Geographic Information Systems

U.S. Department of the Interior
U.S. Geological Survey

Geographic information systems (GIS) technology can be used for scientific investigations, resource management, and development planning. For example, a GIS might allow emergency planners to easily calculate emergency response times in the event of a natural disaster, or a GIS might be used to find wetlands that need protection from pollution.

What is a GIS?

In the strictest sense, a GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e., data identified according to their locations. Practitioners also regard the total GIS as including operating personnel and the data that go into the system.

How does a GIS work?

Relating information from different sources

If you could relate information about the rainfall of your State to aerial photographs of your county, you might be able to tell which wetlands dry up at certain times of the year. A GIS, which can use information from many different sources in many different forms, can help with such analyses. The primary requirement for the source data is that the locations for the variables are known. Location may be annotated by x, y, and z coordinates of longitude, latitude, and elevation, or by such systems as ZIP Codes or highway mile markers. Any variable that can be located spatially can be fed into a GIS.

Several computer data bases that can be directly entered into a GIS are being produced by Federal agencies and private firms. Different kinds of data in map form can be entered into a GIS (figs. 1 and 2). A GIS can also convert existing digital information, which may not yet be in map form, into forms it can recognize and use. For example, digital satellite images can be analyzed to produce a map-like layer of digital information about vegetative cover (figs. 3 and 4). Likewise, census or hydrologic tabular data can be converted to map-like form, serving as layers of thematic information in a GIS (figs. 5 and 6).

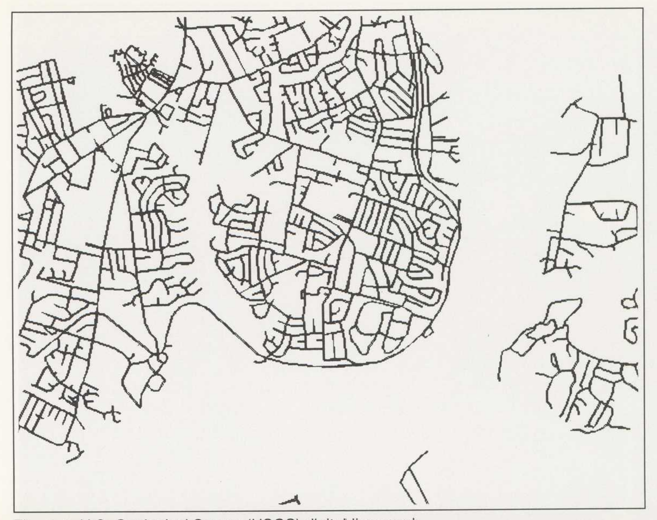

Figure 1. U.S. Geological Survey (USGS) digital line graph (DLG) data of roads.

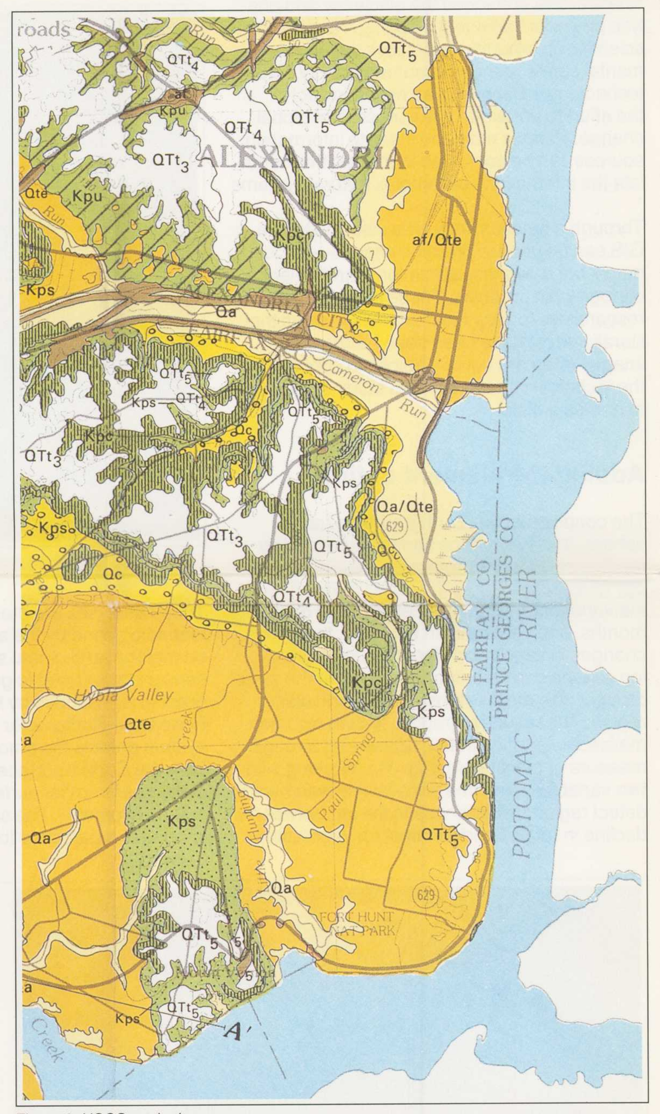

Figure 2. USGS geologic map.

