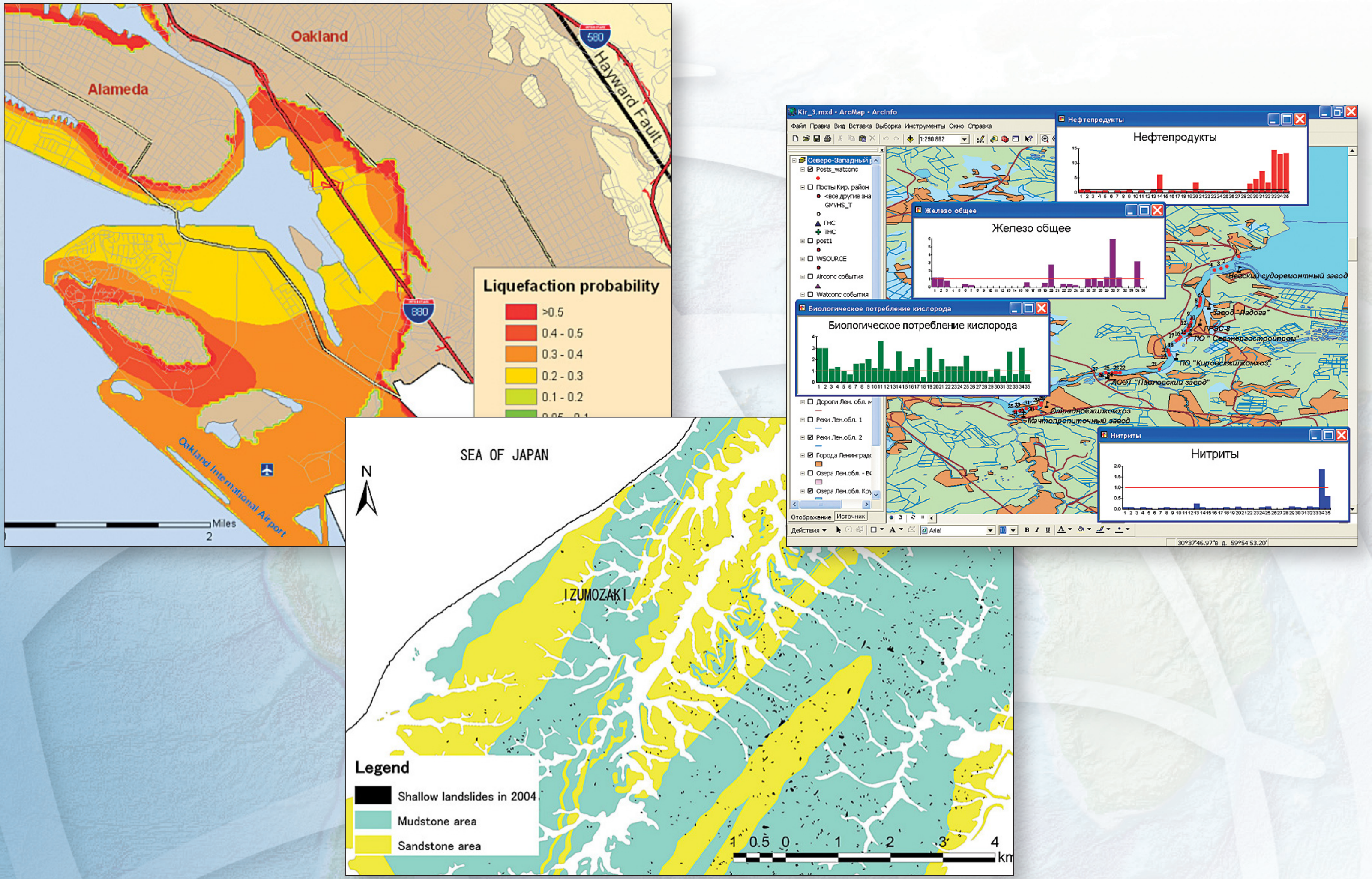
GIS Best Practices

GIS and Science



November 2008

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What Is GIS?

Making decisions based on geography is basic to human thinking. Where shall we go, what will it be like, and what shall we do when we get there are applied to the simple event of going to the store or to the major event of launching a bathysphere into the ocean's depths. By understanding geography and people's relationship to location, we can make informed decisions about the way we live on our planet. A geographic information system (GIS) is a technological tool for comprehending geography and making intelligent decisions.

GIS organizes geographic data so that a person reading a map can select data necessary for a specific project or task. A thematic map has a table of contents that allows the reader to add layers of information to a basemap of real-world locations. For example, a social analyst might use the basemap of Eugene, Oregon, and select datasets from the U.S. Census Bureau to add data layers to a map that shows residents' education levels, ages, and employment status. With an ability to combine a variety of datasets in an infinite number of ways, GIS is a useful tool for nearly every field of knowledge from archaeology to zoology.

A good GIS program is able to process geographic data from a variety of sources and integrate it into a map project. Many countries have an abundance of geographic data for analysis, and governments often make GIS datasets publicly available. Map file databases often come included with GIS packages; others can be obtained from both commercial vendors and government agencies. Some data is gathered in the field by global positioning units that attach a location coordinate (latitude and longitude) to a feature such as a pump station.

GIS maps are interactive. On the computer screen, map users can scan a GIS map in any direction, zoom in or out, and change the nature of the information contained in the map. They can choose whether to see the roads, how many roads to see, and how roads should be depicted. Then they can select what other items they wish to view alongside these roads such as storm drains, gas lines, rare plants, or hospitals. Some GIS programs are designed to perform sophisticated calculations for tracking storms or predicting erosion patterns. GIS applications can be embedded into common activities such as verifying an address.

From routinely performing work-related tasks to scientifically exploring the complexities of our world, GIS gives people the geographic advantage to become more productive, more aware, and more responsive citizens of planet Earth.

