Applications of GIS

Figure 1. Group of stags (cave painting), Lascaux Caves, France (Art Resource, NY).

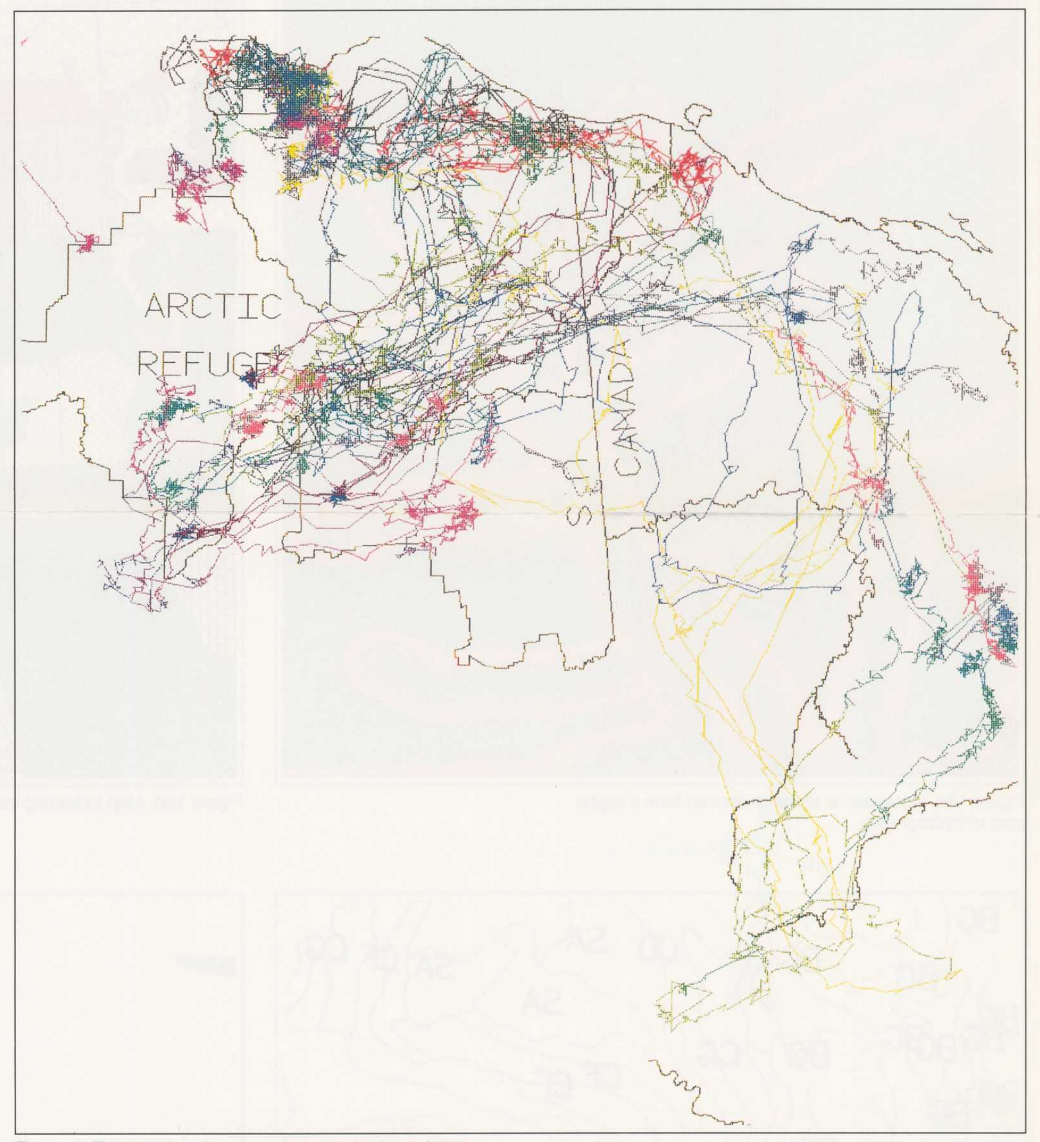

Figure 2. Tracks of caribou routes in Alaska from April 1985, to December 1986 (U.S. Fish and Wildlife Service).

GIS through history

On the walls of caves near Lascaux, France, Cro-Magnon hunters drew pictures of the animals they hunted 35,000 years ago (fig. 1). Associated with the animal drawings are track lines and tallies thought to depict migration routes. These early records followed the two-element structure of modern geographic information systems: a graphic file linked to an attribute data base.

Today, biologists use collar transmitters and satellite receivers to track the migration routes of caribou and polar bears to help design programs to protect the animals. In a GIS, the migration routes were indicated by different colors for each month for 21 months (fig. 2). Researchers then used the GIS to superimpose the migration routes on maps of oil development plans to determine the potential for interference with the animals.

Using GIS

Mapmaking

Researchers are working to incorporate the mapmaking experience of traditional cartographers into GIS technology for the automated production of maps.

Using a GIS and digital versions of the 1:100,000-scale transportation network, political boundaries, and hydrographic features, cartographers produced a 1:500,000-scale standard base map of New Jersey. This digital revision was done in three steps of map scale reduction: 1:100,000, 1:250,000, and 1:500,000 (fig. 3a). Each scale reduction required edge matching, or paneling, of the larger scale maps to produce the next smaller scale map. In addition, through the process known as generalization, the amount of information was reduced to make the smaller scale map readable (figs. 3b, c, and d).

Site selection

The U.S. Geological Survey (USGS), in a cooperative project with the Connecticut Department of Natural Resources, digitized more than 40 map layers for the areas covered by the USGS Broad Brook and Ellington 7.5-minute topographic quadrangle maps (fig. 4). This information can be combined and manipulated in a GIS to address planning and natural resource issues. GIS information was used to locate a potential site for a new water well within half a mile of the Somers Water Company service area (fig. 5).

To prepare the analysis, digital maps of the water service areas were stored in the GIS. Using the buffer function in the GIS, a half-mile zone was drawn around the water company service area (fig. 6). This buffer zone was the "window" used to view and combine the various map coverages relevant to the well site selection.

The land use and land cover map for the two areas shows that the area is partly developed (fig. 7). A GIS was used to select undeveloped areas from the land use and land cover map as the first step in finding well sites. The developed areas were eliminated from further consideration (fig. 8).

The quality of water in Connecticut streams is closely monitored. Some of the streams in the study area were known to be unusable as drinking water sources. To avoid pulling water from these streams into the wells, 100-meter buffer zones were created around the unsuitable streams using the GIS, and the zones were plotted on the map (fig. 9). The map showing the buffered zones was combined with the land use and land cover map to eliminate areas around unsuitable streams from the analysis (fig. 10). The areas in blue have the characteristics desired for a water well site.

Point sources of pollution are recorded by the Connecticut Department of Natural Resources. These records consist of a geographic location and a text description of the pollutant (fig. 11). To avoid these toxic areas, a buffer zone of 500 meters was established around each point (fig. 12). This information was combined with the previous two map layers to produce a new map of areas suitable for well sites (fig. 13).

The map of surficial geology shows the earth materials that lie above bedrock (fig. 14). Since the area under consideration in Connecticut is covered by glacial deposits, the surface consists largely of sand and gravel, with some glacial till and fine-grained sediments. Of these materials, sand and gravel are the most likely to store water that could be tapped with wells. Areas underlain by sand and gravel were selected from the surficial geology map (fig. 15) and combined with the results of the previous selections to produce a new overlay map consisting of sites in undeveloped areas underlain by sand and gravel that are more than 500 meters from point sources of pollution and more than 100 meters from unsuitable streams (fig. 16).