Figure 3. Satellite image from which land cover information can be derived.

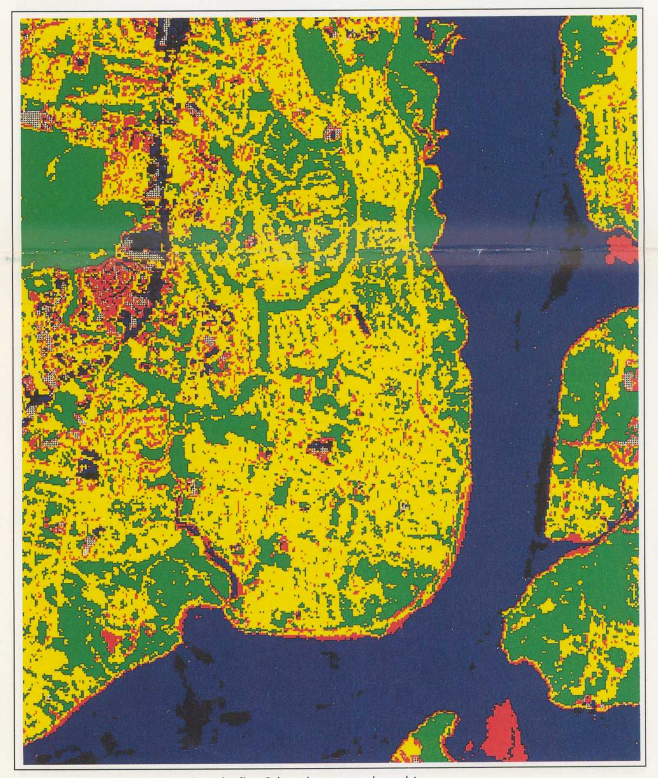

Figure 4. Satellite image data in fig. 3 has been analyzed to show classes of vegetative cover.

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529001         1   Shuteye
                       Br    529001         19   Mu
529001       36N Frk South Fabius
                             529001         54   Da
529001       71   Hickory
 Northern                    529001         89   St
529001      106   Dogwood
                     Road    529001        124E  Po
529001      141   Meadow
                      Ave    529001        159W  Ma
529001      176E Hickory
                       St    529001        194E  Wa
529001      211N Don
                       St    529001        229N  Ma
529001      246S Cottage Grove
                       St    529001        264E  Br
529001      281E Link
                       Dr    529001        299   Be
529001      316   Clg Park
                       St    529001        334   Lo
529001      351   Brushy
nut                          529001        369   El
529001      386   Surratt
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Figure 5. A portion of a census data file containing address information.

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LOCATION.--Lat  39:15:16, Long  077:34:36, H

DRAINAGE AREA.--     89.60  mi2     (  232.07

PERIOD OF RECORD.-- 1971-1987


                             STREAMFLOW (CFS),

DAY         Oct       Nov       Dec       Jan
   1         47       150       360        64
   2         60       143       235       118
   3         66       141       188       111
   4         52       113       165        85
   5         48        96       146       146

