WATER-RESOURCE APPLICATIONS
OF GEOGRAPHIC INFORMATION SYSTEMS
BY THE U.S. GEOLOGICAL SURVEY

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Introduction

A Geographic Information System (GIS) combines data base management with digital mapping into a spatial-tabular data model. This model is a powerful tool for representing and manipulating earth-science information. This article will describe the growth of GIS technology in the U.S. Geological Survey (USGS) and some of the many applications of GIS to water resources studies.

Early GIS Efforts

The USGS has played an important role in developing geographic data and providing it to the public. A key milestone was the production of digital, 1:2,000,000-scale National maps in 1972, and development of the Digital Line Graph standard for representing digital spatial data (Domaratz, 1983). Most early efforts in digital mapping, however, were oriented towards the mapping process itself rather than its applications to water resources. By the early 1980's, mathematical modelers working in the areas of ground water and surface-water quality were experimenting with a variety of ad hoc schemes for better incorporating spatial information in their models, and it was recognized that more formal spatial analysis tools were needed. The first major USGS water-resources project to apply GIS techniques to the examination of water data was a study by Moore and others (1983) of the Fox and Wolf River basins in Wisconsin. Fifty data sets including such themes as drainage basins, runoff, land use, and water quality were incorporated into a raster-based GIS, and various overlays of themes were examined. This study demonstrated the inherent power of spatial analysis, but also pointed out limitations of the hardware and software in use at that time.

A network of minicomputers installed in 1985 increased the computer power available at local USGS offices and provided much better support for graphic terminals. That same year, the ARC/INFO GIS software was procured and installed at 5 USGS sites. Successful GIS projects at these sites encouraged others. Within a year, the demands of GIS projects had spread the GIS software licenses to 20 sites. GIS had arrived!

The System Today

GIS software is now installed on 10 minicomputers and over 150 workstations located at USGS offices throughout the United States to support over 400 users who are conducting water-resources investigations. The minicomputers are gradually being replaced by a network of workstations with even more powerful GIS capabilities.

To support such a large user base, USGS has developed in-house training programs with courses that teach: Introduction to GIS, GIS for managers, spatial data base creation, advanced ARC/INFO, and specialized courses for hydrologic applications.

GIS Applications

With so many users, it is not possible to describe all USGS applications of GIS in a short review article. Some applications feature the improved automation of traditional hydrologic analysis, whereas others take advantage of the integrating power of GIS to combine hydrologic data sets with data from other disciplines. These multi-disciplinary studies can be very important in understanding the larger issues of water resources and protection of the environment. To present a sam-
pling of applications, examples are described below on the themes of National studies, groundwater models, and surface-water models.

National Studies

The importance of GIS to National studies of water resources was recognized by Moore and others (1983): "A digital water-resources information system ... can form a useful part of a national water summary." This advice was applied in developing a GIS data base to support the National Water Summary program (Moody and Lanfear, 1988). An extensive set of basemaps covering such themes as state and county boundaries, drainage basins and river networks is main-tained on-line at scales suitable for National maps.

Even the availability of simple GIS operations to produce county choropleth maps has been an important contribution. One example of the power of such illustrations is shown in figure 1, which summarizes irrigation water use in the United States. The spatial patterns in the data often are not so apparent when the same data are presented in tabular fashion. Automated procedures can prepare these maps in publication-ready, four-color format.

Techniques for exploring large data bases are becoming increasingly sophisticated and more powerful. Lanfear and Alexander (1990), for example, developed an automated method of performing a seasonal Kendall trend test, and are applying it to the entire national water-quality data base of USGS. The data are managed within a GIS, which is used to interactively query the data and to relate water-quality trends to other geographic data such as land use and fertilizer applications (Lanfear, 1990).

Ground-Water Models

Most mathematical models of ground water are based upon finite-element or finite-difference techniques. With large model grids comprised of hundreds of elements on a side, assigning properties to the cells has traditionally been a time-consuming and costly process. GIS has drastically changed this situation. The basic idea is that individual modeling parameter (e.g. transmissivity, depth to a formation) can be regionalized and represented on a digital map that is related to the modeling grid. This process is illustrated in figure 2. The regionalizations can be accomplished either by digitizing existing maps (if available) or by

Figure 1. Choropleth map of irrigation water used by county in the United States.
using a GIS to develop contour maps of point data.

Kernodle and Philip (1988) applied these methods to a finite-difference ground-water model of the San Juan basin in New Mexico, Colorado, Arizona, and Utah. They used data from more than 24,000 oil and gas wells to determine aquifer thickness. Not only was using a GIS much more efficient in terms of data entry, but, by separating the data-entry process from the definition of the model grid, it allowed them to easily test their model for sensitivity to grid size and orientation. Because of their efficiency and flexibility, it is expected that these GIS techniques will be applied to most ground-water models used in the future.

**Surface-Water Models**

Of key importance to surface-water modeling is the ability to define and characterize drainage basins. Digital elevation model (DEM) data are now widely available in the United States at a resolution of about 75 meters. Although inferring drainage from DEM data is more difficult than it may first appear because of random errors and natural phenomena that result in closed basins, recently developed techniques (Jenson and Domingue, 1988, Hutchinson, 1989) are now being commonly applied.

The ability to automatically define basins in far greater detail than previously was practical has heightened interest in topographically-based surface-water models such as TOPMODEL (Bevans and Kirkby, 1979), Price and others (1989) and Wolock and others (1989) used this model to characterize drainage in estimating effects of potential climate changes in the Delaware River basin. This is a fertile field of research where GIS is expected to lead to significant advances.

**Emerging GIS Issues**

As use of GIS has grown and presented new opportunities, it also has raised a number of new issues and problems. Of increasing concern is the management of a growing collection of spatial data sets and applications programs. These data sets and programs are very expensive to produce but relatively easy to share, so there is a great incentive to avoid duplicating production efforts. The trend clearly is towards managing these elements in a spatial library. The Distributed Spatial Data Library (DSDL) is proposed to store commonly-used digital map themes in a library distributed throughout the USGS’s network of workstations. Facilities within DSDL will include map automation guidelines, procedures for storing, manipulating, and updating data, and an index of spatial data holdings.

Improvements in software and hardware also are causing changes in the way GIS is used. Whereas early GIS users had to know an extensive suite of arcane software commands, modern “pull-down” menu systems have made it possible to make a GIS accessible to users who are not specifically trained in GIS. This may lead to increasing specialization in designing such menu systems, and even more widespread use of GIS among the hydrologic community.

An important emerging characteristic of GIS is that it is an integrating technology. GIS makes it possible to combine information themes from many fields. Researchers are beginning to cross disciplines more than ever before, and GIS undoubtedly has accelerated this trend.

**Conclusions**

GIS is one of the fastest growing technologies being applied to the field of water resources. There are now more than 400 GIS users within the USGS, and this number is expected to double in the next few years. The spatial-tabular data model of GIS provides a more effective way of managing earth-science data. This makes possible GIS applications that both improve the efficiency of existing analytical techniques and create new opportunities for advancing science.
Figure 2. Diagram of the process to converting point data to cell data for a groundwater model

Point Data

Form contours with surface-modeling software

GIS: GENERATE MYGRID
Grid origin: -92, 40
Y-axis coord: -92, 41
Cell size: 0.5, 0.5
No. rows, col.: 8, 8

Define grid mathematically

Form Polygons

Intersect with grid

Compute the values for cells
References


Figures

Figure 1. -- Choropleth map of irrigation water use by county in the United States.

Figure 2. -- Diagram of the process to converting point data to cell data for a ground-water model.