A map that shows the thickness of saturated sediments was created by using the GIS to subtract the bedrock elevation from the surface elevation (fig. 17). For this analysis, areas having more than 40 feet of saturated sediments were selected and combined with the previous overlays.

The resulting site selection map shows areas that are undeveloped, are situated outside the buffered pollution areas, and are underlain by 40 feet or more of water-saturated sand and gravel (fig. 18). Because of map resolution and the limits of precision in digitizing, the very small polygons (areas) may not have all of the characteristics analyzed, so another GIS function was used to screen out areas smaller than 10 acres. The final six sites are displayed with the road and stream network and selected place names for use in the field (fig. 19).

The process illustrated by this site selection analysis has been used for a number of common applications, including transportation planning and waste disposal site location. The technique is particularly useful when several physical factors must be considered and integrated over a large area.

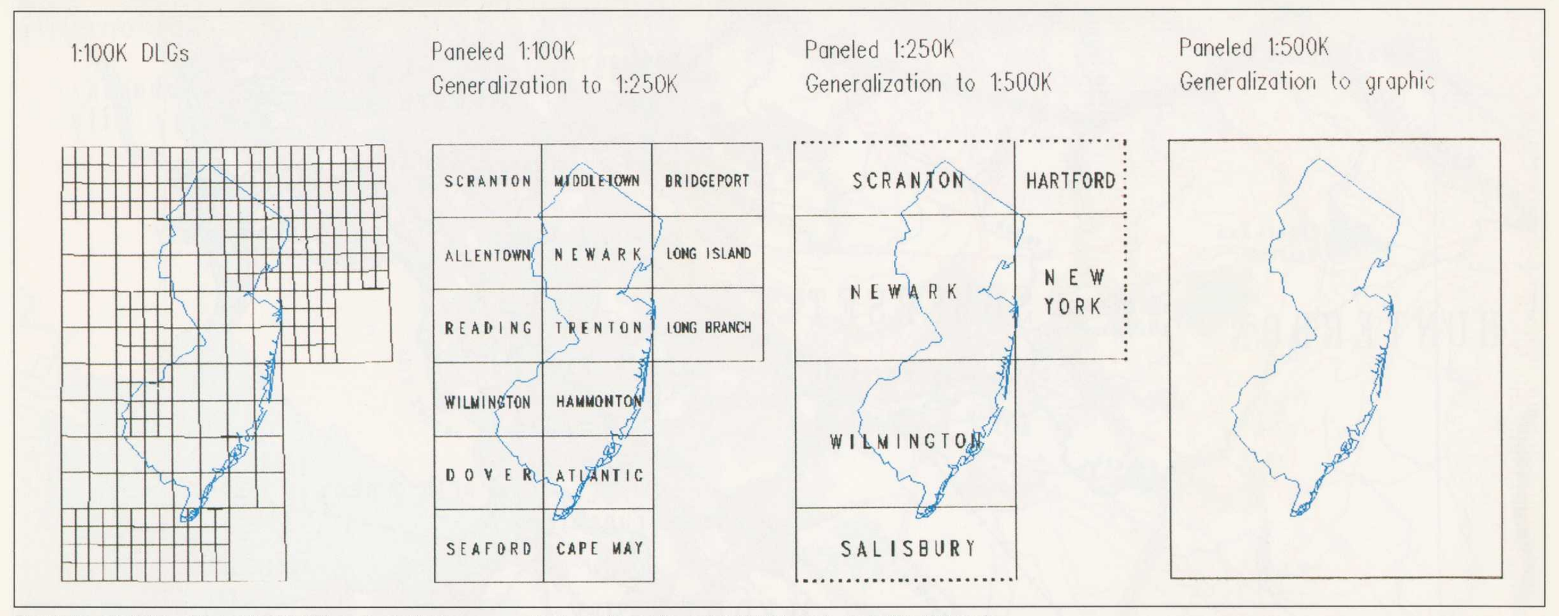

Figure 3a. Digital revision of 1:100,000-scale digital line graph data to produce a 1:500,000-scale New Jersey State base map. Paneling and generalization are shown in three stages from 1:100,000 scale, to 1:250,000 scale, to 1:500,000 scale.

Figures 3b, c, d. These digital maps of Boone County, NJ, are all at a scale of 1:500,000. The information content of the maps has been reduced through the process of generalization in two stages from 1:100,000 scale on the left, to 1:250,000 scale in the center, then from 1:250,000 scale to 1:500,000 scale on the right.

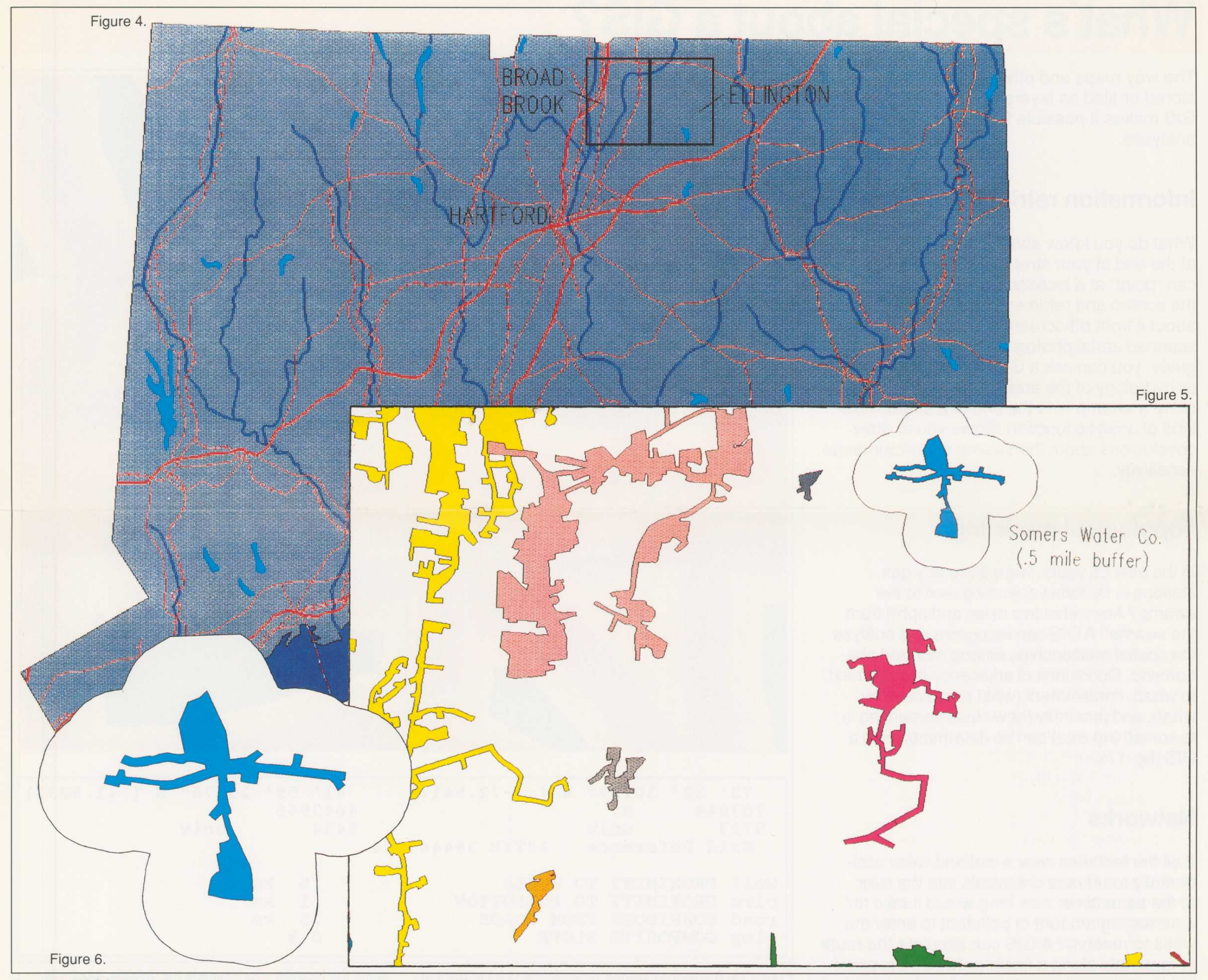

Figure 4. USGS digital line graph map of the State of Connecticut from 1:2,000,000-scale data. The Broad Brook and Ellington 7.5-minute quadrangle areas are outlined in black in the upper middle.