   6         46        90       146       107
   7         40        87       600        84
   8         37        80       475        77
   9         37        75       335        80
  10        349        74       282       148
```

Figure 6. A portion of a hydrologic data report indicating recorded stream flow amounts for a particular stream gage.

Data capture

How can a GIS use the information in a map? If the data to be used are not already in digital form, that is, in a form the computer can recognize, various techniques can capture the information. Maps can be digitized, or hand-traced with a computer mouse, to collect the coordinates of features (fig. 7). Electronic scanning devices will also convert map lines and points to digits (fig. 8).

A GIS can be used to emphasize the spatial relationships among the objects being mapped. While a computer-aided mapping system may represent a road simply as a line, a GIS may also recognize that road as the border between wetland and urban development, or as the link between Main Street and Blueberry Lane.

Data capture—putting the information into the system—is the time-consuming component of GIS work. Identities of the objects on the map must be specified, as well as their spatial relationships. Editing of information that is automatically captured can also be difficult. Electronic scanners record blemishes on a map just as faithfully as they record the map features. For example, a fleck of dirt might connect two lines that should not be connected. Extraneous data must be edited, or removed from the digital data file.

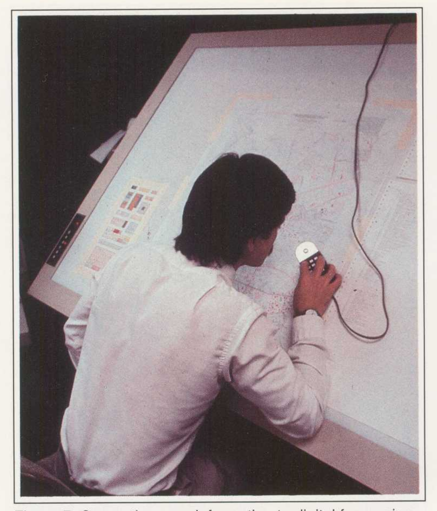

Figure 7. Converting map information to digital form using a hand-held computer mouse.

Figure 8. An electronic scanning device will convert some types of map information to digital form.

Data integration

A GIS makes it possible to link, or integrate, information that is difficult to associate through any other means. Thus, a GIS can use combinations of mapped variables to build and analyze new variables (fig. 9).

