INTRODUCTION TO GEOGRAPHIC INFORMATION SYSTEMS TECHNOLOGY AND ITS APPLICATIONS

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ABSTRACT

It is estimated that more than 90% of the operations and activities of public and private agencies are based on information that possess a "locational" dimension. Thus, daily operations, as well as effective planning and decision making for such agencies, require precise handling and analysis of several layers of such information, commonly referred to as "geographic information". The technology of Geographic Information Systems (GIS), which has evolved since late 1980's, provides an efficient and computer-driven method of managing, manipulating, analyzing, and displaying a huge volume of multi-layered geographic information. This paper starts with a background of this technology and its development history. GIS applications and functional elements are then presented as well as the major challenges of their implementation. The paper concludes with a set of recommendations for a successful implementation of this technology.

INTRODUCTION

Geographic Information Systems, or GIS for short, is "a system of hardware and software that supports the capture, management, manipulation, analysis, and display of Geographic Information." Geographic Information is basically data that specify the exact location of geographic features, man-made or natural, as well as their descriptive attributes. Geographic features could be, for example, manholes (point feature), roads (linear feature), or land parcels (area feature). Associated descriptive attributes of such features could be the type of manhole, the width of road, and the area of land parcel, respectively. Thus, Geographic Information consists of two data components: (1) Locational data that specify the exact location of the concerned feature(s), and (2) Descriptive attributes that describe them. In GIS, the location of features can be specified through any spatial reference system such as the Cartesian *x* and *y* coordinate system or the global latitude and longitude system. In addition, GIS puts no limit on the number of geographic features and the number of descriptive fields that denote any geographic feature in its database.

GIS establishes and maintains an automated one to one link between any given feature, location and its descriptive attributes. For example, in a GIS database of residential land parcels, the locational component of the database would contain the *x* and *y* coordinates (or any other spatial reference system) of the location of each parcel. On the other hand, the descriptive component would include descriptive attributes such as the parcel area, land use, permit number, construction type, owner name and address.

Though "GIS" title is the mostly used acronym to label this technology, nonetheless other alternative titles are also used to denote this technology. The most common titles that are found in GIS literature are Land Information Systems (LIS), Spatial Information Systems, Spatial Handling Information Systems, Geographically Referenced Information Systems, and Multipurpose Geographic Data System. Though the titles are different, they all carry the same concept in terms of automating geographic information and linking them with their descriptive attributes.

GIS HISTORY

GIS early history began in the early 1960's. Prof. Ian McHarg was the first to set the theoretical foundation of GIS in his well-known book "Design with Nature," published in 1969. Canada GIS, developed in the mid 1960's by the Canadian government, was the first nation-wide GIS. Furthermore, its development has provided many conceptual and technical contributions to GIS. In 1967, the Land Use and Natural Resources Inventory System was installed by the State of New York, USA. Two years later, Minnesota Land Management Information System was installed by the State of the Minnesota, USA. Meanwhile, there were two active academic research groups: (1) Harvard Lab for Computer Graphics and Spatial Analysis at Harvard University, USA. This lab was established by Howard Fisher in the mid-1960's to develop general purpose mapping software. (2) The Experimental Cartography Unit, United Kingdom. Both of these research groups had a major influence in the development of GIS until the early 1980s. However, rapid developments in computing hardware and software since the early 1980's, pushed GIS into the commercial arena. According to Geo-directory[1], there are now many more commercial GIS packages. The most common ones, however, are: ARC/INFO and ArcView[2], GeoMedia[3], Geographics[4], MapInfo[5], ILWIS[6], and IDRISI[7].

[1] Geo-Directory, is an annual publication published by GIS World, USA

[2] Developed by US-based Environmental Systems Research Institute (ESRI)

[3] Developed by INTERGRAPH, USA

[4] Developed by Bentley Corp., USA

[5] Developed by MapInfo Corporation, USA

[6] Developed by ITC, Netherlands

[7] Developed by Clark University, USA

Various disciplines have contributed to GIS development. However, the fields of Geography, Cartography, Remote Sensing, Surveying, Statistics, Computer Science, and Civil Engineering are the ones that have most influenced its development.