Figure 5. Map of the areas covered by the Broad Brook and Ellington 7.5-minute quadrangles, showing the Somers Water Company service area at a scale of 1:24,000.

Figure 6. Enlarged view of fig. 5 showing a half-mile buffer zone drawn around the service area of the Somers Water Company.

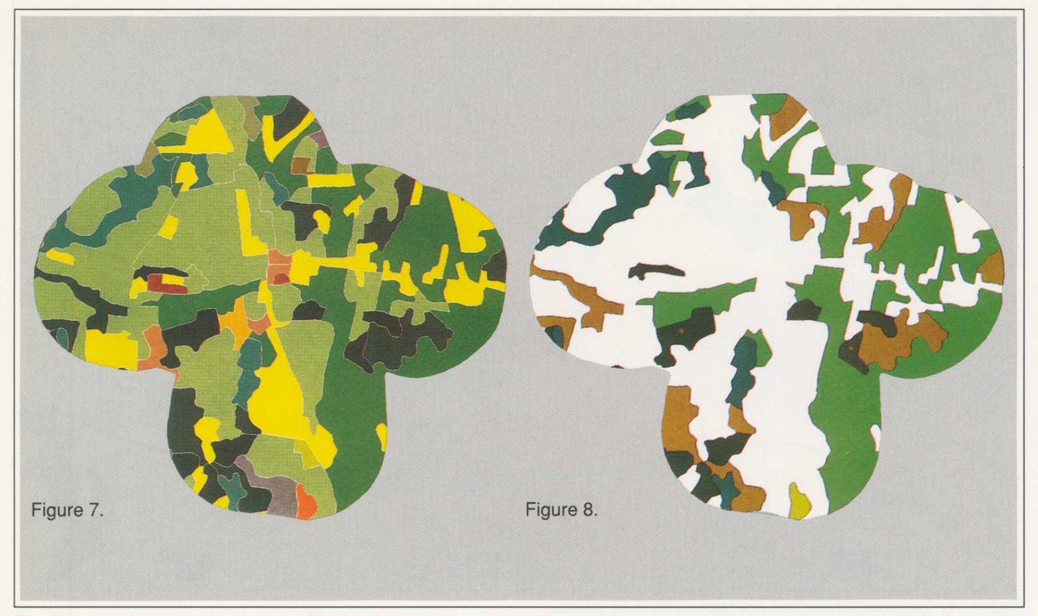

Figure 7. Land use and land cover data for the area bounded by the half-mile buffer zone around the water company service area.

Figure 8. Land use and land cover data shown in fig. 7 has been reselected to eliminate developed areas.

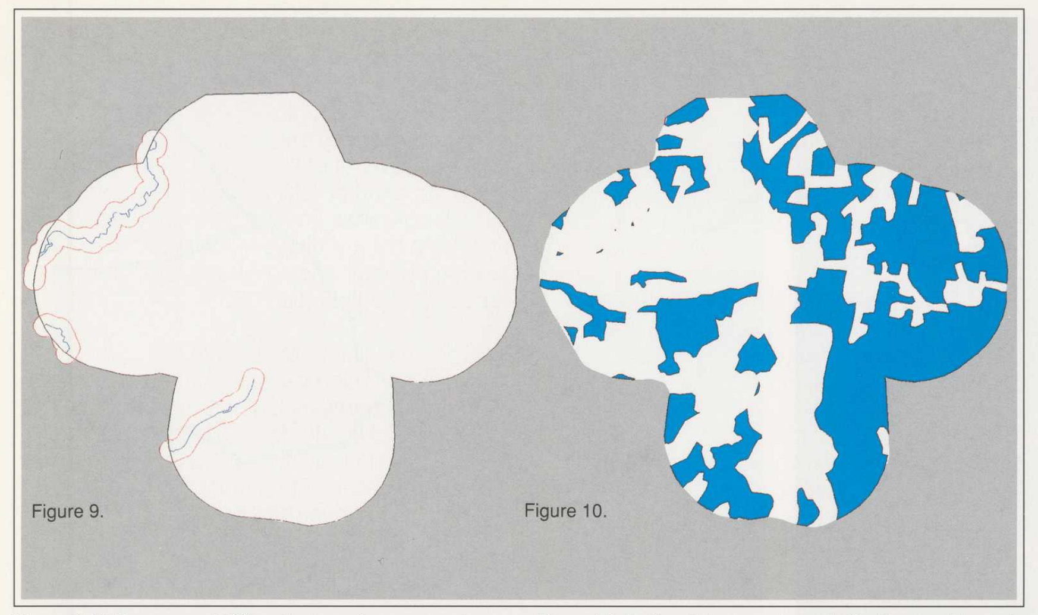

Figure 9. Buffer zones of 100 meters are drawn around polluted streams in the water service area.

Figure 10. Buffered streams shown in fig. 9 are subtracted from areas previously selected with the land use and land cover data.

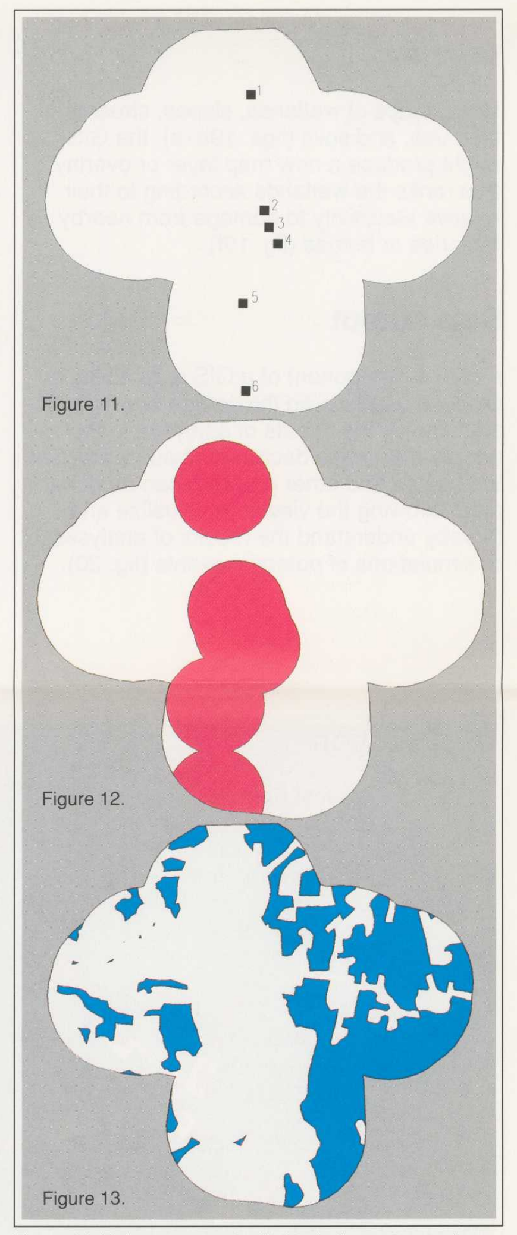

Figure 11. Point sources of pollution in the water service area are identified and entered into a GIS.
Figure 12. Buffer zones of 500 meters are drawn around point sources of pollution.
Figure 13. A new map is created in a GIS by eliminating the buffered sources of pollution from the previously-selected areas shown in fig. 10.