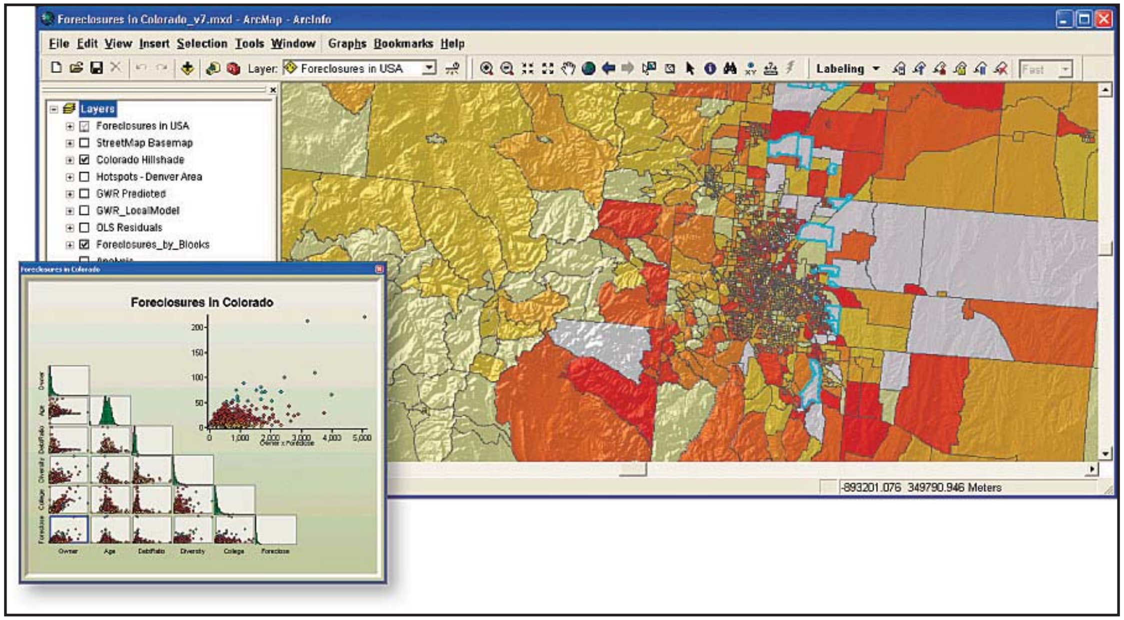
GIS and Science

By David Maguire

The term *science* originates from the Latin *scientia*, or knowledge. In a general sense, science is concerned with the discovery and organization of knowledge. Scientific knowledge is created by employing scientific methods that are founded on the twin principles of observable events and empirically testable theories. It is common to subdivide science into natural—including biological, environmental, and physical—and social sciences. Geography is concerned with the patterns and processes that describe and explain the form and function of the surface of the earth. It is somewhat unique in that it falls at the boundary and overlaps a number of the classes of science (it especially covers both environmental and social science). Indeed, a central axiom of geography is that it is concerned with human-environmental interactions and specializes in the synthesis of multiple concepts, theories, methods, processes, and information types. In this sense, geography is the science of understanding our world.

Science and GIS

All sciences have their portfolio of commonly used tools: astronomers use telescopes to view stars and information systems to record their characteristics, biologists use electron microscopes to visualize the structure of cell organelles and supercomputers to simulate ecological systems, and computer scientists develop new computer architectures using computer-aided design software. Geographic information scientists also have their tools—geographic information systems (GIS)—which are a fundamental and integral part of pursuing geographic information science. GIS is the technology for capturing, managing, manipulating, and visualizing geographic information. GIS is essential to modern geographic information science, for without GIS, it would not be possible to collect large volumes of information about observable events and build and test theories about geographic patterns and processes. Without information system technologies, many interesting geoscientific problems are intractable.



A study of foreclosures in Colorado using exploratory spatial data analysis and geographically weighted regression (a new feature of ArcGIS Desktop 9.3).

Geographic information science is concerned with the fundamental principles that underlie GIS: that is to say, the basic models, methods, and generally held tenets of geography and geographic information. A basic understanding of geographic information science is essential for all geographic information work. It is a necessary foundation for all GIS data management, analysis, and visualization activities. Some examples will help illustrate the importance of the scientific perspective to GIS.

Uncertainty

Consider, for example, how science impinges on GIS from an information-flow perspective. Whenever information is entered into a GIS, a number of choices need to be made about how the continuous complexity of the real world can be represented in the finite complexity of a digital computer system. Sampling strategies are used to decide what to put in and leave out of a GIS database. Representational frameworks require decisions about the precision and method of encoding, which can have profound implications for later operations. One of the biggest mistakes that GIS users make is using information that has a resolution that is too coarse (insufficient precision) to support the analytical methods being used and the conclusions being drawn.

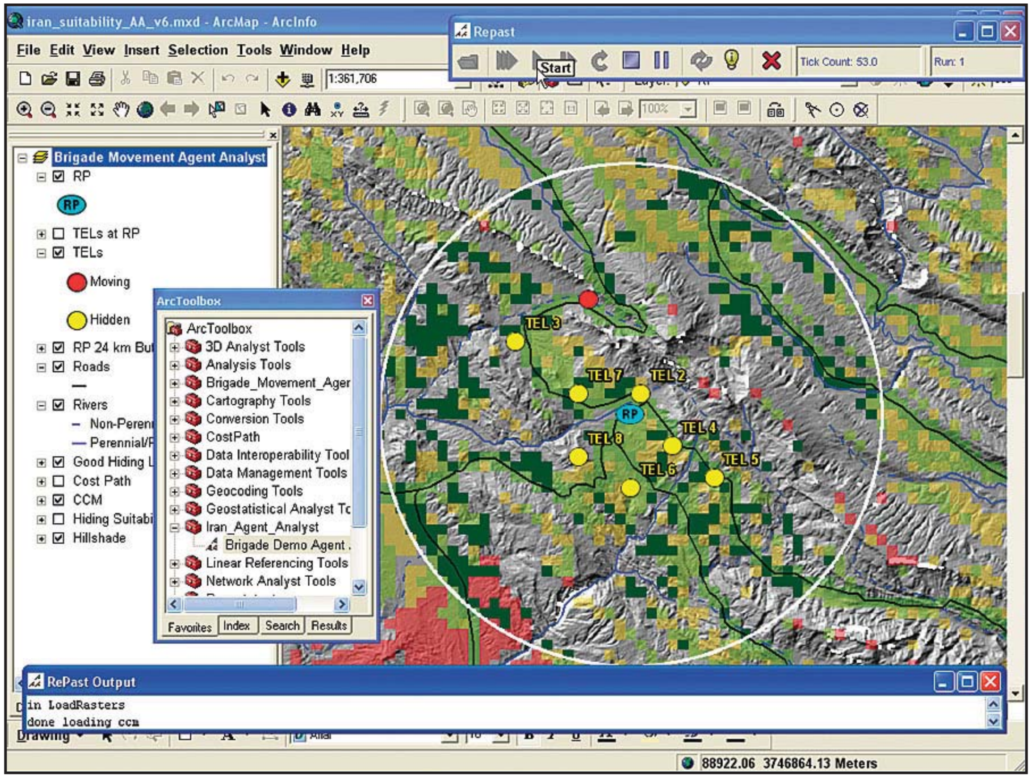
Whenever geographic information is transformed from one state to another (for example, reprojection, raster-to-vector conversion, and polygon overlay), information is lost. The mapping and visualization activities of GIS also have the effect of generalizing information (for example, choropleth maps classify polygons into a small number of classes, 3D displays omit less important points to speed up display, and charts often use a small number of symbols to make it easy to see trends or patterns in data). The true "fitness for purpose" of geographic information can only be properly determined if the history of the information is known or if appropriate measures of accuracy and precision are recorded. Geographic information scientists refer to such issues as the "uncertainty" of geographic information, and a number of spatial statistical techniques have been developed to incorporate uncertainty into analytical operations.

Cartography and Scientific Visualization

GIS typically deals with very large amounts of information. Over the years, many scientific methods have been developed to summarize geographic information so that it can be better understood and communicated to others. The objective principles of cartographic representation and communication are a complete subdiscipline that for many years have drawn on the principles of geographic information science. In the last few years, there has been an upsurge in interest in new ways to visualize geographic information using new and novel scientific geovisualization methods. These include exploratory spatial data analysis (ESDA) tools, on-the-fly calculation and display of local statistics, visualization of the uncertainty of information, and mapping of multivariate data using complex symbology. Collectively, these techniques allow scientists to gain a better understanding of the structure and content of geographic information and to ensure proper model specification and validation.

Spatial Analysis and Modeling

Geographic information science is nowhere more obvious than in the broad area of spatial analysis and modeling. Generally speaking, the field can be split into inductive and deductive approaches (sometimes called descriptive and inferential statistics).



