencies maps' of the ocean floor.

The California Office of Emergency Services is using GIS to aid in data collection and analysis of disaster areas. Beaufort County in South Carolina uses GIS to decrease emergency response times. As soon as an emergency call is received, a map of the area surrounding the point of the emergency call (through the use of Enhanced 911, this information is immediately known) and facilities related to the call is created. For example, in the event of a fire, a map of the area with fire hydrant locations is instantly generated. The Amsterdam (Netherlands) police department uses GIS to analyze crime data and identify "hot spots". The New York City Police Department has also used a similar system, with great success.

GIS also has applications in environmental management. The USDA Forest Service has developed the Ecosystem Management Decision Support (EMDS) system, which assists the Service in analyzing the relationships between ecological assessments. Ontario, Canada is also using GIS for forest management. In addition, the World Wildlife Fund is using GIS to identify those ecoregions most at risk to concentrate and optimize limited monetary resources. It has also used GIS to identify forest areas not protected by governmental regulation. The EPA is using GIS to analyze the after-effects of the production of weapons-grade plutonium in a Washington factory and concentrate cleanup efforts where are most needed. In addition, the EPA's Envirofacts database combines information from six EPA databases (CERCLIS, PCS, RCRIS, TRIS, GICS, AFS and SDWIS) and cross-links the data, allowing for easy analysis of facilities which appear in two or more of the included databases. The EPA website also allows anyone with web access to create maps and reports showing EPA regulated facilities in relation to surrounding demographic and geographic information.

GIS is also used in the private sector. NESA, Denmark's largest electrical utility, is using GIS for data collection, management, manipulation and analysis as it relates to the design and implication of the utility's distribution system. STWEAG-Energie Steiermark, an electrical utility in the Austrian Alps, is using GIS to create a geographically oriented cost unit accounting system which will allow the utility to perform a complete analysis on the costs of electrifying rural towns in the Alps before embarking on potentially costly and money-losing projects in those areas. Andersen Consulting is using GIS to optimize distribution chains and routes as they relate to store locations for a client. GIS has even been used to design a ski resort by combining topography, aspect and soil type information for analysis.

Strathclyde Passenger Transport (in western and central Scotland), a public transportation agency, is using GIS to streamline its operations, eliminating duplicative and unnecessary services. McCann Erikson, an advertising agency, used GIS to identify the locations of billboards which were in areas which matched the demographics of existing and potential customers for a product.

ArcView GIS Tutorials:
Tutorial Example #1:

In the first example, the task was to print out a map of Africa based on life expectancy (Map 1.1). Data was provided for every country of world in terms of projected population and life expectancy. It was necessary to first select the life expectancy theme, then zoom in on Africa. For informational purposes, some countries were also labeled. All of the information (country name, population, life expectancy) is contained within the data file, none was entered by the user. Rather, it was simply a matter of turning on the desired features. A zoomed in view of one country was also created in a like manner (Map 1.2).

Tutorial Example #2:

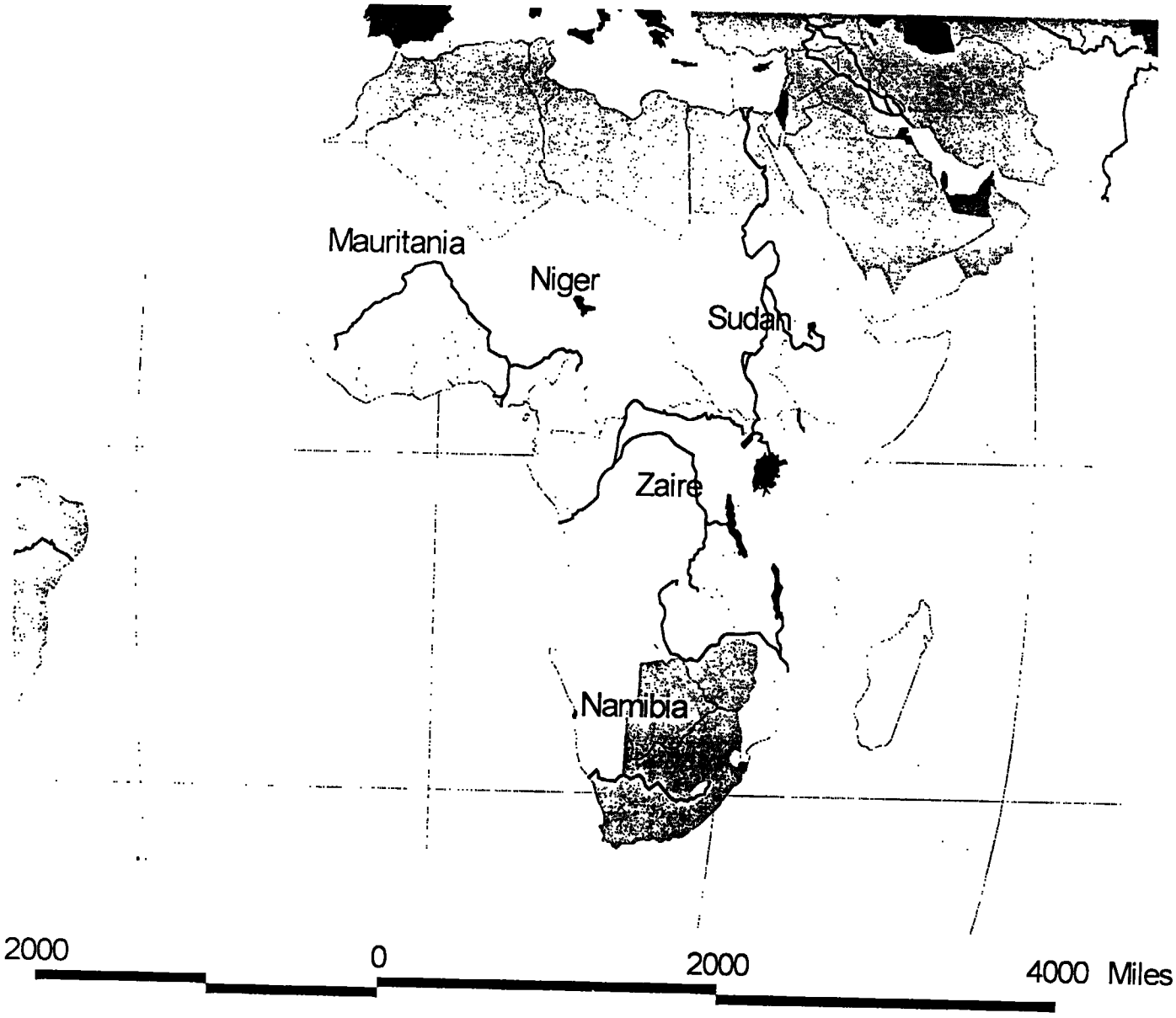
In this example, the task at hand was to identify potential cities for a new company showroom using the previous year's sales figures and the criteria that the new showroom should be within a one day drive of the main distribution center in Atlanta and also be in a city with a population no less than 80,000. To accomplish this, last year's sales figures (from an external .dbf file, sorted by state) and US city populations (also in an external .dbf file) were necessary. The first step was to merge last year's sales figures with the geographic location of each state. This was accomplished using the program's Join feature, which appended sales data to the geographic information database. Each state could then be color coded based on last year's sales figures. The location of every US city was then identified by importing a database of city sizes and locations. The cities included in the database were all US cities of population 10,000 or more. Using the program's Query Builder, the list was modified to meet the minimum population requirement of 80,000 or more. This significantly reduced the number of matching cities. Next, Atlanta, as the object of the final requirement for locating a new showroom, was selected. It was then possible to select all cities within one day's drive, determined to be no more than 300 miles from Atlanta. The final data set was then labeled. Given the color coding of states and the highlighting of eligible cities, Lexington-Fayette, in Kentucky, and Huntsville, Birmingham and Montgomery in Alabama were identified as potential sites (Maps 2.1 and 2.2).