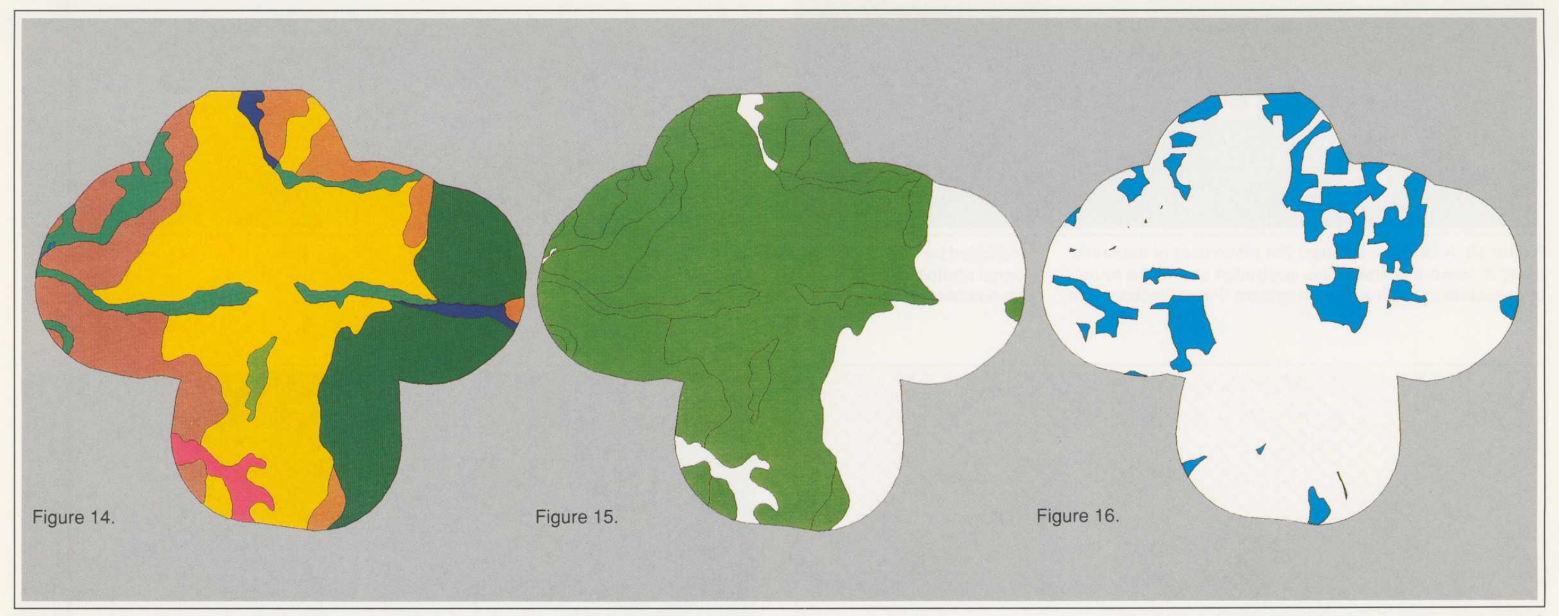

Figure 14. Map of surficial geology of the water service area.

Figure 15. Selection of areas of sand and gravel from the map of surficial geology.

Figure 16. Map produced by combining the areas composed of sand and gravel with the previous selections from fig. 13.

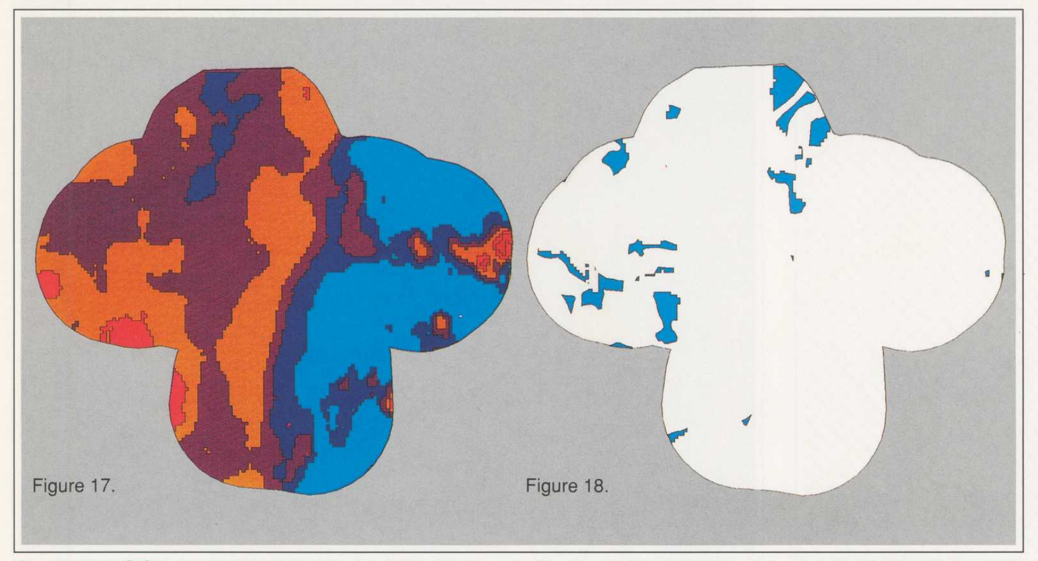

Figure 17. A GIS was used to subtract bedrock elevation from surface elevation producing a map showing the thickness of water-saturated sediments in the water service area.

Figure 18. Potential sites with saturated thicknesses of sediments greater than 40 feet.

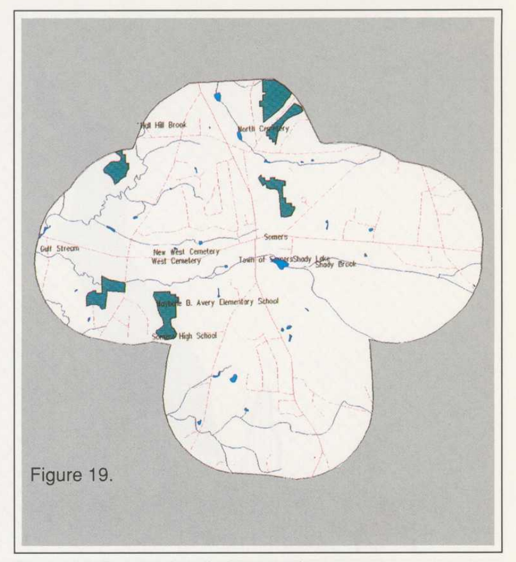

Figure 19. Potential well sites, roads, streams, and place names.