BENEFITS OF GIS

GIS has many benefits; the following are the most common benefits of this technology:

- Integrating Geographic Information for display and analysis within the framework of a single consistent system;
- Allowing manipulation and display of geographical knowledge in new and exciting ways;
- Automating Geographic Information and transferring them from paper to digital format;
- Linking location and attributes of feature(s) within the framework of one system;
- Providing the ability to manipulate and analyze Geographic Information in ways that are not possible manually;
- Automation of map making, production, and updating;
- Providing a unified database that can be accessed by more than one department or agency;
- Storing Geographic Information in coinciding and continuous layers (*Figure 1*);

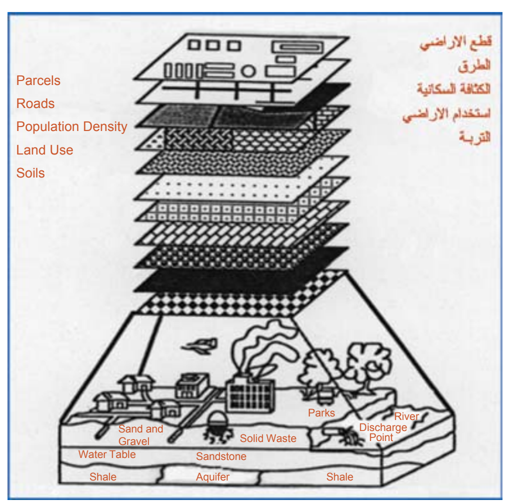

Figure 1. GIS representation of real world in coinciding and continuous layers.

- Unifying scattered islands of information into a unified island of information (*Figures 2 and 3*).

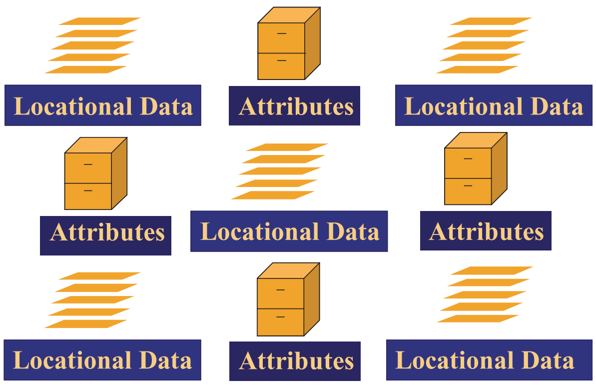

Figure 2. Scattered islands of locational data (layers of maps) and their descriptive attributes before implementing GIS.

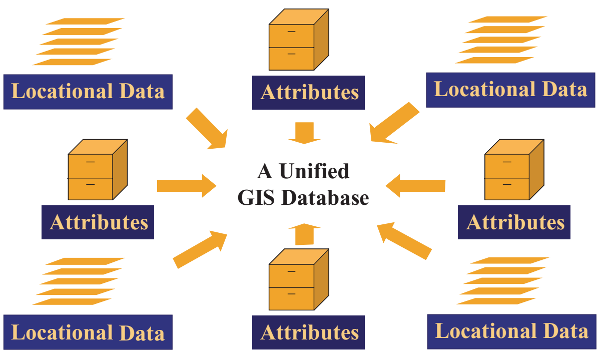

Figure 3. A unified island of locational data (layers of maps) and their descriptive attributes after implementing GIS.

GIS APPLICATIONS

It is estimated that more than 90% of urban affairs involve the use of Geographic Information. This applies to all information about urban features such as land parcels, roads, utilities, schools, medical centers… etc. For urban operations, GIS provides a systematic framework for collecting, retrieving, manipulating, displaying, and analyzing all land-related data. GIS supports a variety of urban applications such as:

- Permit issuing and Tracking
- Municipal Facilities Management
- Zoning and Subdivision Plan Review
- Urban Land Use Planning
- Land Records Management
- Emergency Vehicle Routing and Dispatching
- Inventory of Utilities
- Inventory of Vacant Land Parcels
- Urban Growth Management
- Transportation Analysis and Planning
- Optimum Site Selection for schools, hospitals, and commercial centers.

Other GIS applications support: Natural Resources Management, Water Wells Inventory, Forestry and Wild Life Management, Environmental Impact Assessment, Oil Spill Tracking, and Oil Exploration.

GEOGRAPHIC FEATURES REPRESENTATION IN HARDCOPY STATIC MAPS

Hardcopy static maps represent geographic features as a set of points, lines, and polygons. Points represent geographic phenomena that are too small to be depicted as lines or areas, such as wells or telephone poles. Lines represent geographic objects that are too narrow to depict as areas such as streets and streams. On the other hand, polygons represent the shape of homogenous features such as parcels, soil types, and land use zones.