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Agent-based modeling of missile siting in Iraq.

Inductive analytical scientific methods are used to reveal geographic structures and trends within information sets. For example, distribution maps of crime are used to inform decisions about the deployment of policing resources, spatial clustering algorithms form the basis of attempts to search for higher-than-expected incidences of cancer cases, and cokriging is used to predict the location of a precious metal based on its association with a second mineral whose distribution is more widely known.

Deductive analytical scientific methods are generally thought of as more powerful than inductive methods because they are used to test hypotheses, which eventually allow scientists to create general models and laws about the world. For example, geographically weighted regression models have been used to test hypotheses about the relationship between house prices and various socioeconomic indicators, and spatial clustering algorithms used in conjunction with significance tests can determine if the distribution of plant species is random.

In recent years, geographic modeling has also become increasingly widespread. Advances in computer processing have enabled advanced geocomputational processing of large information sets. Many types of models have been created, including process models that help explain how existing geographic systems function and simulation models that predict future states.

GIS and "New" Science

Science is not static but is in a constant state of evolution. Theories are constantly being challenged, new ideas and models are being advanced, and there is much healthy debate. In the past few years, scientists across many disciplines have started to use a new approach to advancing knowledge and understanding. In part, this new science originated from the contribution of new information technologies, but it is also a result of the way scientific communities are being organized and funded.

In this new organizational paradigm, the time-scales for developing and reporting scientific progress are decreasing from decades to years and, with Web publishing on the rise, to months and weeks. Ideas about the central importance of so-called "blue-skies" research, which is driven by curiosity, are being challenged, and there is a call for more applied science that is relevant to society and able to generate economic value. Especially in the field of GIS, industrial research and development are outpacing academic and government research in many areas. In the private sector, there are larger teams, and funding is greater for both short- and long-term research. At the same time, the model of lone scientists or small, narrowly focused research teams is being replaced by larger, interdisciplinary teams that operate across the traditional academic boundaries. This all comes quite naturally to geographers who have basic training in problems that span the environmental and social science fields (e.g., the impact of climate change, sustainable development, and the conservation of natural resources).

Geographers are increasingly dependent on the science and technology of GIS to describe the form of geographic entities and the relationships between them. At the same time, they are undertaking analyses and building models that help us understand the complex processes that operate over space and time. In the past, it was possible to separate science from technology, but it is now becoming increasingly clear that there is a symbiotic relationship between them and that one cannot exist isolated from the other.

About the Author

Dr. David Maguire is chief scientist of ESRI. He is coeditor of *GIS, Spatial Analysis, and Modeling* (ESRI Press, 2005) and *Geographical Information Systems: Principles, Techniques, Management and Applications,* 2nd edition (Wiley & Sons, 2005).

More Information

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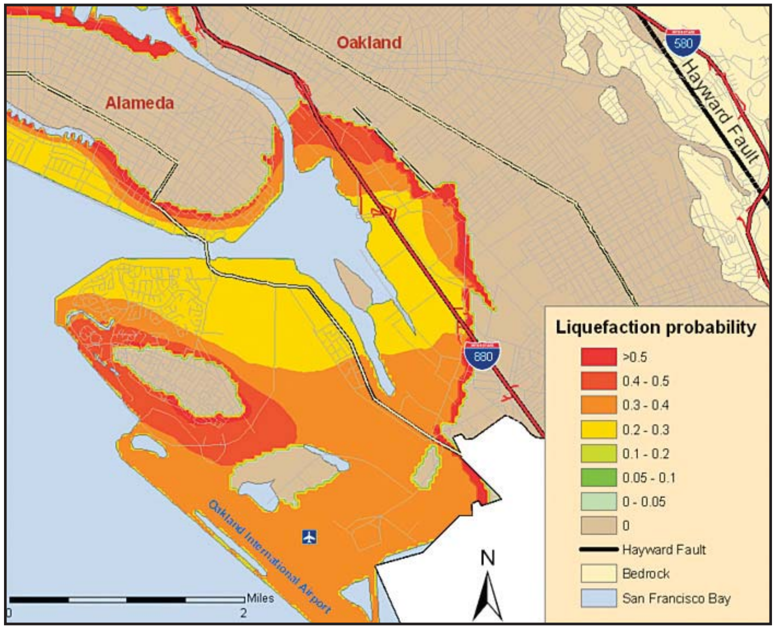
USGS Soil Liquefaction Models Reveal Buildings and Roads at Risk

Earthquakes are notorious for what appear to be selective assaults. Why do some buildings seem untouched while others crumble to rubble? The United States Geological Survey (USGS) is using GIS to study the phenomenon of soil liquefaction to understand urban neighborhoods' risk levels for earthquake destruction.

One of the world's most infamous fault lines is the San Andreas Fault. Its reputation is due to the havoc it has wreaked on some of the nation's most well-known cities, such as its demolishing of San Francisco in 1906. A wealth of infrastructure has been built on or adjacent to the fault, such as interstate highways, bridges, and pipelines. The amount of destruction an earthquake inflicts on urban infrastructure is related not only to the shaking intensity of the quake but also to the liquefaction.



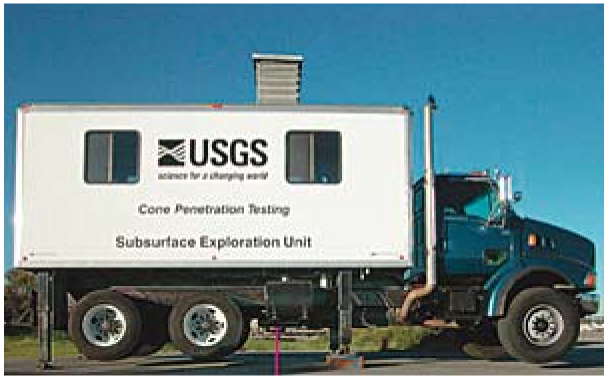
Liquefaction models show where earthquakes could cause the greatest structural damage.

Recently, USGS designed a method for assigning hazardous risk ratings of liquefaction to urban areas. By using sensors to determine subsurface soil behavior and GIS technology to calculate and display data, probabilistic scenarios can be created for a given area. Based on geologic data collected on earthquakes in the past, geologists use the technology to model how that earthquake phenomena would affect the exact same area today.

Ground with high liquefaction response is composed of newly formed sediments, such as that on the margins of San Francisco Bay. These young sediments will slow the velocity of the earthquake waves, trapping the energy and causing large amplitudes of shaking. Older compacted materials that over time have densified or transitioned from sand to sandstone and cemented together are less responsive to liquefaction and less hazardous. Ground made up of newer sediments near water will often contain water-filled pore spaces. As an earthquake's energy cyclically compresses these sediments, the pore pressure in the pore spaces increases to a level greater than the confining pressure of the soils above them, causing small geyser-like sand boils that spew water and sand and result in ground subsidence. If buildings and other structures sit atop these hazardous areas, they have a high risk of damage or collapse.

To determine liquefaction probability, USGS scientists have created a liquefaction potential index that indicates what the impact of a given size earthquake from a specific fault will be on a certain geographic area. Liquefaction data is captured from fieldwork using a cone penetrometer with a conical tip, which penetrates the ground at a constant rate. During the penetration, the forces on the cone and the friction sleeve are measured and recorded. The probe is pushed 30 meters into the earth to capture data about the terrain's subsurface properties, such as the relative strength of the soil. During the test, small shear (shock) waves are periodically generated, simulating earthquake energy. The wave forms and their travel times are recorded, providing geologists with data about the relative density of the soil and how fast seismic waves will travel through it.