Emergency response planning

The Wasatch Fault zone runs through Salt Lake City along the foot of the Wasatch Mountains in north-central Utah (fig. 20). A GIS was used to combine road network and earth science information to analyze the effect of an earthquake on the response time of fire and rescue squads. The area covered by the USGS Sugar House 7.5-minute topographic quadrangle map was selected for the study because it includes both undeveloped areas in the mountains and a portion of Salt Lake City. Detailed earth science information was available for the entire area.

The road network from a USGS digital line graph includes information on the types of roads, which range from rough trails to divided highways (fig. 21). The locations of fire stations were plotted on the road network, and a GIS function called network analysis was used to calculate the time necessary for emergency vehicles to travel from the fire stations to different areas of the city. The network analysis function considers two elements: distance from the fire station, and speed of travel based on road type. The analysis shows that under normal conditions, most of the area within the city will be served in less than 7 minutes and 30 seconds because of the distribution and density of fire stations and the continuous network of roads.

The accompanying illustration (fig. 22) depicts the blockage of the road network that would result from an earthquake by assuming that any road crossing the fault trace would become impassable. The primary effect on emergency response time would occur in neighborhoods west of the fault trace, where travel times from the fire stations would be lengthened noticeably.

The Salt Lake City area lies on lake sediments of varying thicknesses. These sediments range from clay to sand and gravel, and most are water saturated. In an earthquake, these materials may momentarily lose their ability to support surface structures, including roads. The potential for this phenomenon, known as liquefaction, is shown in a composite map portraying the inferred relative stability of the land surface during an earthquake. Areas near the fault and underlain by thick, loosely consolidated, water-saturated sediments will suffer the most intense surface motion during an earthquake (fig. 23). Areas on the mountain front with thin surface sediments will experience less additional ground acceleration. The map of liquefaction potential was combined with the road network analysis to show the additional effect of liquefaction on response times.

The final map shows that areas near the fault, as well as those underlain by thick, water-saturated sediments, are subject to more road disruptions and slower emergency response than are other areas of the city (fig. 24).

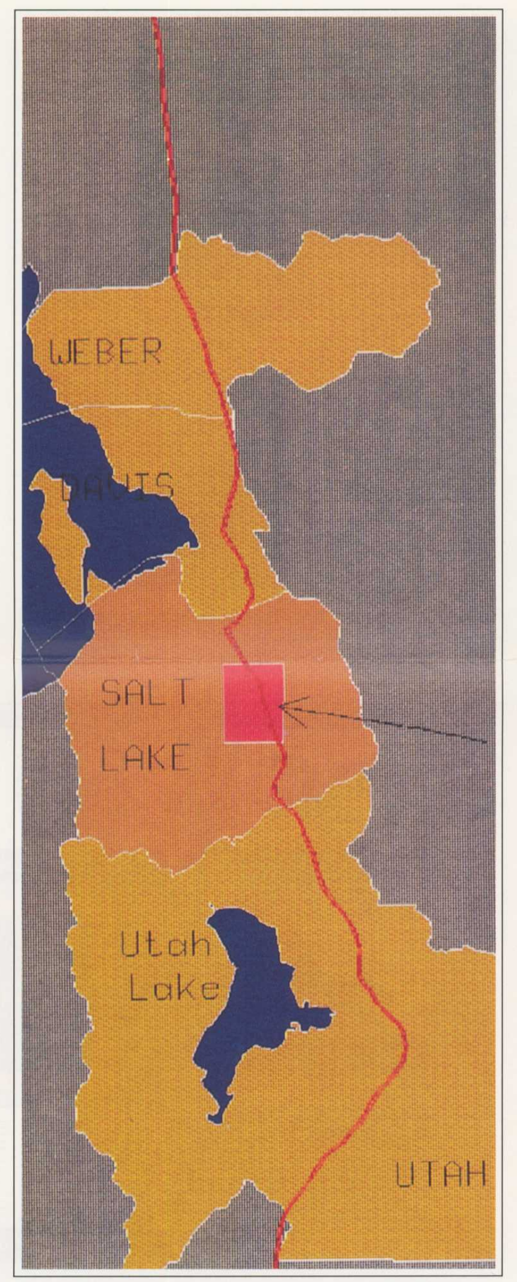

Figure 20. Map of the area surrounding the USGS Sugar House 7.5-minute quadrangle, Salt Lake City, UT, showing the location of the Wasatch Fault zone.

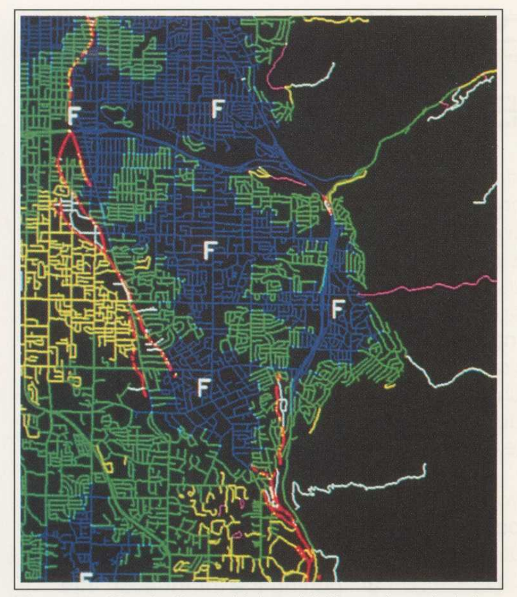

Figure 22. After faulting, initial model. Network analysis in a GIS produces a map of travel times from fire stations after faulting. The fault is in red. Emergency response times have increased for areas west of the fault.

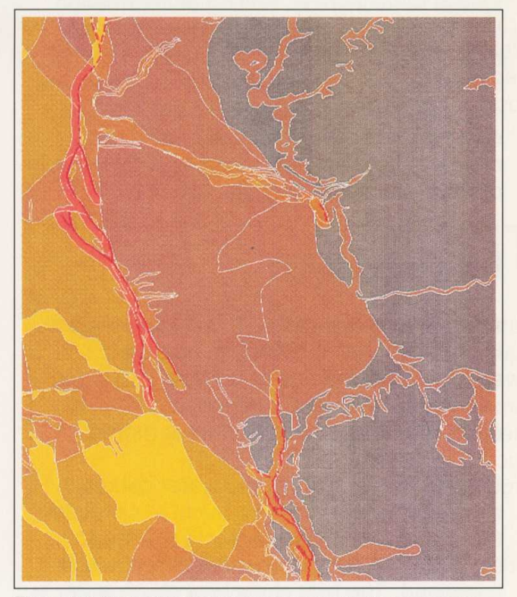

Figure 23. Map of potential ground liquefaction during an earthquake. The least stable areas are shown by yellows and oranges, the most stable by grays and browns.

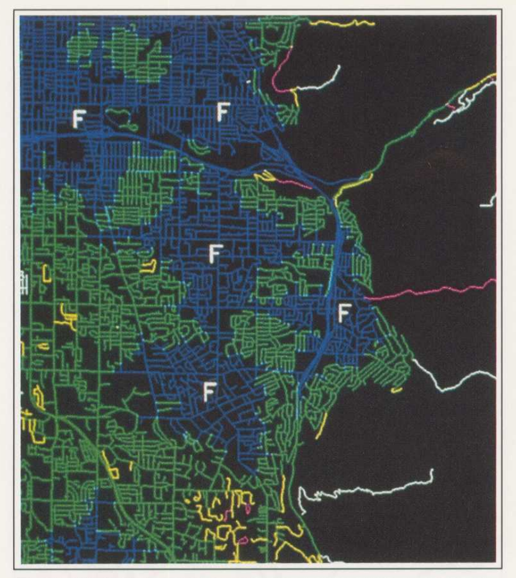

Figure 21. Before faulting. Road network of area covered by the Sugar House quadrangle plotted from USGS digital line graph data, indicating the locations of fire stations and the travel times of emergency vehicles. Areas in blue can be serviced within 2½ minutes, areas in green within 5 minutes, areas in yellow within 7½ minutes, and areas in magenta within 10 minutes. Areas in white cannot be serviced in 10 minutes.