Tutorial Example #3:

The task at hand was to identify the top five stores in terms of sales for your product last year in Atlanta. To accomplish this, a street map of Atlanta was necessary (supplied), as is a database of store locations and corresponding sales figures. The customer database was "geocoded" onto the streetmap of Atlanta, identifying the locations of all 50 outlets for the company's products. However, this database includes all distribution location, which include not only stores but restaurants, service stations, cafes and movie theaters as well. Only stores were selected by using the Query Builder to highlight all stores. Next, the customer database was sorted by sales, leaving only stores highlighted in order of descending sales. The top five stores were selected and displayed on the map (Map 3.1).

Africa

Map 1.1

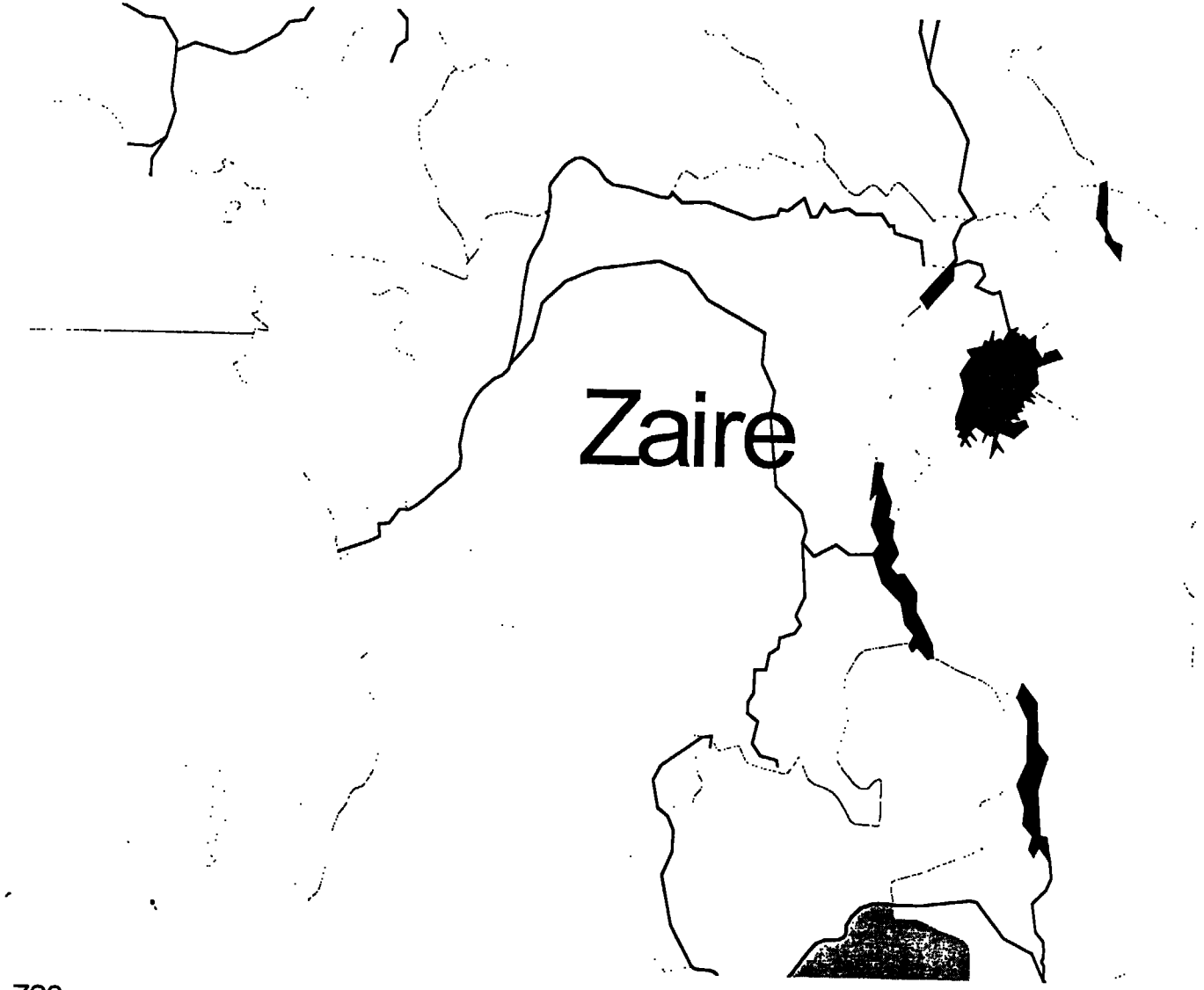


Rivers
Lakes
Life Expectancy
39.8 - 49.5
49.5 - 59
59 - 67.5
67.5 - 73
73 - 79.3
No Data
Ocean