The liquefaction that affects the human-built environments is mostly limited to the upper 15 meters of soil, but USGS performs testing down to 30 meters so that it can accurately determine the velocity of the material through which the waves pass. Approximately 30 of these tests, or soundings, are taken in each type of geologic environment within the study area. The data is recorded and stored in the liquefaction database and input into the USGS's ArcGIS for processing, calculating, modeling, and creating 2D and 3D visualizations.



U.S. Geological Survey truck uses cone penetrometer to record soil liquefaction characteristics.

The first part of the model calculates the nearest distance from the fault to each 50-meter grid point within the study area and populates a table with that information. The grid is attributed with geologic data, including subsurface velocity values, water table depth, and the liquefaction characteristics for each type of geologic unit. Then the model factors earthquake magnitude levels into the equation and calculates the peak ground acceleration at each grid point. Finally, the GIS model combines all the aforementioned data and calculations to calculate the liquefaction probability at each 50-meter grid cell. The results are valuable to city planners and transportation engineers, who can factor in the index rating when choosing site locations for buildings, roads, and bridges. The model has also attracted the attention of the Nuclear Regulatory Commission. It is interested in using the liquefaction potential index for planning nuclear generator site locations. Nuclear generators are often built near water on potentially saturated, young, liquefiable deposits.

USGS geologist Tom Noce explains, "We use GIS software to automate our velocity map processes, allowing us to create more detailed models. We are also moving toward creating a new type of earthquake response map, the LiqueMap, which displays near real-time projections within 20 minutes of an earthquake. After a disaster, first responders will be able to view data via the Web and immediately anticipate damage to vulnerable infrastructure, such as pipelines and bridges."

Cities continue to change, but the threat of earthquake and liquefaction remains. What if the 1989 Loma Prieta earthquake that brought down part of the San Francisco Bay Bridge happened today? What damage to the city could be expected? GIS temporal models bring together the past and the present. USGS scientists join liquefaction data captured from the Loma Prieta earthquake with current liquefaction data and overlay as-built urban structure data to show the impact that the earthquake could have if it occurred today. The combination of historical data and probabilistic modeling displays a high level of correlation, indicating that the models should indeed provide a good estimation of the effects of similar earthquakes.

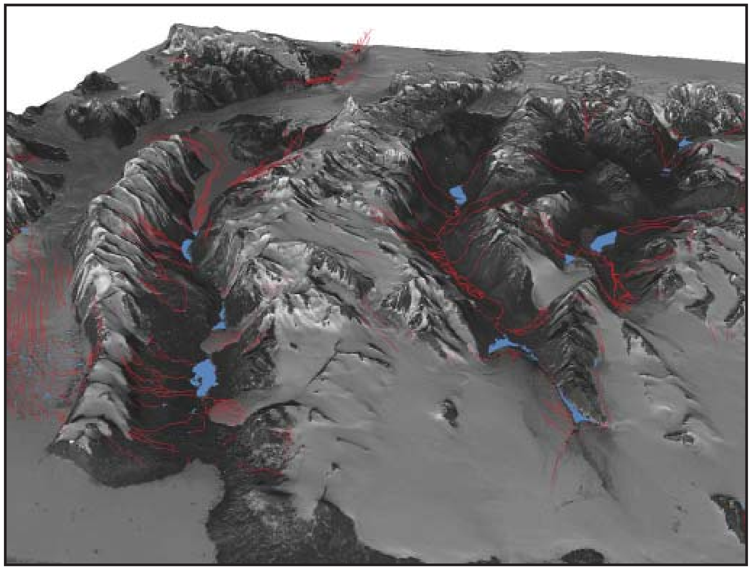
Scientists continue to add greater depth and complexity to their studies of earthquakes and liquefaction in the New Madrid, Missouri, seismic region of the United States. During the series of earthquakes of 1811 and 1812, there was liquefaction over very large areas that are now rapidly becoming more urbanized. The USGS team is also creating these temporal what-if maps by inputting 1906 San Francisco earthquake data into the model and creating comparisons with today's downtown Oakland, California, data to see what the effects would be on various areas of the city. Next on the itinerary is the 1906 data's effect on California's Santa Clara Valley, along with scenario maps for anticipated earthquakes on the nearby Hayward and Calaveras faults.

Ultimately, USGS' goal is to provide the public and state and local officials with the information necessary to mitigate liquefaction hazard zones prior to an earthquake and be able to respond to possible liquefaction after an earthquake.

(Reprinted from the Summer 2008 issue of *ArcNews* magazine)

Scientific Research Uses GIS in the McMurdo Dry Valleys, Antarctica

By Michael Prentice, University of New Hampshire



Looking west over the McMurdo Dry Valleys. From left to right (south to north), the valleys are named Taylor, Wright, and Victoria. The permanently ice-covered lakes are shown in blue. Red lines represent intermittent streams.

Many scientists, primarily from the United States and New Zealand, work on a wide variety of research projects in the McMurdo Dry Valleys (MDV), South Victoria Land, Antarctica. Covering 8,000 square kilometers, MDV is the largest ice-free area on Antarctica. How Antarctica formed, the role of Antarctica in global climate change, and the biologic processes necessary to sustain life in a polar desert are a few of the scientific questions being addressed. The scientists, as well as science program administrators and science support personnel, all need the capability to search for and use digital, highly resolved geospatial information describing the physical features of MDV. Additionally, because the location of sampling points is vital to sharing scientific data, the MDV science community needs a geospatial technology to manage and facilitate access to the data. A few specific examples follow.

- Geologists need digital rectified imagery and topography, as well as sediment and soils data, to identify and map rock formations and sediment deposits. Accurate maps permit improved reconstruction of processes by which these features formed.

- Biologists studying the diverse microscopic biota and microenvironments of the MDV polar desert, a site in the National Science Foundation (NSF) Long-Term Ecologic Research Program, need digital geospatial information on rock, sediment, ice, and water features to set the context for their work.
- Planetary geologists studying Mars using MDV features as a terrestrial analog need digital geospatial access to geological, biological, and meteorological data.
- McMurdo Dry Valleys are a Specially Protected Area under the Antarctic Treaty; thus, the NSF's programs need accurate geospatial information to manage research and tourism activities so as to minimize impact.

To address this need, a University of New Hampshire (UNH) team led by this author produced the first GIS of the major physical features of MDV. This effort was made possible by funding from NSF and collaboration with the U.S. Geological Survey (USGS) and the New Zealand Institute of Geological and Nuclear Sciences (NZ IGNS). The GIS has two major components. The first is landscape framework data. This includes a network of geographic control points, a satellite image basemap for use in mapping at a scale of 1:50,000 and aerial photographic basemaps for mapping restricted areas at a scale of 1:10,000. The second component is information describing the major physical features of MDV, principally bedrock geology, surficial geology and geomorphology, soils, glaciers, lakes, and streams. Both geospatial and tabular information for these features have been captured. A time dimension was added because MDV hydrologic features changed in size over the last few decades because of climate change.

