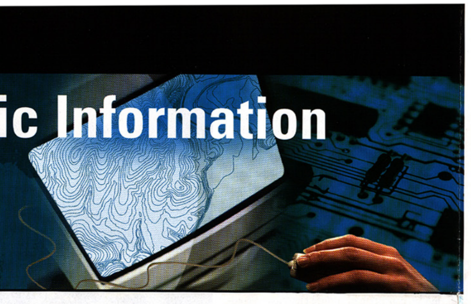
USGS
science for a changing world

Geographic Information Systems



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

Geographic information system (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?

A GIS is a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information; that is, data identified according to location. Practitioners also define a GIS as including the procedures, operating personnel, and spatial data that go into the system.

How does a GIS work?

Relating information from different sources

The power of a GIS comes from the ability to relate different information in a spatial context and to reach a conclusion about this relationship. Most of the information we have about our world contains a location reference, placing that information at some point on the globe. When rainfall information is collected, it is important to know where the rainfall is located. This is done by using a location reference system, such as longitude and latitude, and perhaps elevation. Comparing the rainfall information with other information, such as the location of marshes across the landscape, may show that certain marshes receive little rainfall. This fact may indicate that these marshes are likely to dry up, and this inference can help us make the most appropriate decisions about how humans should interact with the marsh. A GIS, therefore, can reveal important new information that leads to better decisionmaking.

Many computer databases that can be directly entered into a GIS are being produced by Federal, State, tribal, and local governments, private companies, academia, and nonprofit organizations. Different kinds of data in map form can be entered into a GIS (figs. 1a, 1b, 1c, 1d, 1e, 1f, 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 of digital information about land use and land cover (figs. 3 and 4). Likewise, census or hydrologic tabular data can be converted to a maplike form and serve as layers of thematic information in a GIS (figs. 5 and 6).

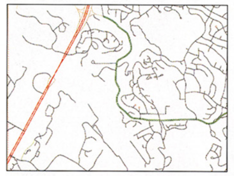


Figure 1a. U.S. Geological Survey (USGS) digital line graph (DLG) data of roads.

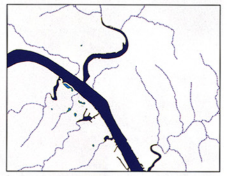


Figure 1b. USGS DLG of rivers.

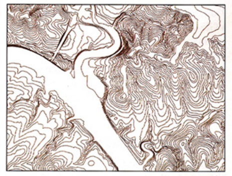


Figure 1c. USGS DLG of contour lines (hypsography).

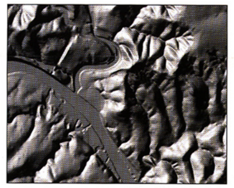


Figure 1d. USGS digital elevation model (DEM).

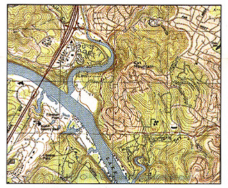


Figure 1e. USGS scanned, rectified topographic map, called a digital raster graphic (DRG).

Figure 1f. USGS digital orthophoto quadrangle (DOQ).

Figure 2. USGS geologic map.

Figure 3. Landsat 7 satellite image from which land cover information can be derived.

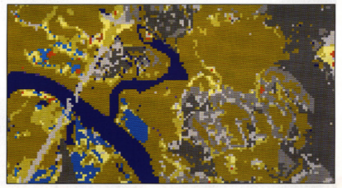


Figure 4. Satellite image data in figure 3 have been analyzed to indicate classes of land use and land cover.

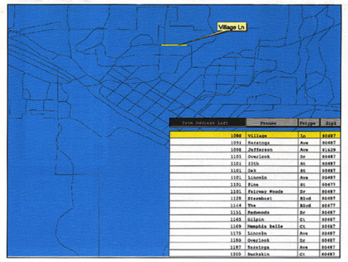


Figure 5. Part of a census data file containing address information.

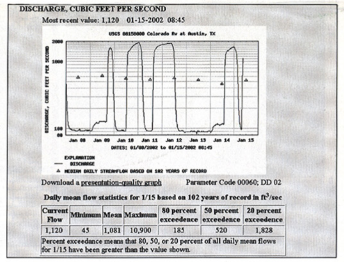


Figure 6. Part of a hydrologic data report indicating the discharge and amount of river flow recorded by a particular streamgage that has a known location.