Using GIS technology and water company billing information, it is possible to simulate the discharge of materials into the septic systems in a neighborhood upstream from a wetland. The bills show how much water is used at each address. The amount of water a customer uses will roughly predict the amount of material that will be discharged into the septic systems, so that areas of heavy septic discharge can be located using a GIS.

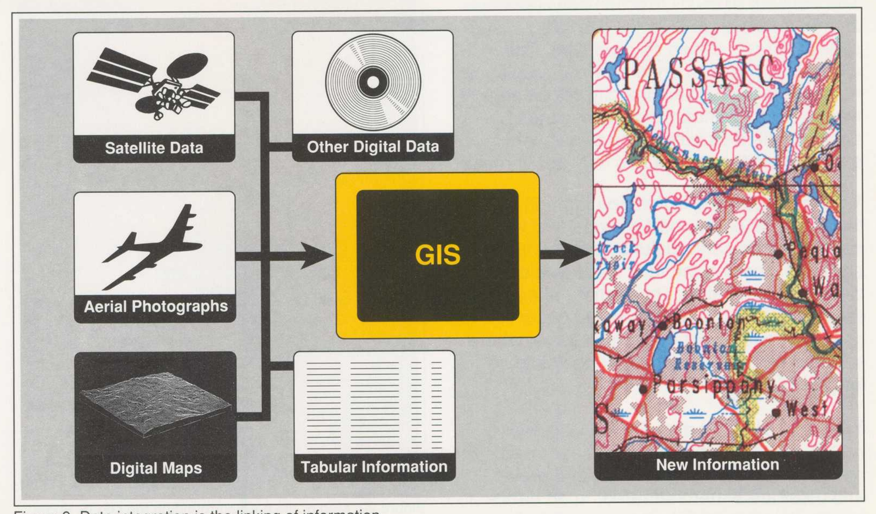

Figure 9. Data integration is the linking of information in different forms through a GIS.

Projection and registration

A property ownership map might be at a different scale from a soils map. Map information in a GIS must be manipulated so that it registers, or fits, with information gathered from other maps. Before the digital data can be analyzed, they may have to undergo other manipulations—projection conversions, for example—that integrate them into a GIS.

Projection is a fundamental component of mapmaking. A projection is a mathematical means of transferring information from the Earth's three-dimensional, curved surface to a two-dimensional medium—paper or a computer screen. Different projections are used for different types of maps because each projection is particularly appropriate to certain uses. For example, a projection that accurately represents the shapes of the continents will distort their relative sizes.

Since much of the information in a GIS comes from existing maps, a GIS uses the processing power of the computer to transform digital information, gathered from sources with different projections, to a common projection (figs. 10a and b).

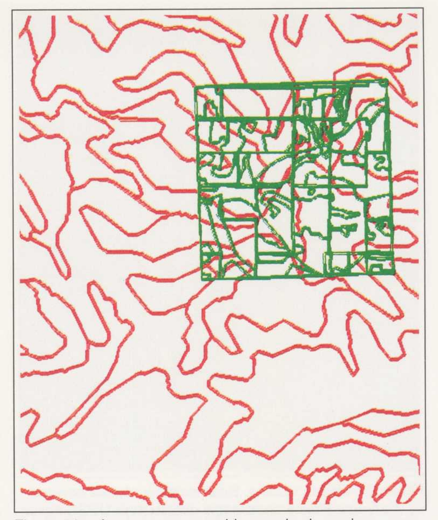

Figure 10a. A property ownership map is shown in green on top of a soils map in red. The two maps have different scales and projections.

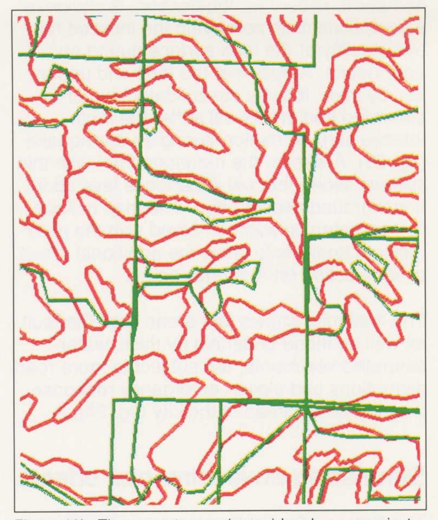

Figure 10b. The property map (green) has been reprojected to match the projection and scale of the soils map (red).

Data structures