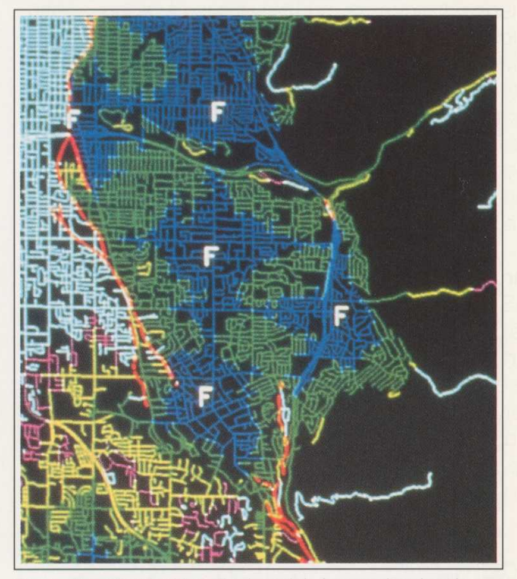

Figure 24. After faulting, final model. A map showing the effect of an earthquake on emergency travel times is produced by combining the liquefaction potential information from fig. 23 with the network analysis from fig. 22.

Simulating environmental effects

The National Forest Service was offered a land swap by a mining company seeking development rights to a mineral deposit in the Prescott National Forest of Arizona. Using a GIS and a variety of digital maps, the USGS and the Forest Service created perspective views of the area to depict the terrain before and after mining (figs. 25–27). Existing digital data were combined in a GIS and displayed using a function that creates perspective drawings.

The mining company provided planimetric (two-dimensional) drawings of the proposed mine (fig. 26). This plan was digitized, along with elevation information on the proposed mine and associated piles and ponds. The resulting perspective view illustrates the dramatic changes to the topography that mining would cause (fig. 27).

A GIS can combine map types and display them in realistic three-dimensional perspective views that convey information more effectively and to wider audiences than traditional, two-dimensional maps.

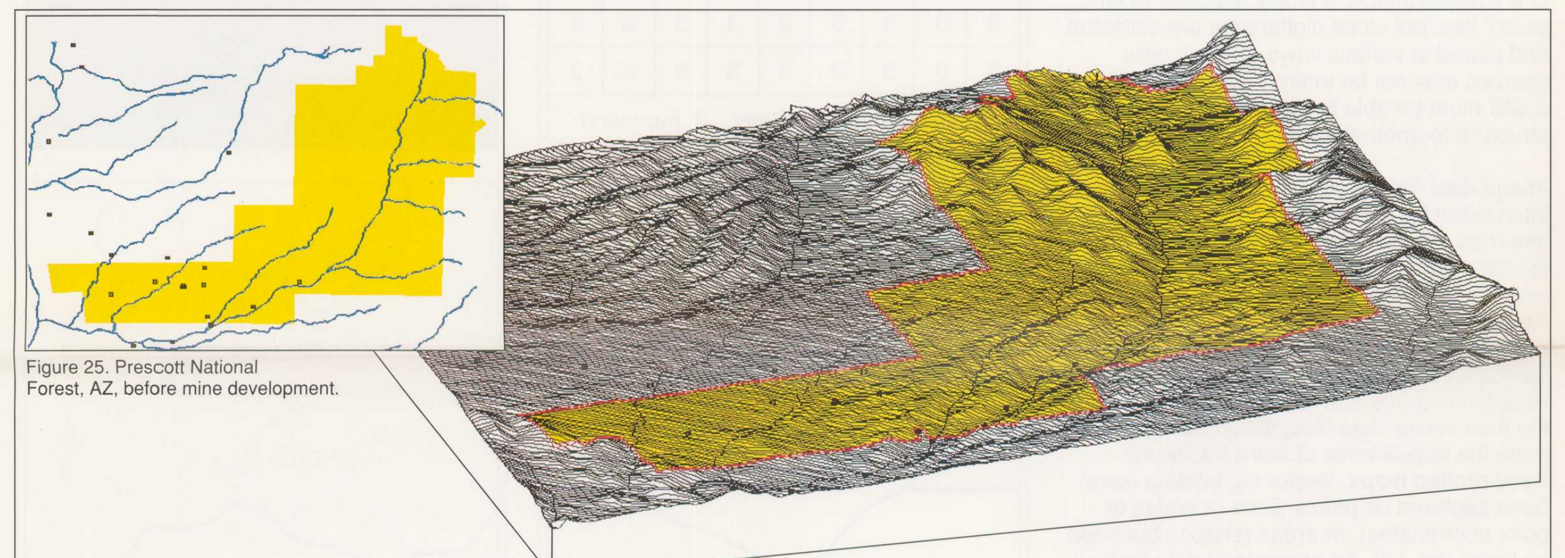

Figure 25. Prescott National Forest, AZ, before mine development.

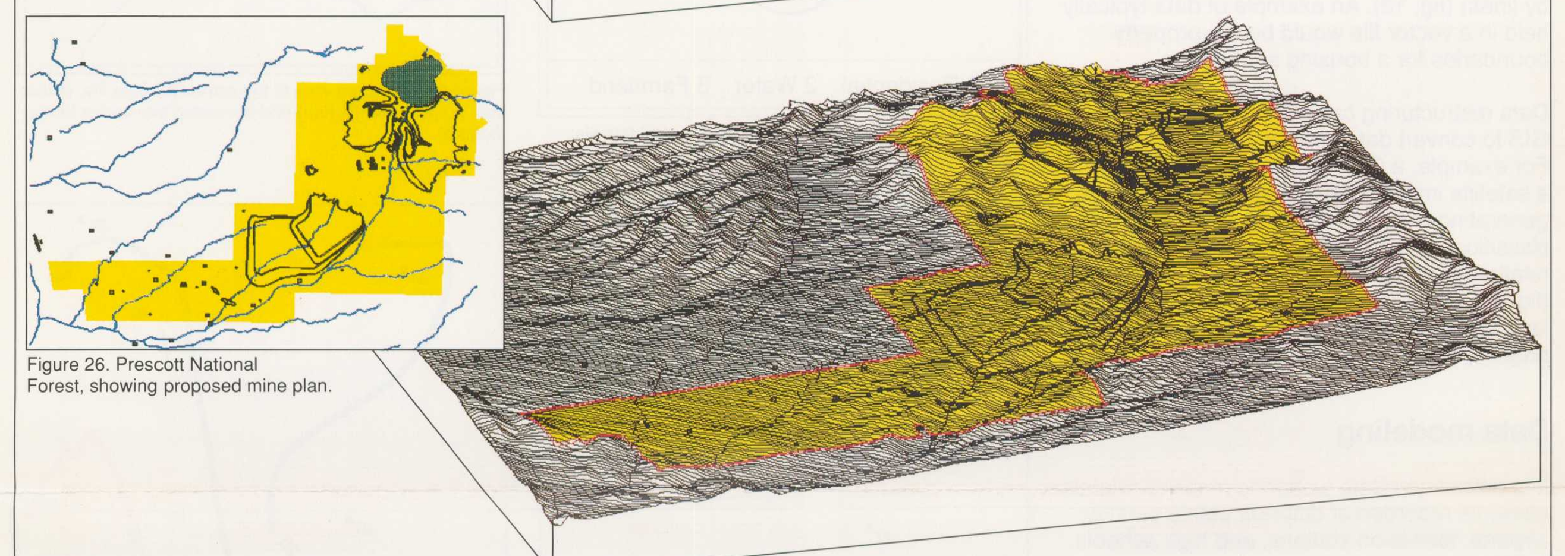

Figure 26. Prescott National Forest, showing proposed mine plan.