Hardcopy maps represent descriptive information using symbols and labels. Roads, for example, are drawn with various line widths, patterns and colors representing different road classes. Streams and water bodies are drawn in blue indicating water. Special point symbols are used to denote special features such as airports, while city streets are labeled with their names.

GEOGRAPHIC FEATURE REPRESENTATION IN GIS: VECTOR vs RASTER

In GIS, there are two common formats for representing geographic features in a GIS database: the Vector format and the Raster format. Hence, there are two kinds of GIS, Vector-based GIS and Raster-based GIS. In a vector structure, geographic features are represented as points, lines, and polygons through *x*,*y* coordinate system or any other spatial reference system; such as the global Latitudes and Longitude reference system. Points are recorded as single x,y locations, lines as a series of continuous x,y coordinates, and polygons as a series of x,y coordinates that start and end at the same point (*Figures 4 and 5*).

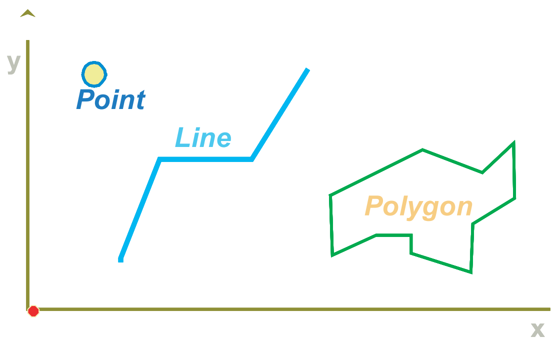

Figure 4. Vector-based representation of features: *Points, Lines,* and *Polygons.*

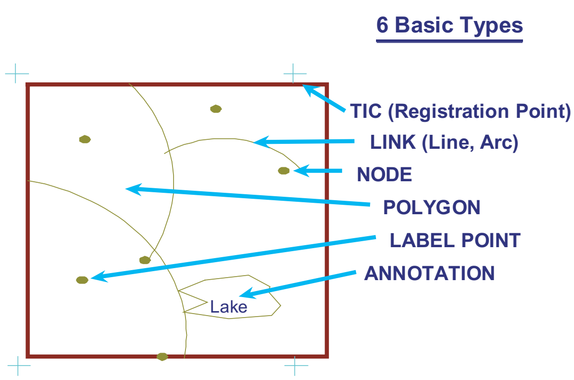

Figure 5. Common object classes in vector-based representation in ARC/INFO GIS package.

In a raster GIS, reality representation is divided into a rectangular grid or matrix of cells that is organized into a set of rows and columns. This structure encompasses cells that have values representing geographic phenomena such as soil type, elevation, landuse class, and slope (*Figure 6*).

In general, a vector-based GIS is more suitable for large-scale applications that require high resolution such as urban and regional applications. A Raster-based GIS is mostly used for small-scale applications such as natural resource and wildlife management where high accuracy is not required.

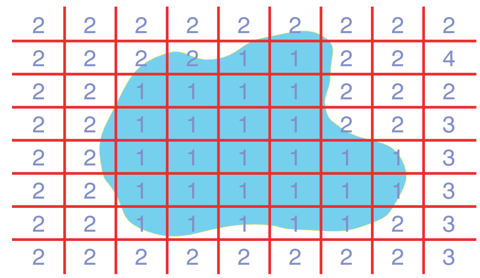

Figure 6. Raster-based representation of geographic features.

TOPOLOGY IN GIS

When the human brain reads a static hardcopy map, it implicitly comprehends how geographic features relate spatially to each other. However, when dealing with a machine, such as the case in vector-based GIS, the GIS database must store how geographic features relate to each other spatially or provide tools to derive them in order to process any requested spatial analysis operation. Thus, topology in vector-based GIS is a concept that is used to represent spatial relationships in GIS databases. Accordingly, topology in a vector-based GIS is used to define polygons, describe how linear features connect, and identify contiguous polygons. On the other hand, a raster-based GIS database does not store pointers on how cells might be related spatially to each other. Thus, a raster-based GIS does not have topology.