The GIS project, referred to as VALMAP (for Valleys in Antarctica: Layered Mapping, Analysis, and Planning), involved numerous scientists from the United States and New Zealand. They chose ArcGIS Desktop (ArcInfo) as the GIS software because of its many features and wide usage both in the United States and New Zealand. They also used image processing software. The work was accomplished on both UNIX and PC machines.

Framework Data

VALMAP digitally captured the metadata for geographic control points (GCPs) collected previously in MDV by USGS and Land Information New Zealand. A USGS/VALMAP team also went into the field to collect new GCPs, as well as photographs of existing GCPs. A GCP point theme was produced as was extensive metadata, including imagery of the GCPs. Three SPOT images were rectified in ERDAS IMAGINE using these GCPs and served as the satellite image basemap for VALMAP.

Aerial photographic coverage of MDV is extensive (more than 20,000 frames) and dates to the late 1940s. VALMAP produced an arc theme that inventories all 250 flight lines and provides metadata. ArcInfo software's ARC Macro Language (AML) was used to produce point coverages of the center points of the individual frames. Michael Routhier, GIS scientist at UNH's Institute for the Study of Earth, Oceans, and Space, notes, "The power of GIS gives researchers easy access to invaluable resources that were previously difficult to access with conventional mapping methods."

Because detailed mapping was an important goal of VALMAP and aerial photography provided the only high-resolution imagery available at low cost, VALMAP personnel determined that some photographs should be rectified. "This provided us with a low-cost solution for producing quality high-resolution images for mapping," explains GIS scientist Stanley Glidden, also at UNH's Institute for the Study of Earth, Oceans, and Space.

Additional framework elements added to the VALMAP GIS by using ArcInfo geoprocessing tools were separate surface topographies for glaciers, unconsolidated sediment, and bedrock. The 50 m surface contours that were provided to VALMAP from the USGS 1977 topographic maps of MDV, as well as contours from miscellaneous topographic maps digitized by VALMAP, were the starting point. VALMAP added contours from point estimates of depth to glacier base, depth to lake bottom, and depth to bedrock from a variety of scientific studies. Prentice explains, "The dimensions for ice, lake, and sediment bodies today are fundamental to validating geophysical models that simulate past fluctuations in these systems. Despite meager data density, getting these data sets into the GIS is important for raising community awareness."

Thematic Data

Thematic layers on major physical features were provided by experts in their respective fields. Bedrock geologic information over much of MDV was provided by Mike Isaac, Ian Turnbull, and Dave Herron, of NZ IGNS, from the quadrangle maps published by that agency. The locations of more than 500 soil pits in MDV were reconstructed by the original investigators, Jim Bockheim, professor at the University of Wisconsin; Iain Campbell of Land and Soil Consulting NZ; and Graham Claridge, NZ IGNS, using points marked on aerial photographs that were also identifiable on VALMAP image basemaps. The value of the extensive morphological, physical, chemical, and climatic data from these pits was increased dramatically once the pits were geolocated. The distribution, character, and laboratory data describing unconsolidated MDV sediments, both at and below surface, was provided by a UNH team using the literature and original data. ArcInfo permitted VALMAP to improve consistency and agreement between the different data sets that share boundaries. Additionally, explains James Gaynor, UNH graduate student in the Department of Earth Sciences, "GIS, especially ArcGIS Desktop and its ArcMap application, strongly facilitated on-screen mapping of glacial deposits given the ability to interpret and edit multiple layers and tabular data simultaneously using various color, shading, and transparency options. This saved time because it cut out the step of producing hand drawn map sheets."

Thematic layers were also produced for the dynamic elements of the MDV landscape, including glaciers, semipermanent snowbanks, lakes, and streams. Some themes were produced for different years using the aerial photographs for change detection. Trevor Chinn, New Zealand National Institute of Water and Atmospheric Research, provided point data detailing the seasonal budget of snow accumulation and ice ablation on selected MDV alpine glaciers between 1972 and 1984. The sum of these terms gives the mass balance of the glaciers, which indicates whether they are growing or shrinking. Anna Krusic, UNH Earth Sciences graduate student, used ArcInfo to integrate point mass balance data with the surface topography to determine mass balance over glacier surface elevation zones and total glacier mass balance.

The VALMAP GIS has been used and significantly extended by MDV Long-Term Ecological Research project members. VALMAP GIS components are being made available using ArcIMS 9 at the USGS Atlas for Antarctic Research Web site (usarc.usgs.gov/antarctic_atlas) and at www.valmap.unh.edu.

About the Author

Dr. Michael Prentice is a research associate professor at the University of New Hampshire.

(Reprinted from the Fall 2004 issue of *ArcNews* magazine)

Getting Along on the Range

Managing Elk and Cattle Grazing Interactions

By Melanie A. Smith and C. Travis Benton, Ecosystem Research Group

Environmental scientists at Ecosystem Research Group (ERG) recently completed a study to help resolve a long-standing question between ranchers and public land managers in Montana. Are elk and cattle successfully sharing the same range in the Elkhorn Mountains of Montana?

An elk herd grazes inside a cattle allotment.

Other questions follow: Exactly where are the elk and cattle grazing? Is summer use by cattle compatible with the forage requirements for elk on their winter range? Is the ecological condition of elk winter range in the Elkhorn Mountains degrading? Are there too many cattle on the grazing allotments or too many elk in the elk herd units?

The study was conducted for the Elkhorn Working Group, a collaboration of local stakeholders and public agencies that includes representatives from Helena National Forest; Montana Fish, Wildlife & Parks; Rocky Mountain Elk Foundation; Bureau of Land Management; private ranchers; and Broadwater Conservation District.

ERG first collected field measurements, then used creative GIS techniques to synthesize the information. Over a three-year period, vegetation specialists routinely measured variables at several locations across the study area to quantify the level of use by cattle and elk by season. Those variables included vegetation production, percent of forage utilization, ecological condition, and similarity index (comparison to historic grassland communities).

Such range measurements provide great information for inference about grazing interactions. Vegetation production tells how much forage is available in a given year. Percent of forage utilization estimates the amount used compared to the amount produced. Measuring ecological condition and the similarity index of the vegetative resource help map areas that historically had high levels of use so that the ways elk and cattle are currently using forage versus historical high-use areas can be compared. Areas where dual use is highest and the land is most impacted can also be mapped. When measured seasonally and with carefully placed grazing enclosures, studies can measure how much forage the cattle are leaving for the elk and how much of the remaining forage elk are using and leaving behind.

Cattle grazing in the Elkhorn Mountains.

The authors of this article, Melanie A. Smith and C. Travis Benton, with support from other GIS technicians at ERG, performed key tasks such as mapping hot spots where elk and cattle grazing overlap and describing the environmental characteristics of the area including historic range of variability and conifer encroachment.

Data Sources

Scenic view of the Elkhorn Mountains.

GIS specialists acquired eight years of elk radio-collar telemetry data (approximately 700 elk and 10,000 relocation points) from Montana Fish, Wildlife & Parks. Satellite Image Landcover Classification (SILC) data was collected from the Helena National Forest, and digital elevation model (DEM) data was downloaded from the Montana Natural Resource Information System (NRIS). Elk herd unit boundaries and cattle grazing allotment boundaries were compiled from Forest Service, Bureau of Land Management, and Montana Fish, Wildlife & Parks documents and databases. Local stakeholders wrote comments onto large field maps at public meetings that provided information about cattle use, elk calving grounds, and areas where forage conflicts are known to exist.