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 by hand-tracing with a computer mouse on the screen or on a digitizing tablet to collect the coordinates of features. Electronic scanners can also convert maps to digits (fig. 7). Coordinates from Global Positioning System (GPS) receivers can also be uploaded into a GIS (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 boundary between wetland and urban development between two census statistical areas.

Data capture—putting the information into the system—involves identifying the objects on the map, their absolute location on the Earth's surface, and their spatial relationships. Software tools that automatically extract features from satellite images or aerial photographs are gradually replacing what has traditionally been a time-consuming capture process. Objects are identified in a series of attribute tables—the "information" part of a GIS. Spatial relationships, such as whether features intersect or whether they are adjacent, are the key to all GIS-based analysis.

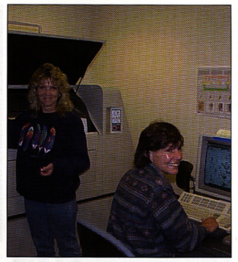


Figure 7. Scanning paper maps to produce digital files for input into a GIS.

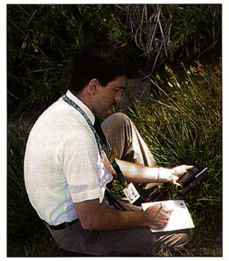


Figure 8. Collecting latitude and longitude coordinates with a Global Positioning System (GPS) receiver.

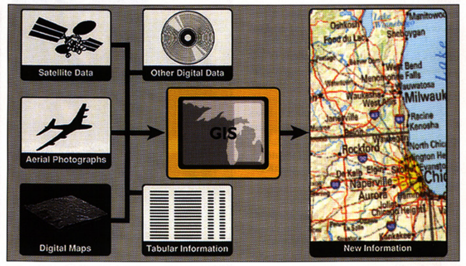


Figure 9. Data integration is the linking of information in different forms through a GIS.

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).

For example, using GIS technology, it is possible to combine agricultural records with hydrography data to determine which streams will carry certain levels of fertilizer runoff. Agricultural records can indicate how much pesticide has been applied to a parcel of land. By locating these parcels and intersecting them with streams, the GIS can be used to predict the amount of nutrient runoff in each stream. Then as streams converge, the total loads can be calculated downstream where the stream enters a lake.

Projection and registration

A property ownership map might be at a different scale than 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 for 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).

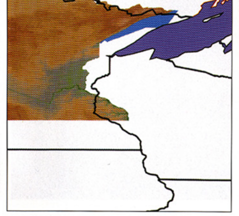


Figure 10a. An elevation image classified from a satellite image for Minnesota exists in a different scale and projection than lines in the digital file of the State and Province boundaries.

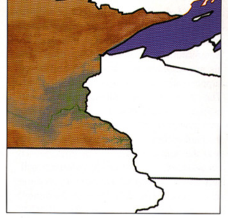


Figure 10b. The elevation image has been reprojected to match the projection and scale of the State and Province boundaries.

Data structures

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

Satellite image data that have 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 is land cover classification (fig. 11). Raster 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 particular housing subdivision.

Data restructuring can be performed by a GIS to convert data between different formats. For example, a GIS can 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 spatial relationships of the cell, such as adjacency or inclusion (fig. 13).

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

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

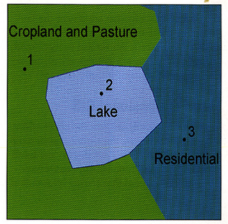


Figure 12. Example of the structure of a vector data file.

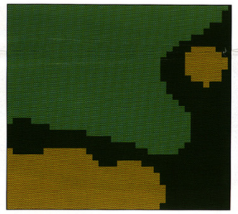


Figure 13a. Magnified view of the same GIS data file, shown in raster format.

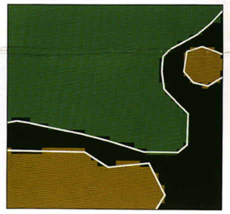


Figure 13b. Magnified view of the same GIS data file, converted into vector format.

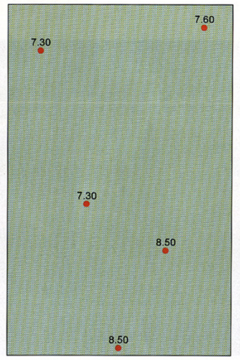


Figure 14. Points with pH values of soil.