DESCRIPTIVE ATTRIBUTES REPRESENTATION IN VECTOR-BASED GIS

In a Vector-based GIS, descriptive attributes are stored as sets of characters. For example, descriptive attributes of roads might include: road names, road types, surface material, width, and number of lanes. Descriptive attributes of each road segment are stored as a string of values in a predefined tabular format. Such a data file is referred to as a Feature Attribute Table (FAT) where each row is a record for a single feature and each column is an item or field for all geographic features. GIS establishes a link between descriptive attributes to features in a GIS database and their descriptive attributes (*Figure 7*). Thus, a query can be made to display descriptive attributes information of a certain feature or vice versa.

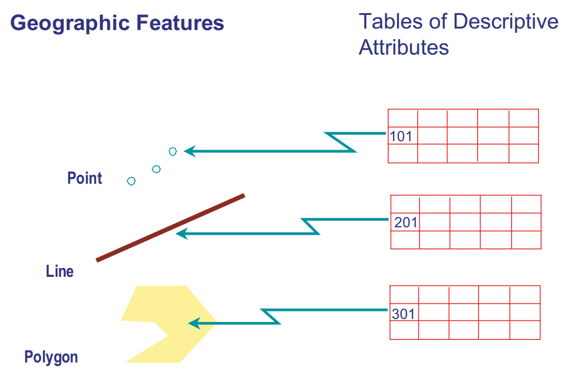

Figure 7. The layers concept in GIS.

The real world consists of many geographies, which can be represented as a number of related data layers. Thus, in a GIS database, map features are organized into a set of layers or themes of information. Typically, layers are organized so that point, line and area features are stored in separate layers. Typical layers in a GIS database include (*Figure 8*):

- Basemap layer
- Geodetic control points
- Contour lines
- Permanent geographic features such as coast lines and rivers
- Building footprints
- Utilities network layers: Electric, Phone, Water, and Sewer networks
- Roads network
- Boundaries of land parcels.

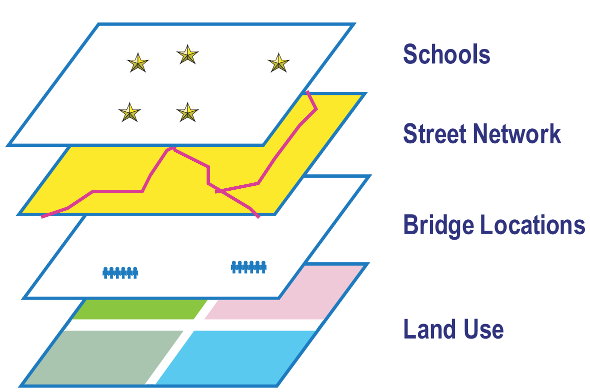

Figure 8. Real world consists of many geographies which can be represented as a number of related data layers.

SOURCES OF GEOGRAPHIC INFORMATION

Maps, aerial photographs, and satellite images denoting geographic features are the primary sources for the spatial component of a GIS database. Their related descriptive information is the primary source of the descriptive attributes component of the GIS database.

For satellite images, there are two well-established commercial firms that provide Satellite Images. EOSAT (Earth Observation Satellite Company) at USA and SPOT Image Corp., a French Satellite. IKONOS satellite, deployed lately, provides high-resolution images. However, satellite images so far are not very useful for urban applications that require high accuracy and resolution. They are most useful for natural resources and forest management applications that involve small-scale applications.

GIS COMPONENTS AND FUNCTIONAL ELEMENTS

GIS consists of four components and four functional elements. The four components of GIS are: Software; Hardware; Database; and Users (*Figure 9*). On the other hand, GIS has four functional elements: Data Input, Data Management, Data Manipulation and Analysis, and Data Output.

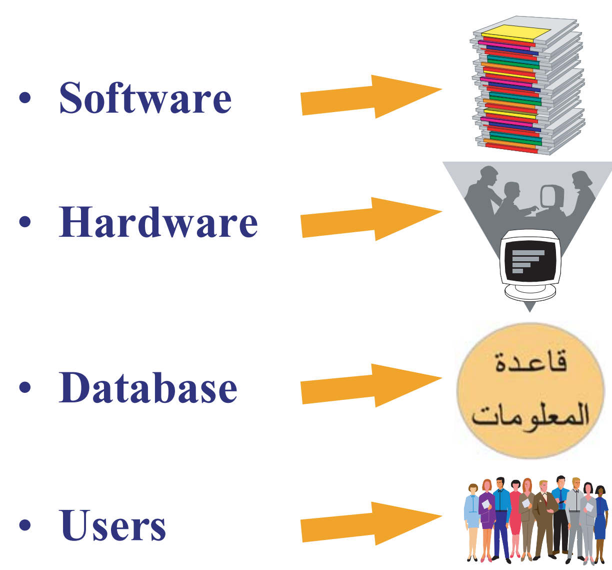

Figure 9. GIS components.