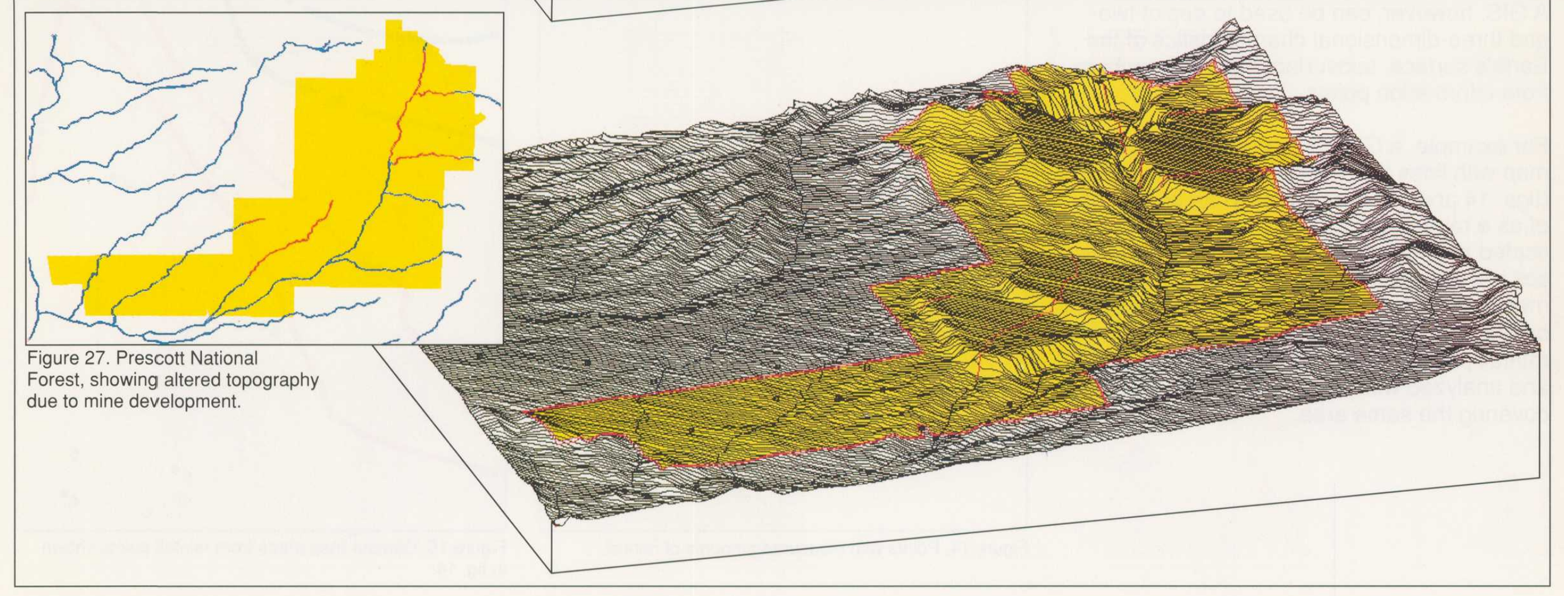

Figure 27. Prescott National Forest, showing altered topography due to mine development.

Graphic display techniques

Traditional maps are abstractions of the real world, a sampling of important elements portrayed on a sheet of paper with symbols to represent physical objects. People who use maps must interpret these symbols. Topographic maps show the shape of the land surface with contour lines. The actual shape of the land can be seen only in the mind's eye. Graphic display techniques in GIS's make relationships among map elements visible, heightening one's ability to extract and analyze information.

Two types of data were combined in a GIS to produce a perspective view of a portion of San Mateo County, California. The digital elevation model, consisting of surface elevations recorded on a 30-meter horizontal grid, shows high elevations as white and low elevations as black (fig. 28). The accompanying Landsat Thematic Mapper image shows a false-color infrared image of the same area in 30-meter pixels, or picture elements (fig. 29). A GIS was used to register and combine the two images to produce the three-dimensional perspective view looking down the San Andreas Fault (fig. 30).

Figure 28. Digital elevation model of San Mateo County, CA.

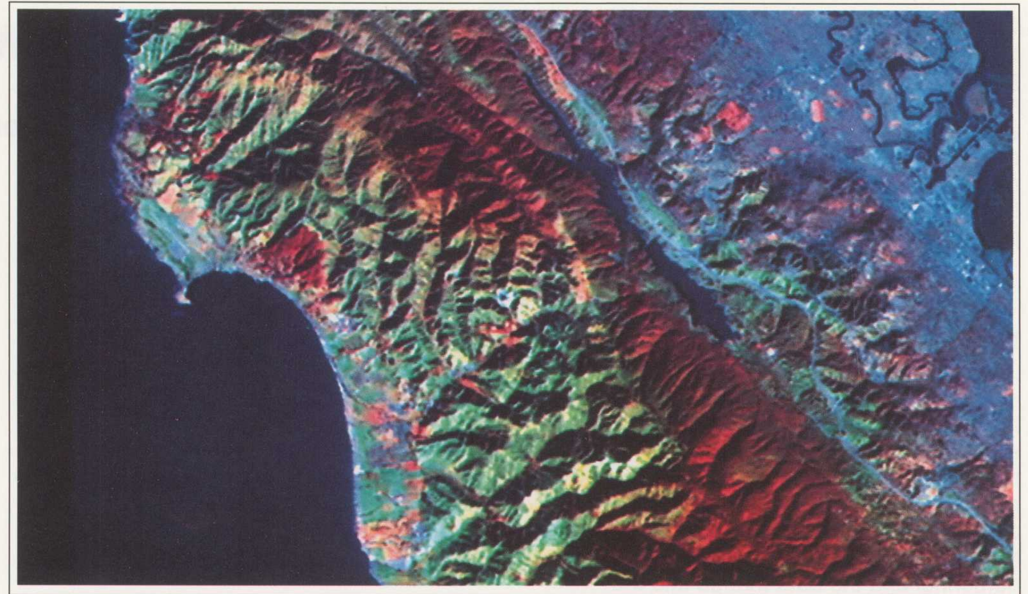

Figure 29. Landsat Thematic Mapper image of San Mateo County, CA.