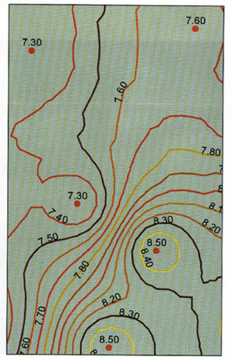


Figure 15. Contour map made from soil pH values shown in figure 14.

Data modeling

It is impossible to collect data over every square meter of the Earth's surface. Therefore, samples must be taken at discrete locations. A GIS can be used to depict two- and three-dimensional characteristics of the Earth's surface, subsurface, and atmosphere from points where samples have been collected.

For example, a GIS can quickly generate a map with isolines that indicate the pH of soil from test points (figs. 14 and 15). Such a map can be thought of as a soil pH contour map. Many sophisticated methods can estimate the characteristics of surfaces from a limited number of point measurements. Two- and three-dimensional contour maps created from the surface modeling of sample points from pH measurements can be analyzed together with any other map in a GIS covering the area.

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 offscreen 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 type of analysis allows you to draw conclusions about the swamp's environmental sensitivity.

Topological modeling

Have there ever been gas stations or factories that operated next to the swamp? Were any of these uphill from and within 2 miles of 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

When nutrients from farmland are running off into streams, it is important to know in which direction the streams flow and which streams empty into other streams. This is done by using a linear network. It allows the computer to determine how the nutrients are transported downstream. Additional information on water volume and speed throughout the spatial network can help the GIS determine how long it will take the nutrients to travel downstream (figs. 18a and b).

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 nutrient runoff.

Data output

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

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 production, roads, and 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 dark green.

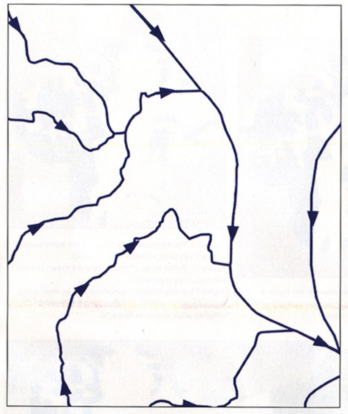


Figure 18a. A GIS can simulate the movement of materials along a network of lines. These illustrations show the route of pollutants through a stream system. Flow directions are indicated by arrows.

Figure 18b. Flow superimposed on a digital orthophotoquad of the area.

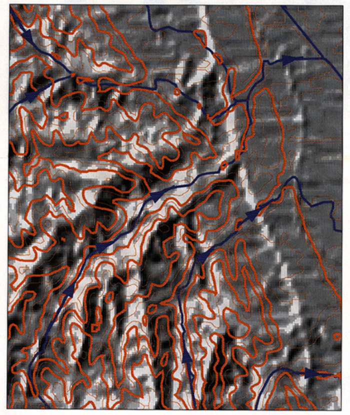


Figure 19a. Shaded-relief map and contour lines generated from the digital elevation model in the study area.

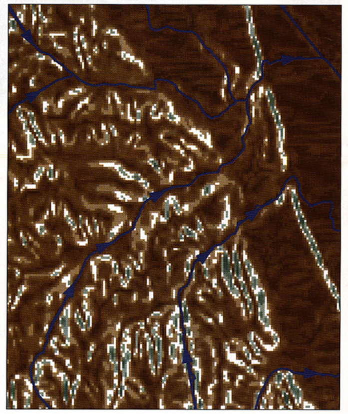


Figure 19b. Map showing the steepness of slopes in the study area, created by a GIS from the digital elevation model.

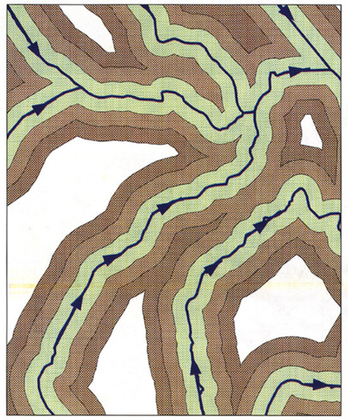


Figure 19c. Distances to streams as measured by three 200-meter buffers derived from a digital map of hydrography.