Finding Areas Suitable for Cattle Grazing

The GIS analysis consisted of four major steps.

1. Locating suitable cattle grazing areas
2. Locating areas of high elk presence
3. Extracting areas of overlap between these two areas by overlaying the layers and vegetation utilization measurements from field data to classify the overlap areas into low, medium, and high use
4. Overlaying comments from local stakeholders to verify the results

Collecting field measurements.

Tree canopy cover measurements from SILC data were classified into four categories: 0–9 percent, 10–24 percent, 25–44 percent, and 45 percent and greater. National Agriculture Imagery Program (NAIP) digital orthophoto quadrangles (DOQs) from 2005 were visually inspected for additional high-canopy coverage areas, and those areas identified were digitized, converted to raster, and merged into the 45 percent and greater cover category using the ArcGIS Spatial Analyst extension.

Next, a mosaicked DEM was reclassified into four slope categories: 0–15 percent, 16–30 percent, 31–60 percent, and greater than 60 percent. Using the Raster Calculator in ArcMap, the grids for tree canopy cover and slope were added, then divided by two to yield a range of numbers between 1 and 4.

In this classification system, 1 represents excellent grazeability and 4 represents poor grazeability. All half numbers were rounded down. Table 1 below illustrates this process. Additional areas of rock outcrop and areas infrequently used by cattle were merged into the poor category; all areas classified as poor were then removed from further study.

Percent and Grid Classification of Tree Canopy	Percent and Grid Classification of Slope	Result from Adding Two Grids	Final Cattle Grazing Classification
0–9 (1)	0–15 (1)	2	1—Excellent
10–24 (2)	0–15 (1)	3	
0–9 (1)	16–30 (2)	3	
25–44 (3)	0–15 (1)	4	2—Good
10–24 (2)	16–30 (2)	4	
0–9 (1)	31–60 (3)	4	
>44 (4)	0–1 (1)	5	
25–44 (3)	16–30 (2)	5	
10–24 (2)	31–60 (3)	5	
0–9 (1)	>60 (4)	5	
>44 (4)	16–30 (2)	6	3—Fair
25–44 (3)	31–60 (3)	6	
10–24 (2)	>60 (4)	6	
>44 (4)	31–60 (3)	7	
25–44 (3)	>60 (4)	7	
>44 (4)	>60 (4)	8	4—Poor

Table 1: Raster calculations for locating suitable cattle grazing areas.

Locating High Elk Presence in the Project Area

More than 10,000 elk relocation points were used to create a density grid using the ArcGIS Spatial Analyst extension. The kernel density function was used with a search radius of one mile. Results were calculated in relocations per square mile. The total number of relocations was divided by the number of square miles in the project area. The resulting statistic described the number of relocations per square mile, assuming uniform distribution. This was used as a threshold for significant elk presence. Using the Raster Calculator, all cells in the density grid greater than the threshold were extracted. The result, labeled Preferential Use, consisted of those areas elk seem to prefer because they are present in these areas more frequently than would be the case if they were distributed uniformly across the area.

Dr. Don Bedunah, a professor of range science at the University of Montana and an associate/subcontractor to ERG during this project, is shown collecting data.

Finding Elk and Cattle Grazing Overlap Hot Spots

The cattle grazing suitability and the elk preferential use grids were each reclassified to a value of 1, and the two grids were multiplied using the Raster Calculator. This returned the overlap areas between the two grids—the boundary of the elk/cattle overlap hot spots. From there, the degree of use within the boundary was determined. Measurements of the utilization of available vegetation collected by ERG over a two-year period were interpolated. This was done using the Inverse Distance Weighted method with a layer of pasture fences used as barriers in the calculation. The resulting grid was reclassified into three categories: low, medium, and high utilization. This was the final product. As a further step, these findings were compared with comments drawn on maps by local stakeholders. The comments aligned well with the GIS analysis and met the expectations of the GIS specialists involved, the Elkhorn Working Group, and stakeholders.

When measured seasonally and with carefully placed grazing enclosures, studies can measure how much forage the cattle are leaving for the elk and how much of the remaining forage elk are using and leaving behind.

Describing Environmental Characteristics of the Area

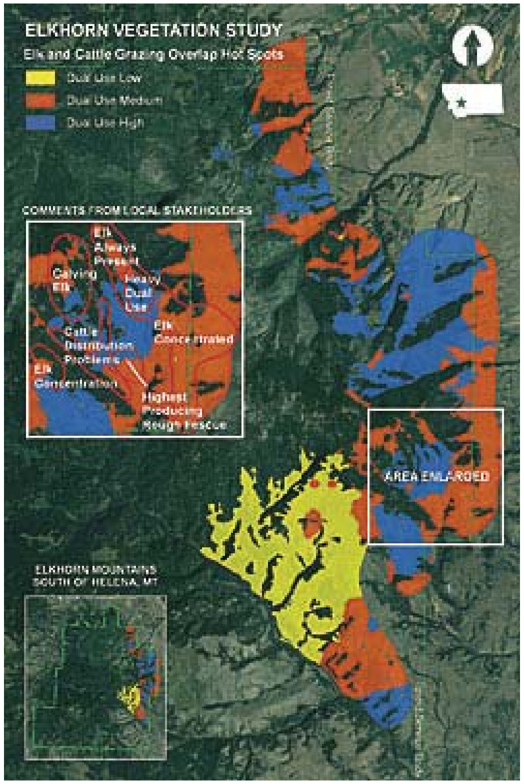
Additional GIS techniques were employed during this study. While describing the environmental characteristics of the project area, some of the oldest landscape data and newest GIS technologies were integrated. Portions of a historic Forest Service 1922 rangeland vegetation map were scanned, rectified, and digitized. The vegetation classification from the map was compared to rectified aerial photos from the 1950s, 1970s, and 1990s for the purpose of studying conifer encroachment into historic grassland communities.

Evidence of grazing.

The Forest Service's SIMulating Patterns and Processes at Landscape scaLEs (SIMPPLLE) Model was also used. SIMPPLLE is a spatially explicit landscape model that forecasts future and estimates historic changes in vegetation based on natural processes and management activities. ERG's GIS staff modeled the Elkhorn Mountains to construct a better picture of the historic range of variability of the landscape to quantify historic vegetation production and current forest encroachment.

Conclusion

This project significantly contributed to the understanding of vegetation dynamics in the Elkhorn Mountains of Montana and answered some long-standing questions regarding elk and cattle interactions. Findings from the Elkhorn Vegetation Study were used to recommend improved cattle allotment management strategies, prioritize areas for pasture fence realignments, propose weed control measures, and recommend further sampling and monitoring. In June 2006, the methods, results, and maps for this three-year study were published by ERG for the Elkhorn Working Group. Visit the Projects section of ERG Web site (www.ecosystemrg.com) to read more about this study.



Results of the GIS analysis correlate well with comments from local stakeholders.

About the Authors

Melanie Smith is an environmental scientist and the GIS director for Ecosystem Research Group, a private environmental consulting company in Missoula, Montana. In the course of completing her master's degree in geography from the University of Montana, she created a spatially explicit dynamic model that simulates habitat interactions of nesting northern goshawks. She holds a bachelor's degree in environmental studies from Prescott College, Arizona, and her interests include landscape modeling and ecology; spatial statistics; and wildlife habitat analysis, particularly for avian species.