Can a property ownership map be related to a satellite image, a timely indicator of land uses? Yes, but since digital data are collected and stored in various ways, the two data sources may not be entirely compatible. So a GIS must be able to convert data from one structure to another.

Image data from a satellite that has been interpreted by a computer to produce a land use map can be "read into" the GIS in raster format. Raster data files consist of rows of uniform cells coded according to data values. An example would be land cover classification (fig. 11). Raster data files can be manipulated quickly by the computer, but they are often less detailed and may be less visually appealing than vector data files, which can approximate the appearance of more traditional hand-drafted maps. Vector digital data have been captured as points, lines (a series of point coordinates), or areas (shapes bounded by lines) (fig. 12). An example of data typically held in a vector file would be the property boundaries for a housing subdivision.

Data restructuring can be performed by a GIS to convert data into different formats. For example, a GIS may be used to convert a satellite image map to a vector structure by generating lines around all cells with the same classification, while determining the cell spatial relationships, such as adjacency or inclusion (fig. 13). Thus, a GIS can be used to analyze land use information in conjunction with property ownership information.

1	1	1	3	3	3	3	3	3
1	1	1	3	3	3	3	3	3
1	1	2	2	2	2	3	3	3
1	1	2	2	2	2	2	3	3
1	2	2	2	2	2	3	3	3
3	3	3	2	2	2	3	3	3
3	3	3	3	2	3	3	3	3
3	3	3	3	3	3	3	3	3

1 Residential 2 Water 3 Farmland

Figure 11. Example of the structure of a raster data file.

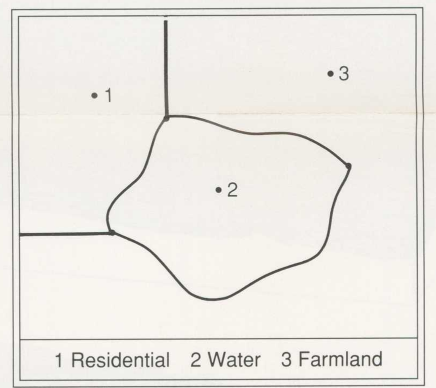

Figure 12. Example of the structure of a vector data file.

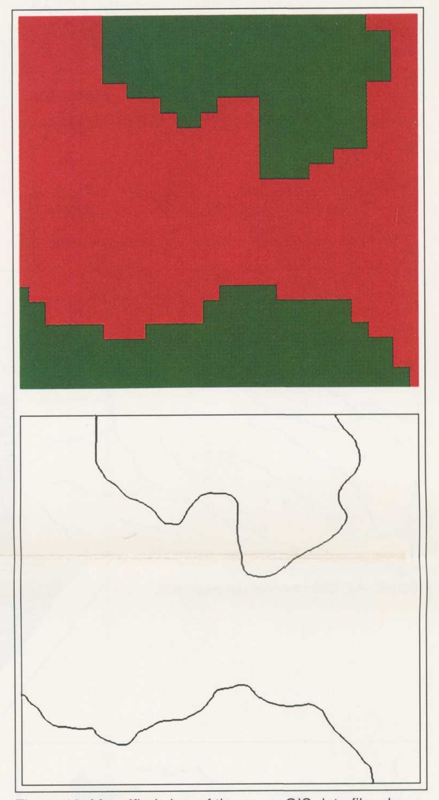

Figure 13. Magnified view of the same GIS data file, shown both in raster format (top) and converted into vector format (bottom).

Data modeling