N
W
E
S

Africa

Map 1.2



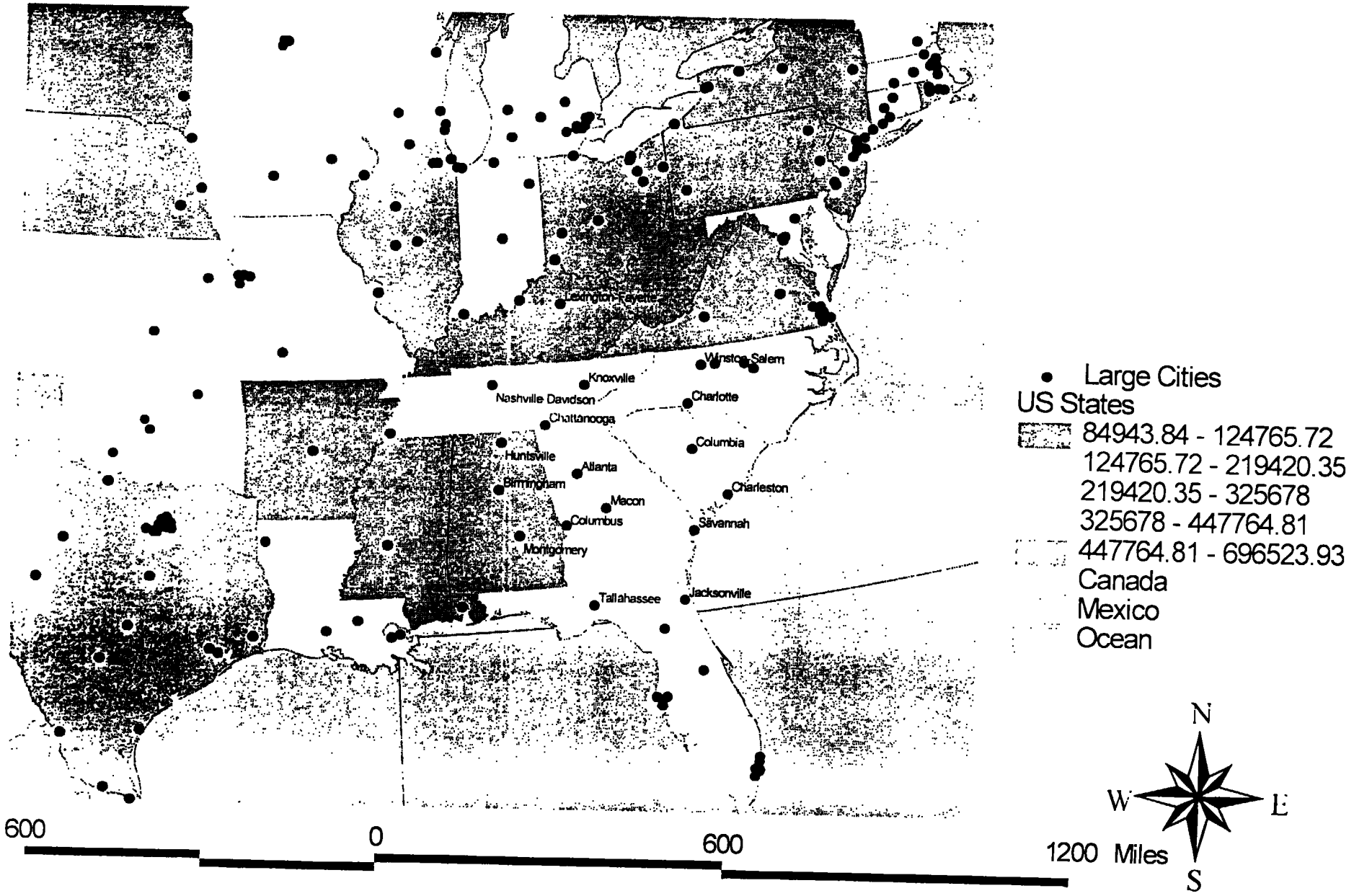
Rivers
Lakes
Life Expectancy
39.8 - 49.5
49.5 - 59
59 - 67.5
67.5 - 73
73 - 79.3
No Data
Ocean