Travis Benton is an environmental scientist and GIS specialist for Ecosystem Research Group in Missoula, Montana. He earned his bachelor's degree in forest resource conservation from the University of Montana in 1999. His professional work and interests include rangeland vegetation mapping and sampling, plant ecology, and landscape vegetation modeling.

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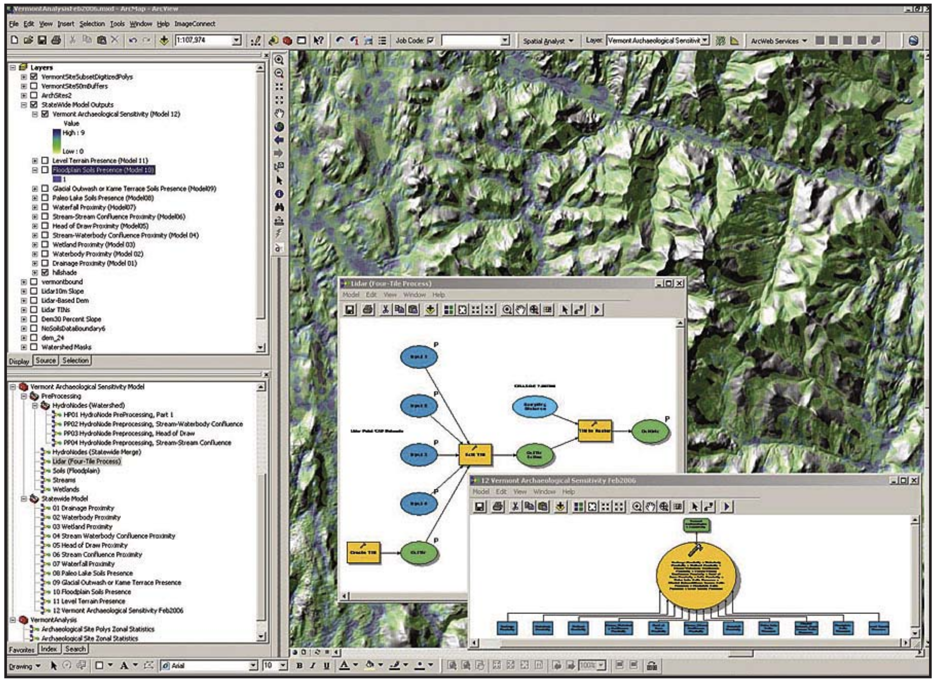
Modeling Archaeological Sensitivity in Vermont with GIS

Over the past several decades, significant improvements in processing capacity and GIS software sophistication have encouraged the development and use of computer-based models of archaeological sensitivity to augment traditional research approaches and field investigations. The Vermont Archaeological Sensitivity Model (VTASM), a GIS-based framework for simulating archaeological sensitivity statewide, is a recent example of this trend.



Screenshot of Vermont Archaeological Sensitivity Model (VTASM) map document showing sensitivity surface, custom toolbox, and a couple of model examples.

A key element of archaeological research and cultural resources management is estimating the relative potential for buried cultural deposits in specific geographic areas. Reliable estimates of archaeological potential or sensitivity are necessary for the implementation of effective sampling strategies. Quality assessments of relative archaeological potential are also useful planning tools, facilitating the avoidance of potentially significant cultural resources and minimizing the costs of regulatory compliance associated with development.

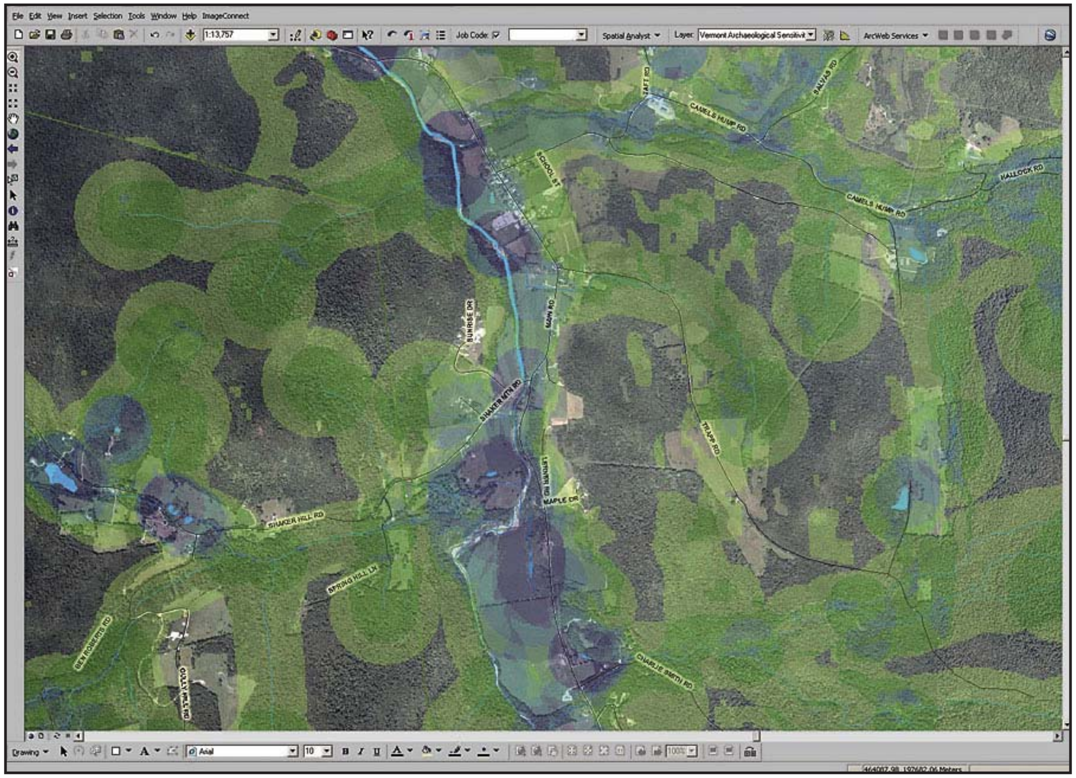
VTASM emerged out of an interest expressed by the Vermont Division of Historic Preservation (DHP) and the Vermont Agency of Transportation (VTrans) for a statewide GIS map showing relative potential for subsurface prehistoric archaeological deposits. For several years, DHP has been involved in GIS modeling of archaeological sensitivity at the watershed level, utilizing environmental criteria specified on a field assessment scoring form used by the DHP and consulting archaeologists. These criteria were adapted from a paper-based environmental stratification model developed in 1989 by researchers from the University of Maine at Farmington Archaeology Research Center (UMFARC) for a major pipeline project. Most of the criteria highlight proximity to water and landform features that would have been central to prehistoric travel and subsistence strategies.

VTASM is an integrated GIS solution for modeling archaeological sensitivity in Vermont based on the well-established DHP environmental criteria. Structured by the new ArcGIS (ArcInfo) geoprocessing framework, VTASM provides a suite of tools and a custom data management system designed to allow on-the-fly modification of data inputs and analytical parameters, facilitating the evaluation of different scenarios in a scientifically repeatable manner.