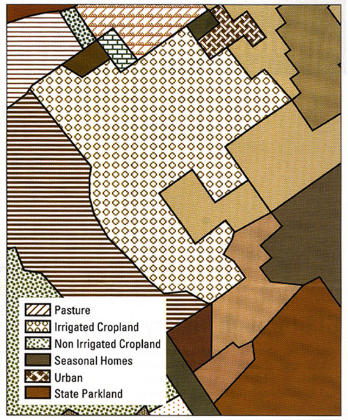


Figure 19d. Map indicating various land uses in the study area.

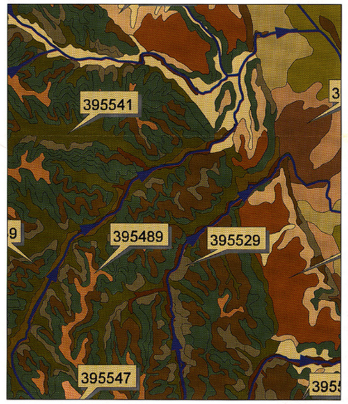


Figure 19e. A soils map stored in a GIS database. Numbers indicate the type of soil.

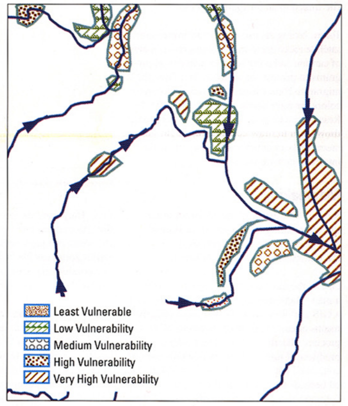


Figure 19f. The wetlands in the study area ranked according to their vulnerability to pollution on the basis of a combination of factors evaluated by a GIS.

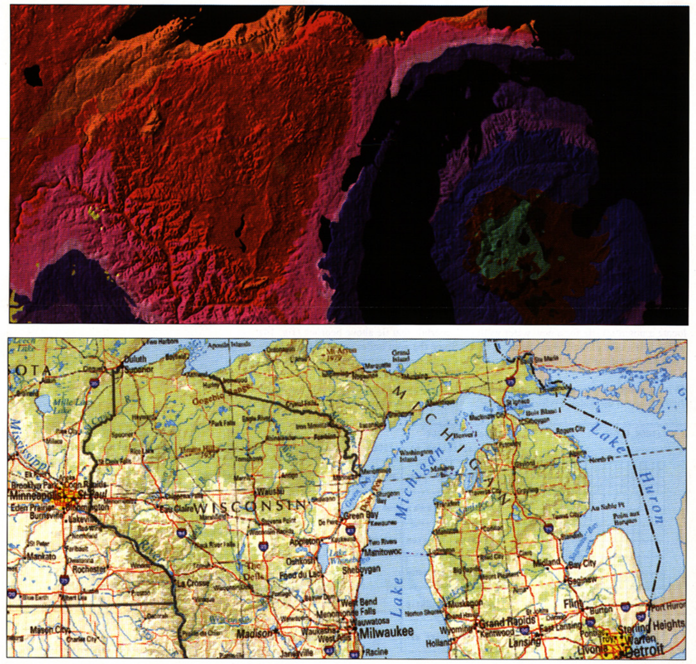


Figure 20. Examples of finished maps that can be generated using a GIS, showing landforms and geology (top) and human-built and physical features (bottom).

Framework for cooperation

The use of a GIS can encourage cooperation and communication among the organizations involved in environmental protection, planning, and resource management. The collection of data for a GIS is costly. Data collection can require very specialized computer equipment and technical expertise.

Standard data formats ease the exchange of digital information among users of different systems. Standardization helps to stretch data collection funds further by allowing data sharing, and, in many cases, gives users access to data that they could not otherwise collect for economic or technical reasons. Organizations such as the University Consortium for Geographic Information Science (www.ucgis.org) and the Federal Geographic Data Committee (www.fgdc.gov) seek to encourage standardization efforts.

For more information

Good places to learn more about GIS technology and methods include the geography department of your local university, the GIS site at www.gis.com, your county planning department, your state department of natural resources, or a USGS Earth Science Information Center (ESIC). To locate your nearest ESIC, call 1-888-ASK-USGS, or visit www.usgs.gov.

November 2002