700 0 700 1400 Miles

N
W E
S

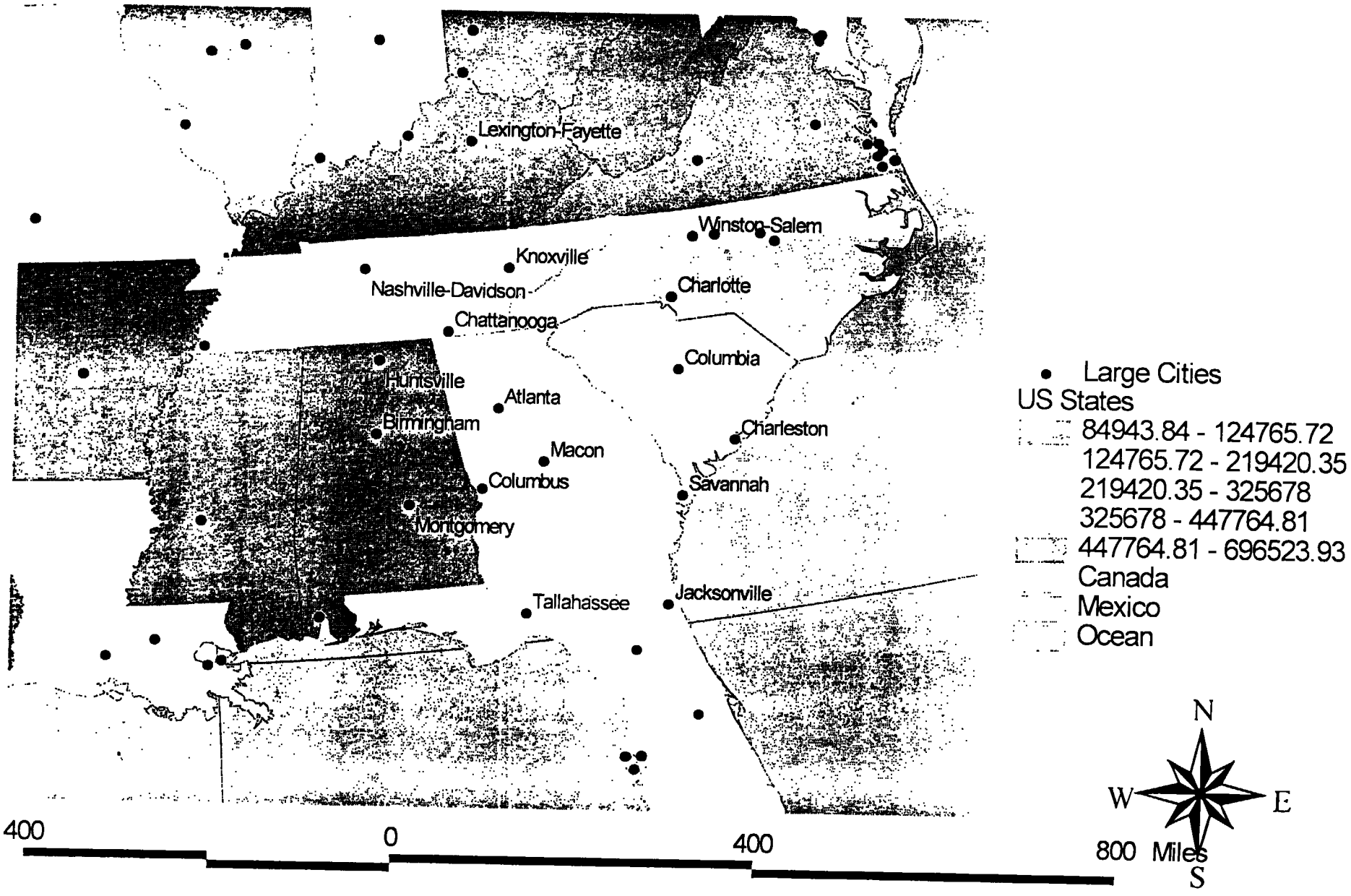
Cities Near Atlanta

Map 2.1



Cities Near Atlanta