It is difficult to relate wetlands maps to rainfall amounts recorded at different points such as airports, television stations, and high schools. A GIS, however, can be used to depict two- and three-dimensional characteristics of the Earth's surface, subsurface, and atmosphere from information points.

For example, a GIS can quickly generate a map with lines that indicate rainfall amounts (figs. 14 and 15). Such a map can be thought of as a rainfall contour map. Many sophisticated methods can estimate the characteristics of surfaces from a limited number of point measurements. A two-dimensional contour map created from the surface modeling of rainfall point measurements may be overlain and analyzed with any other map in a GIS covering the same area.

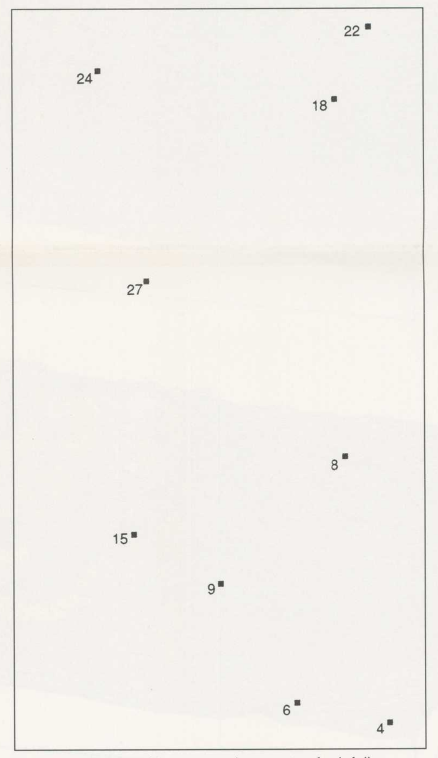

Figure 14. Points with measured amounts of rainfall.

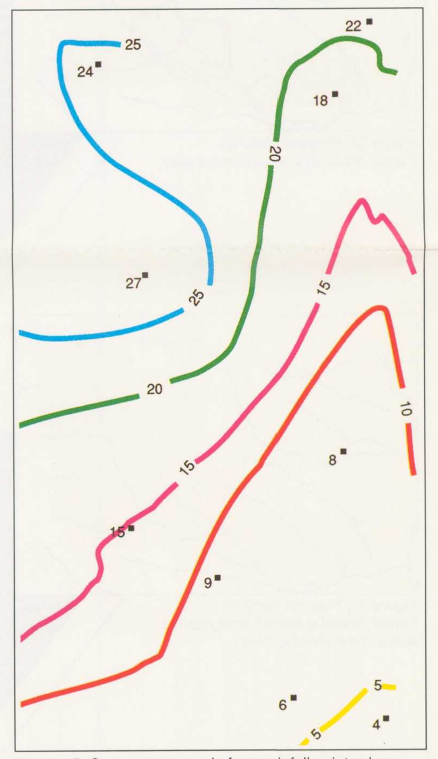

Figure 15. Contour map made from rainfall points shown in fig. 14.

What's special about a GIS?

The way maps and other data have been stored or filed as layers of information in a GIS makes it possible to perform complex analyses.

Information retrieval

What do you know about the swampy area at the end of your street? With a GIS you can "point" at a location, object, or area on the screen and retrieve recorded information about it from off-screen files (fig. 16). Using scanned aerial photographs as a visual guide, you can ask a GIS about the geology or hydrology of the area or even about how close a swamp is to the end of a street. This kind of analytic function allows you to draw conclusions about the swamp's environmental sensitivity.

Topological modeling

In the past 35 years, were there any gas stations or factories operating next to the swamp? Any within two miles and uphill from the swamp? A GIS can recognize and analyze the spatial relationships among mapped phenomena. Conditions of adjacency (what is next to what), containment (what is enclosed by what), and proximity (how close something is to something else) can be determined with a GIS (fig. 17).

Networks