DATA INPUT

Data Input in GIS, in terms of acquiring relevant data and placing them into the system, is the first step in developing the database for GIS. It is considered one of the greatest operational problems and costs in the development of any GIS project. The cost of building the GIS database is commonly 5 to 10 times the cost of GIS hardware and software together. However, the value of any GIS is due in large to the quality of the data that are contained within the system. Hence, data input into GIS is usually the major bottleneck in implementing a GIS.

There are two common systems of data input in GIS: Manual Digitizing and Automated Scanning. Manual Digitizing is done through a digitizer tablet (*Figure 10*) which contains a magnetic surface on which the map to be digitized is placed. Coordinates of map features are entered through a cursor. Digitizing maps is a slow and costly operation. However, it produces accurate results.

In Automated Scanning, map features are captured through a scanner (*Figure 11*). Compared to Manual Digitizing, this process is faster and incurs a lower cost, however it typically requires a substantial amount of editing. It also produces digital maps with lower accuracy.

Figure 10. A digitizer and its tablet.

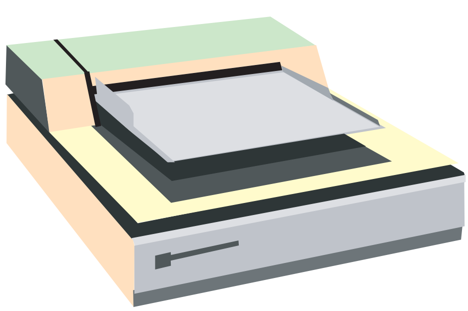

Figure 11. A scanner.

DATA MANAGEMENT

Data Management in GIS is the functional element that governs and controls the GIS database. This element is commonly referred to as the Data Base Management System (DBMS). DBMS is comprised of a set of programs that manipulate and maintain the data in a database. It acts as a central control over all interactions between the GIS database and the application programs, which in turn interact with the user. Hence, the DBMS provides the users of the application program a safe and efficient access to the database in terms of retrieval and manipulation. Virtually all commercial GIS systems incorporate some form of DBMS.

DATA MANIPULATION AND ANALYSIS

Data Manipulation and Analysis is at the core of GIS. This is where the justification to acquire GIS is usually made. In addition, the analytical capabilities of GIS are what differentiate it from other traditional types of information systems.

DATA OUTPUT

Data Output in GIS provides the user with a powerful means to document and present findings. These means enable the user to produce accurate maps, and

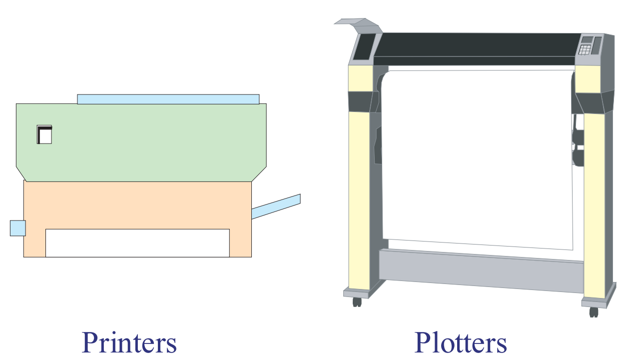

Figure 12. Data output peripherals.

tabular reports that contain tables and graphic products such as Bar Charts and Pie Charts. Data output in GIS is typically documented through two peripherals: Plotters and/or Printers (*Figure 12*).

CHALLENGES IN GIS IMPLEMENTATION

Challenges in GIS implementation can be categorized into two major categories; (1) data collection and input; and (2) lack of leadership and coordination. For data collection and input, maps as well as descriptive attributes data needed to build the GIS database are either outdated or nonexistent at all. This leads to the need to establish the GIS database from scratch. This substantially increases the cost of the GIS project considering that data collection and input constitute about 80% of the total expenditure in any GIS project.

On the other hand, leadership and coordination is instrumental for the success of GIS technology. This element is important to initialize needed administrative and organizational changes for proper adoption of this technology. Thus, the lack of this element will definitely lead to the failure of the GIS project. This is especially true if the beneficiary is more than one party.