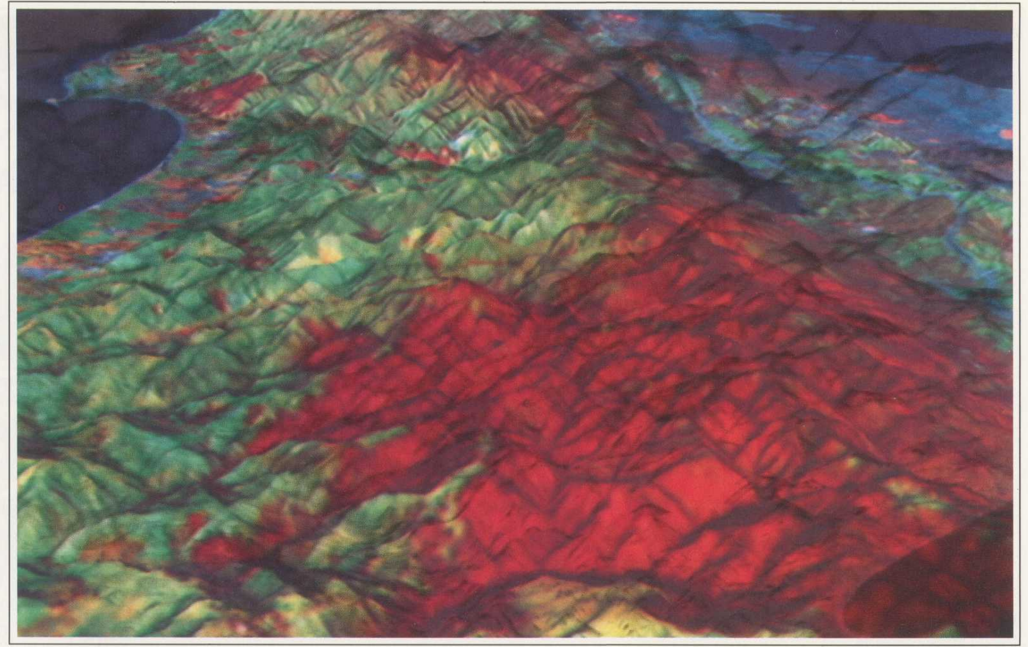

Figure 30. Perspective view of San Mateo County, CA.

The future of GIS

Many disciplines can benefit from GIS techniques. An active GIS market has resulted in lower costs and continual improvements in the hardware and software components of GIS. These developments will, in turn, result in a much wider application of the technology throughout government, business, and industry.

Global change research

Maps have traditionally been used to explore the Earth and to exploit its resources. GIS technology, as an expansion of cartographic science, has enhanced the efficiency and analytic power of traditional mapping. Now, as the scientific community recognizes the environmental consequences of human activity, GIS technology is becoming an essential tool in the effort to understand the process of global change. Various map and satellite information sources can be combined in models that simulate the interactions of complex natural systems.

Through a function known as visualization, a GIS can be used to produce images—not just maps, but drawings, animations, and other cartographic products. These images allow researchers to view their subjects in ways that literally never have been seen before. The images often are equally helpful in conveying the technical concepts of GIS study subjects to non-scientists.

Adding the element of time

The condition of the Earth's surface, atmosphere, and subsurface can be examined by feeding satellite data into a GIS. GIS technology gives researchers the ability to examine the variations in Earth processes over days, months, and years. As an example, the changes in vegetation vigor through a growing season can be animated to determine when drought was most extensive in a particular region. The resulting graphic, known as a normalized vegetation index, represents a rough measure of plant health (fig. 31). Working with two variables over time will allow researchers to detect regional differences in the lag between a decline in rainfall and its effect on vegetation.

These analyses are made possible both by GIS technology and by the availability of digital data on regional and global scales. The satellite sensor output used to generate the vegetation graphic is produced by the Advanced Very High Resolution Radiometer or AVHRR. This sensor system detects the amounts of energy reflected from the Earth's surface across various bands of the spectrum for surface areas of about 1 square kilometer. The satellite sensor produces images of a particular location on the Earth twice a day. AVHRR is only one of many sensor systems used for Earth surface analysis. More sensors will follow, generating ever greater amounts of data.

GIS and related technology will help greatly in the management and analysis of these large volumes of data, allowing for better understanding of terrestrial processes and better management of human activities to maintain world economic vitality and environmental quality.

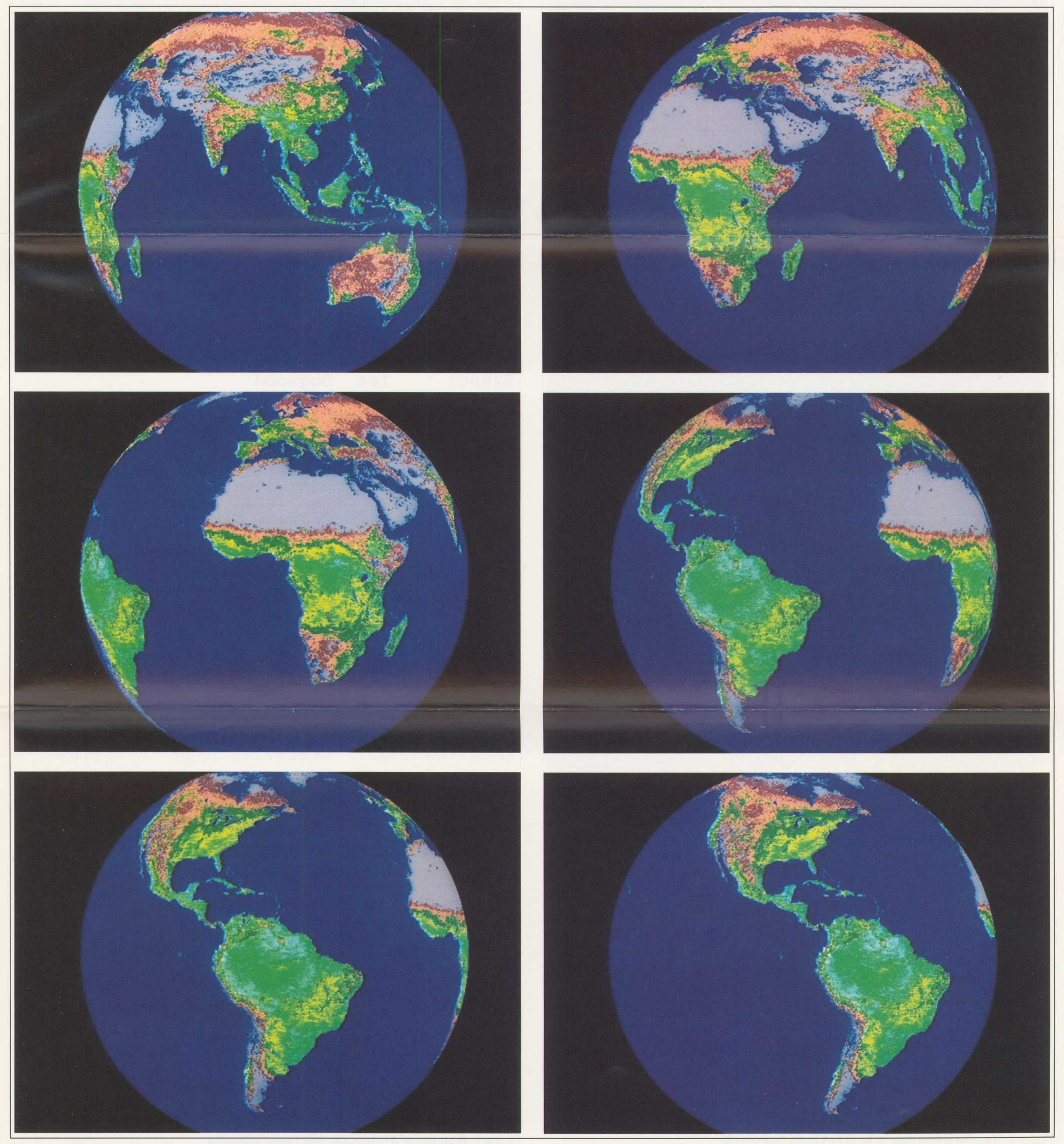

Figure 31. One time slice of the vegetation index for the entire globe from AVHRR data.

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