If all the factories near a wetland were accidentally to release chemicals into the river at the same time, how long would it take for a damaging amount of pollutant to enter the wetland reserve? A GIS can simulate the route of materials along a linear network. It is possible to assign values such as direction and speed to the digital stream and "move" the contaminants through the stream system (fig. 18).

Overlay

Using maps of wetlands, slopes, streams, land use, and soils (figs. 19a–e), the GIS might produce a new map layer or overlay that ranks the wetlands according to their relative sensitivity to damage from nearby factories or homes (fig. 19f).

Data output

A critical component of a GIS is its ability to produce graphics on the screen or on paper that convey the results of analyses to the people who make decisions about resources. Wall maps and other graphics can be generated, allowing the viewer to visualize and thereby understand the results of analyses or simulations of potential events (fig. 20).

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 72° 32' 30.27" W (  -72.5417)     41° 55' 23.76" N ( 41.9233)
703844      m                      4643966     m
9723        univ                   5434        univ
 Grid Reference    18TYB 384443966

well PROXIMITY TO WELLS               .5  km
circ PROXIMITY TO POLLUTION            1  km
road CORRIDORS FROM ROADS             .5  km
slop COMPOSITE SLOPE                  0 %
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Figure 16. A crosshair pointer (top) can be used to point at a location stored in a GIS. The bottom illustration depicts a computer screen containing the kind of information stored about the location—for example the latitude, longitude, projection, coordinates, closeness to wells, sources of pollution, roads, and the slope of the land.

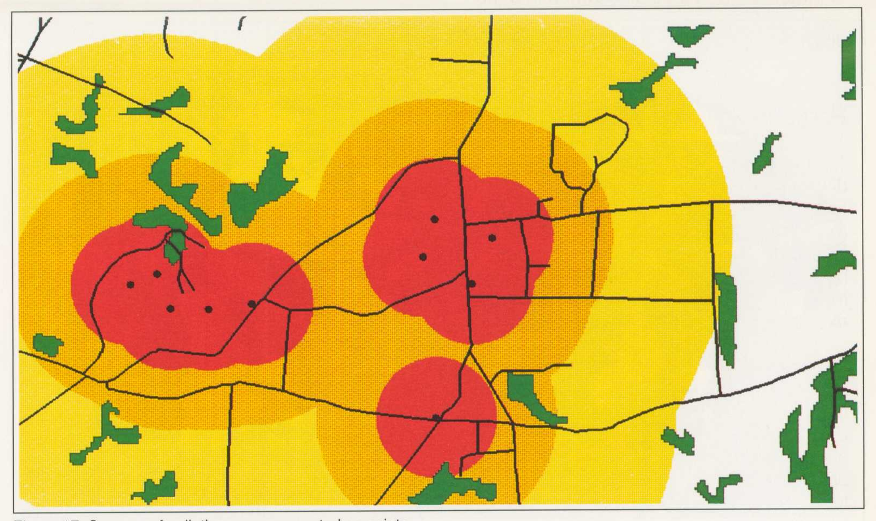

Figure 17. Sources of pollution are represented as points. The colored circles show distance from pollution sources. The wetlands are in green.