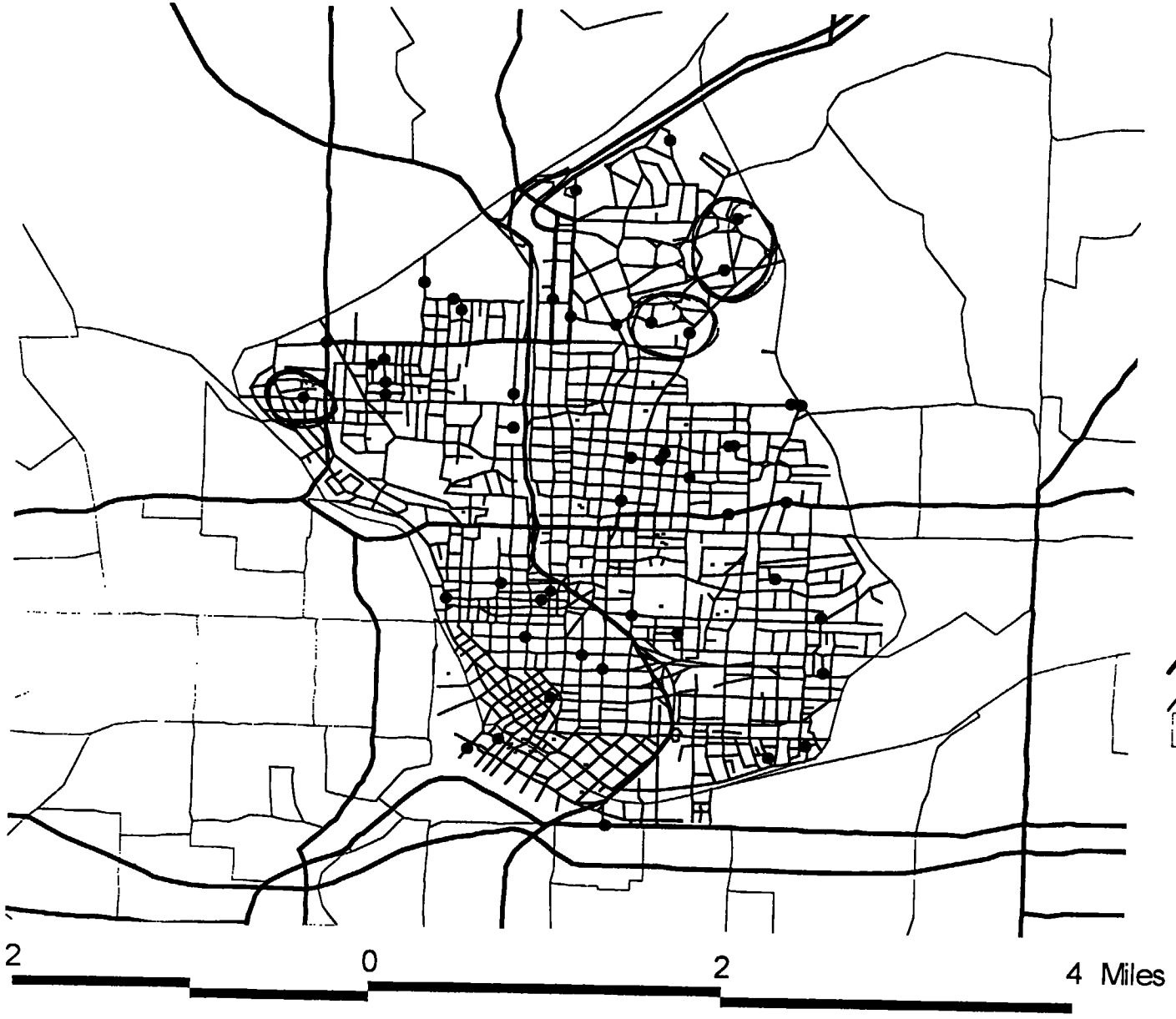
Map 2.2



Atlanta

Map 3.1

* Five stores meeting criteria are circled (appear yellow on screen; others are blue).