There are also other challenges, though less important. One of them is the lack of GIS specialists, which is attributed to lack of specialized curricula and training in the GIS field. Ignorance of the benefits of this technology by decision makers is yet another challenge. This negatively impacts securing needed funds to finance the GIS project. Other challenges include the insufficient study of user needs and the lack of procedures for a periodic update of the GIS database once collected.

RECOMMENDATIONS

Before the start of the GIS project, it is highly recommended to form a steering committee that includes representatives of all parties to lead the project. One of the main charges of this committee is to provide coordination among benefiting parties and to carry out a detailed User Needs Study. Another important charge of this committee is to determine the goals and functions of the proposed GIS system and assess its costs. To secure needed funds from upper management, this committee should increase the awareness of decision makers of the potential benefits of GIS technology through relevant seminars and symposiums. It should also look for potential outside participants in this project to share costs and increase the benefits of the system.

Furthermore, extensive efforts should be exerted to look for data that are already in digital format that might have been collected by other public or private agencies. This will help in substantially reducing the cost of data collection and input. It is also recommended to start the project with a pilot study on a limited area. This will expose any mishap that might have been overlooked. Finally, a GIS project should be dealt with as an ongoing event, which does not conclude, by buying Software and Hardware. On the part of the academic community, specialized GIS curricula in colleges and universities should be established. In addition, specialized GIS training should also be offered.

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GIS EXTENDED REFERENCES

Antenucci, John C. et al., eds. (1991), *Geographic Information Systems: a Guide to the Technology*. New York, N.Y.: Van Nostrand Reinhold.

Aronoff, S. (1989), *Geographic Information Systems: A Management Perspective*. Ottawa, Canada: WDL Publications.

Bernhardsen, T. (1992), *Geographic Information Systems*. Norwegian Mapping Authority.

Burrough, P.A. (1986), *Principles of Geographical Information Systems for Land Resources Assessment.* Oxford: Clarendon Press.

Council of State Governments and Lisa Warnecke (1992), *State Geographic Information Activities Compendium.* Lexington, KY: Council of State Governments.

Davis, D. (2001), *GIS for Every One*. ESRI, Redlands, California, USA.

GIS World, Inc. and Stutheit, J., ed. (1990), *The GIS Sourcebook*. Fort Collins: GIS World, Inc., (Published annually).

Heit, M. and Shortreid, A., *GIS Applications in Natural Resources*. Fort Collins, CO: GIS World, Inc., N.D.

Huxhold, W.E. (1991), *An Introduction to Urban Geographic Information Systems*. New York, N.Y.: Oxford University Press.

Institute for Land Information. *Land Information Systems - Geographic Information Systems: A Directory of Organizations.* Bethesda, MD: Institute for Land Information, n.d.

International City Management Association (1991), *The Local Government Guide to Geographic Information Systems: Planning and Implementation.* Washington, D.C.: ICMA.

Korte, G. (1994), *The GIS Book*. Santa Fe, USA: ONWORD Press.

Laurini, R. and Dereck, T. (1992), *Fundamentals of Spatial Information Systems.* Academic Press.

Maguire, D.J., Goodchild, M.F., and Rhind, D.W. eds. (1991), *Geographical Information Systems: Principles and Applications*. Essex, England: Longman Scientific and Technical.

Marble, D.F. and H Sazanami, eds., *The Role of Geographic Information Systems in Development Planning.* Japan: United Nations Centre for Regional Development, n.d.

Peuquet, D.J. and Marble, D.F., eds. (1990), *Introductory Readings in Geographic Information Systems.* London: Taylor & Francis.

Rhind, D. (1990), *Understanding Geographic Information Systems.* London: Taylor and Francis.

Ripple, W.J. (1987), *GIS for Resource Management: A Compendium.* Bethesda, MD: American Society of Photogrammetry and Remote Sensing.

Fundamentals of Geographic Information Systems: A Compendium. Bethesda, MD: American Congress on Surveying and Mapping, 1989.

Scholten, H. and Stillwell, J., eds. (1990), *Geographical Information Systems for Urban and Regional Planning.* Boston, MA: Kluwer Academic Publishers.

Snowbird (1998), *GIS-T Presentation*. Utah.

Star, J.L. and Estes, J.E. (1990), *Geographic Information Systems: An Introduction.* Englewood Cliffs, NJ: Prentice-Hall.

Walker, T.C. and Miller R.K. (1990), *Geographic Information Systems: Technology, Applications, and Practice.* Madison, GA: SEAI Technical Publications.

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