Figure 18. A GIS can simulate the movement of materials along a network of lines. This illustration shows the route of pollutants through a stream system. Flow directions are indicated by arrows. On the left, flow is superimposed on aerial photography of the area; on the right, flow is shown on a schematic drawing of the streams.

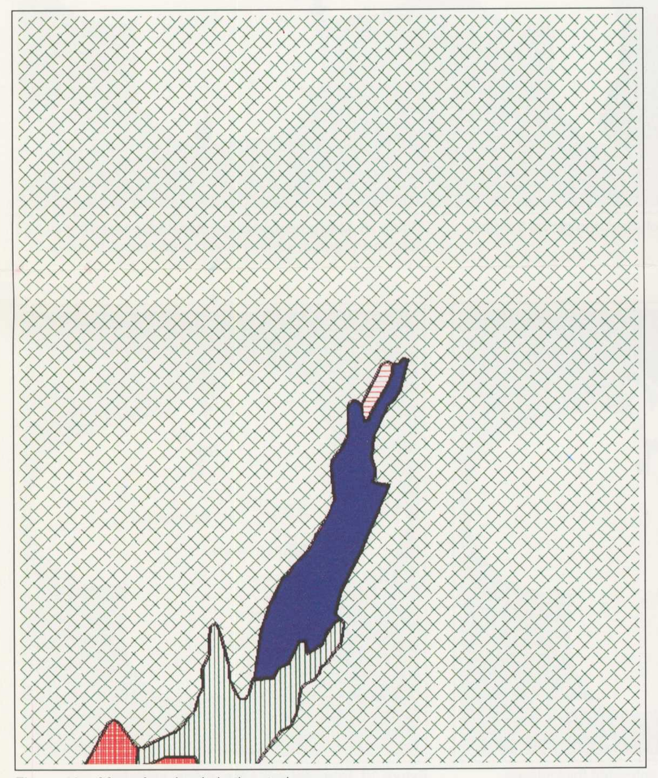

Figure 19a. Map of wetlands in the study area.

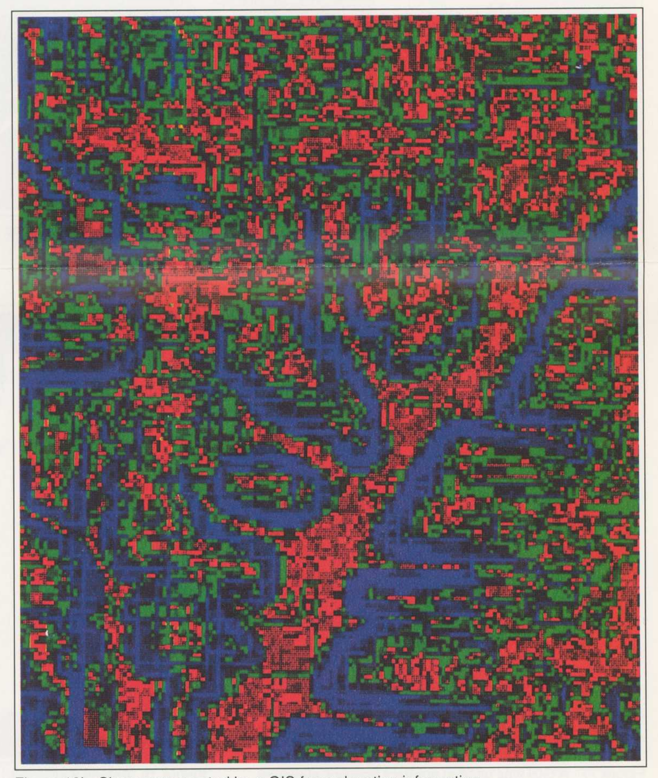

Figure 19b. Slope map created by a GIS from elevation information.

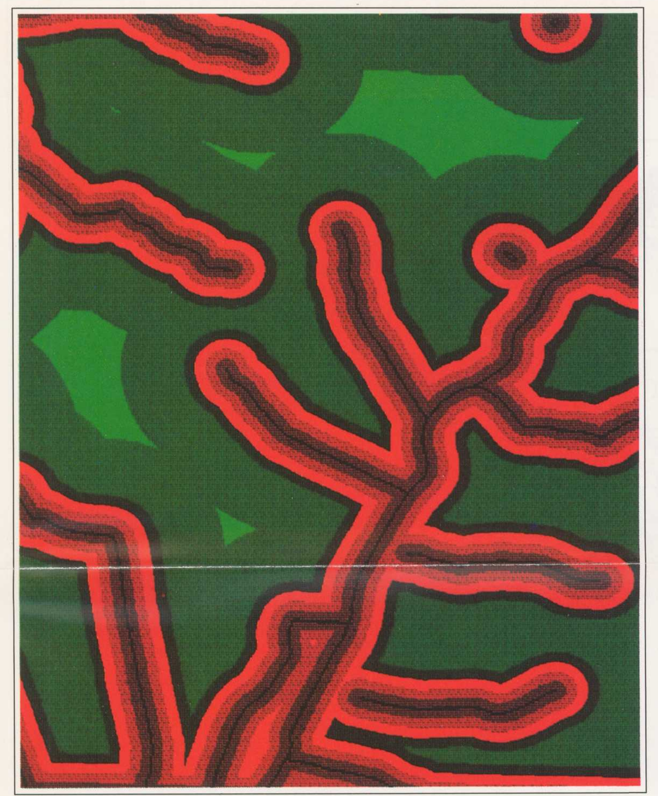

Figure 19c. Distances to streams derived from a digital map of hydrography.

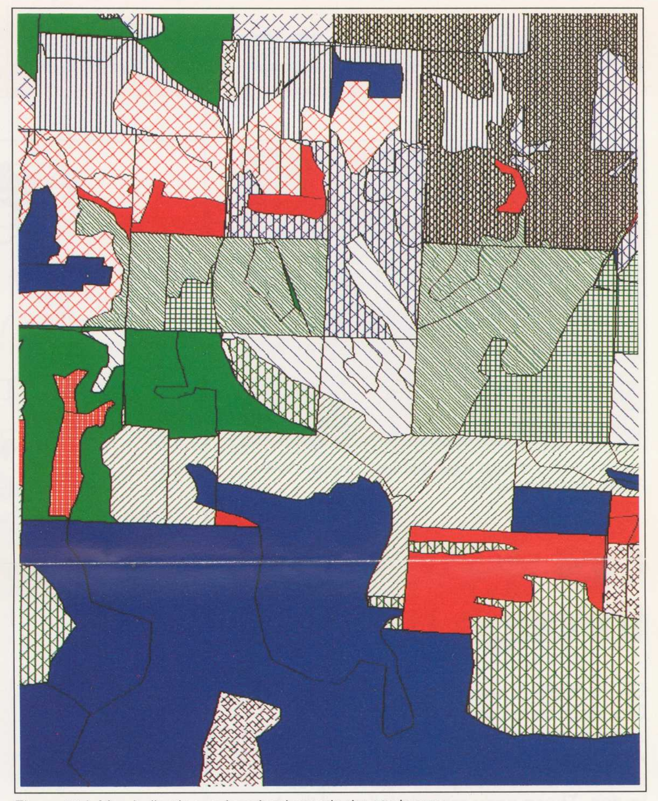

Figure 19d. Map indicating various land uses in the study area.

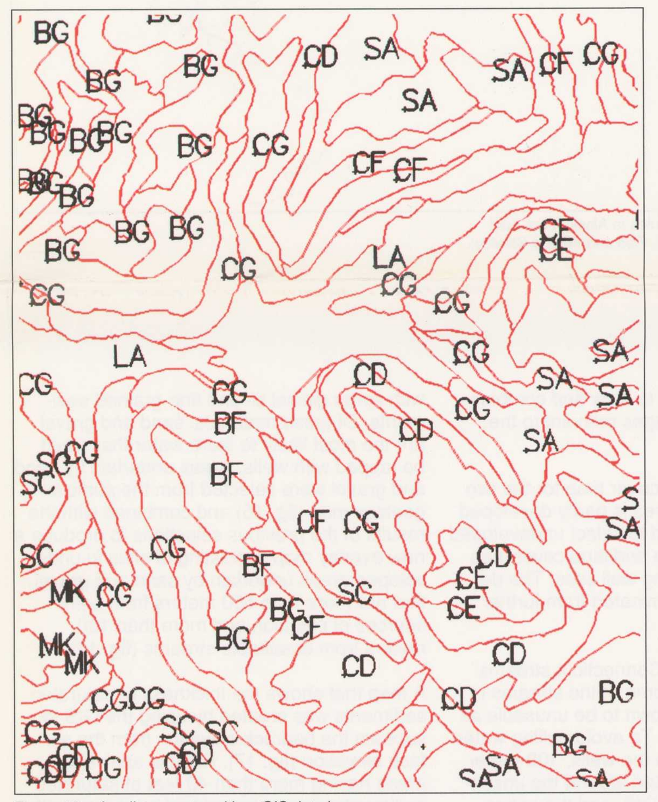

Figure 19e. A soils map stored in a GIS data base. Letter codes indicate soil type.

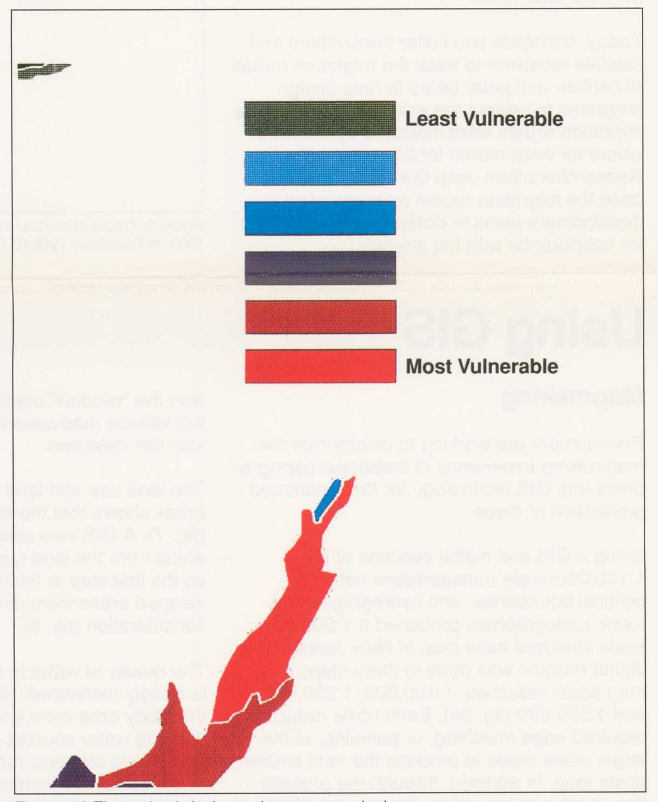

Figure 19f. The wetlands in the study area are ranked according to their vulnerability to pollution based on the combination of factors related by using a GIS.

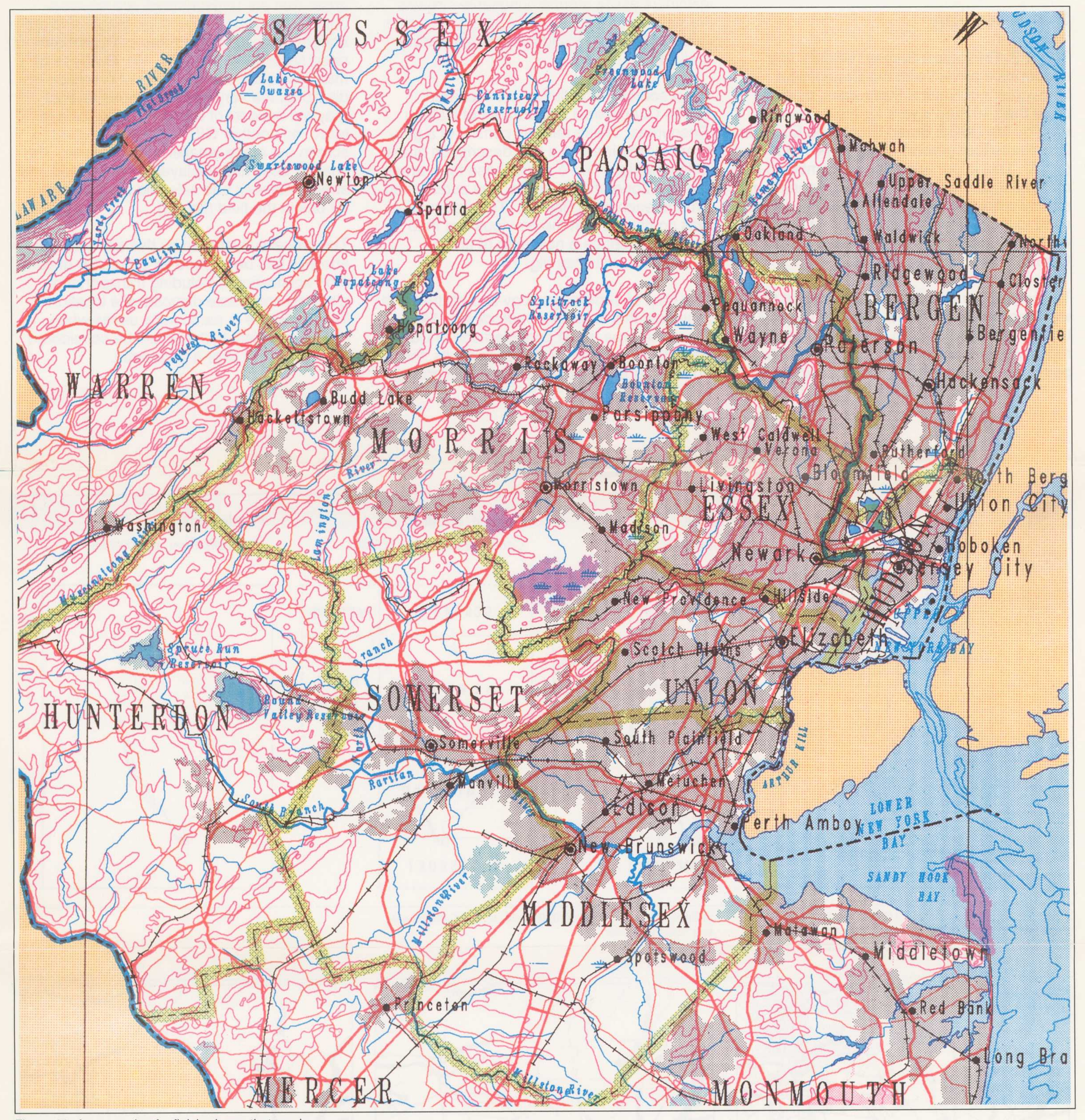

Figure 20. An example of a finished map that can be generated using a GIS.

Framework for cooperation

The use of GIS may encourage cooperation and communication among the agencies involved in environmental protection and resource management. The collection of data for a GIS, however, is costly. Data collection requires computer equipment and technical expertise that may be very specialized.

Standard data formats ease the exchange of digital information among users of different systems. So standardization helps to stretch data collection funds further by allowing data sharing, and, in many cases, gives users access to data they could not otherwise collect for economic or technical reasons.

For more information

A good place to begin to learn more about GIS technology would be the geography department of your local university. Other sources of information might be your State or county department of natural resources, or a USGS Earth Science Information Center (ESIC). To locate your nearest ESIC, call 1-800-USA-MAPS.