Geocd1.shp
Highways
Streets in downtown
Census tracts

N
W
E
S

Interfacing With Other Software:

The ability of GIS software to open other data sources and work with other applications is crucial to its functionality. Arc/View, for example, is able to open dBase and ASCII text files as data sources, both of which are common data export options on other software packages. For example, specific demographic information on a city, county, ZIP code or even census tract basis could be generated by using software such as CensusCD+ and exported as a dBase or ASCII test file and then imported into Arc/View. A potential problem area, however, lies in the compatibility of data generated by two separate programs. For example, Arc/View comes with a database of counties within the US. The CensusCD+ program can generate a report of, say, median income by county, which can then be exported as a dBase file. However, if county names are abbreviated by one program (or differently by both programs), or if the data is formatted differently (for example, the data included with Arc/View lists the county name and state separately in two fields, whereas CensusCD+ reports only one area description, which includes the two-letter state abbreviation and the county names in one field, such as "NY, Queens County"), the GIS application may have trouble or fail completely in matching the data between two sources. For example, if the program cannot match the "Queens" and "NY" fields from Arc/View with "NY, Queens County" from CensusCD+, then the CensusCD+ data is totally useless.

PROJECT IMPLEMENTATION/EVALUATION

The evaluation and study of and familiarization with the purchased software over the summer has led to the selection of and planning for several modules and ways to be used for GIS implementation, demonstration of its applications in various disciplines, and dissemination of the information to the Gateway coalition and other institutions in the Fall 1998 semester. In each case, feedback will be received from participating students and professors to evaluate and improve the project implementation. Both the Gateway Multimedia Center and the Computer Design Center, where the software has been installed, will be used for group presentations as follows:

CE 141 - Introduction to Environmental Engineering

At least one presentation/demonstration will be made in this required class for juniors, focusing on applications in environmental science/engineering and in water resources management

EID 101 – Engineering Design I

In this Gateway created and supported freshman course, the Fall 1998 semester project includes the design of a floating highway segment to assist on the repair of the FDR Drive on the east side of Manhattan, NY, and plans for future uses. This project lends itself perfectly to the use of GIS as a design tool, therefore, presentations will be made to the professors involved in the course and to all the freshmen classes. Then, the groups of students in each class that will be doing the design part of

the project will be assisted individually to make use of the ArcView GIS, etc. software in the project execution and presentation.

Environmental Student Club

A presentation/demonstration of the ArcView GIS environmental applications will be made during club hours in the Fall 1998 semester.

Video-conferencing Presentation

Sometime in late October, a video-conferencing presentation/demonstration of GIS applications in various disciplines will take place at Cooper Union. Professors from the Gateway universities (Columbia, Polytechnic, NJIT, and Cooper Union) will be invited to come and participate on-site. The others will participate through real-time video-conferencing or by retrieving the tape and other project information from the Cooper Union Gateway web-page.

REFERENCES

USEPA (March 1994), GIS/Key Environmental Data Management System, EPA/540/R-94/505

Birkin, et. al. (1996), Intelligent GIS, Pearson Professional Ltd, Cambridge, UK

Masser, et. al. (1996), GIS Diffusion, Taylor & Francis Ltd., Bristol, PA

Mitchell, Andy (1997), Zeroing In, ESRI Inc., Redlands, CA

Lang, Laura (1998), Managing Natural Resources with GIS, ESRI Inc., Redlands, CA

Huxhold, et. al. (1997), GIS County User Guide, Oxford University Press, New York, NY

Goodchild, et. al. (1993), Environmental Modeling with GIS, Oxford University Press, New York, NY