VTASM was developed by a team of researchers from three organizations: ESRI Business Partner Earth Analytic, Inc.; UMFARC; and the University of Vermont Consulting Archaeology Program (UVMCAP). Project funding was provided by the Vermont Agency of Transportation and the Vermont Division for Historic Preservation. Earth Analytic, Inc., served as the GIS technical lead for the development and implementation of VTASM. A GIS steering committee composed of archaeologists from a variety of state and federal agencies and institutions provided oversight and feedback.

VTASM is implemented with ArcInfo, ArcGIS Spatial Analyst, and ArcGIS 3D Analyst, taking full advantage of ArcGIS ModelBuilder software and the ArcGIS application ArcToolbox. At the core of the system is a functionally and thematically organized directory structure for GIS data, documents developed with the ArcInfo application ArcMap, toolboxes, exported maps, and documentation. The VTASM user interface is an ArcInfo document that points to all required model inputs and a custom toolbox containing about 20 ArcGIS models: flowchart-like representations of sequences of GIS data management and analysis processes. The VTASM toolbox is subdivided into two toolsets: one for data preprocessing and one for statewide analysis. Geoprocessing environment settings are configured at the level of the toolbox, simplifying the process of changing default settings (workspace and scratch space locations, output extent, mask, and cell resolution) for the entire statewide model.

The project database includes statewide wetland and hydrological datasets, including the high-resolution (1:5,000) Vermont Hydrographic Dataset (VHD), as well as Soil Survey Geographic (SSURGO) data for most of the state. A notable data limitation is the absence of 10-meter digital elevation models (DEMs) for the state, although the model does incorporate lidar-based 8-meter DEMs for a subset of the project area.



Putting the model to use, this shows the VTASM surface overlaid on the NRCS Vermont OnePlan map service.

Five major preprocessing models prepare specific datasets for use in the statewide model: hydrological nodes (confluence and terminus points, collectively referred to as hydronodes), lidar, floodplain soils, streams, and wetlands. For example, one of these models draws on outputs from four watershed-specific hydronode preprocessing models applied to each of the 17 Vermont watersheds (USGS HUC8). Another preprocessing model converts multiple CAD point datasets into a triangular irregular network (TIN), then converts the TIN into an eight-meter resolution raster.

The statewide analysis toolset consists of 11 environmental component models (ECMs) that are combined in a composite archaeological sensitivity model. Each ECM yields a statewide 10-meter resolution raster with binary cell values. In each raster, cells meeting model criteria are assigned a value of one and remaining cells get values of zero.

Six ECM models assign archaeological sensitivity scores to buffer zones associated with specific water-related features: drainages, water bodies, wetlands, stream confluences, stream-water body confluences, heads of draws, and waterfalls. For example, the Drainage Proximity ECM generates a raster buffer zone of 180 meters around the preprocessed statewide VHD drainages. All cells within 180 meters of streams are assigned a value of one in the output raster. Given the large size of input datasets, the use of raster-based buffering methods (integer-based reclassifications of Euclidean distance surfaces) greatly reduced CPU requirements and time relative to vector-based buffer operations.

The five remaining ECMs assign sensitivity scores to relict lakes, kame terraces, glacial outwash deposits, floodplains, and areas of level terrain. One example is the "Paleo" Lake ECM, which creates a statewide raster of all areas covered by soils (Vermont Center for Geographic Information/SSURGO) formed in late glacial periods, just prior to the arrival of Paleo-Indians. "Paleo" lake parent materials are assigned a value of one, and all other areas are assigned a value of zero.

The final archaeological sensitivity model combines the results of the 12 component models using a weighted sum function. For the preliminary release of the VTASM, all ECMs were assigned equal weights by default. The resulting statewide raster has values ranging from zero to nine, representing the number of overlapping environmental criteria for each cell.

While the preliminary results of the VTASM analysis are encouraging given that the model has strong predictive value, project stakeholders recognize that, in many cases, computer modeling is not a substitute for firsthand, field-based archaeological assessments. The project has provided tools for modeling and visualizing reasonable proxies of prehistoric archaeological sensitivity that can be used in concert with traditional archaeological approaches.

The Vermont Agency of Transportation is the major sponsor of this work.

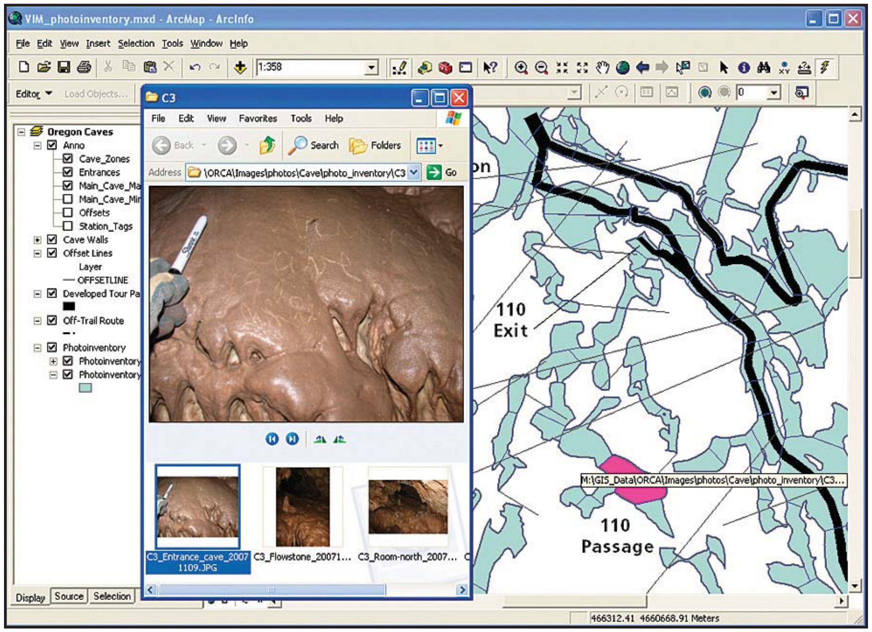
(Reprinted from the Spring 2006 issue of *ArcNews* magazine)

Protecting Oregon Caves

GIS Plays Growing Role in Monitoring and Limiting the Impact of Visitors

By Elizabeth Hale, U.S. Department of the Interior, National Park Service, Oregon Caves National Monument

Nature has filled Oregon Caves with many wonders to see. But visits by 48,000 people a year to the national monument, located 50 miles south of Grants Pass, Oregon, significantly impact the natural resources in the "Marble Halls of Oregon." Damage can include broken cave formations, darkened and polished rock caused by touching, and lint deposits. Cave sediments and animal bones also get disturbed.



Cave photos, both scanned and digital, can be retrieved by location through a hyperlink.

GIS technology is playing a growing role in helping the National Park Service protect the cave and its resources. In the past two years, the most basic GIS layers of the cave—survey stations (points), survey shots (lines), and cave walls (polygons)—have been the starting point for developing datasets and maps to help visualize the cave's hazardous and fragile areas, protect paleontological resources, manage a growing collection of photos, and develop a new public off-trail caving tour. The National Park Service at the Oregon Caves National Monument used GIS software for its project, along with COMPASS, a cave survey management software package and extension to ArcView software.

Implementing a Fair System for Issuing Caving Permits

A complete cave map provides some information about potential safety hazards and the cave's vulnerability to human impact via labels for ceiling heights and pit depths and symbols for slopes and delicate cave formations. But this information can be viewed and synthesized in many ways, leading to varied conclusions about how hazardous or how fragile a particular area is.

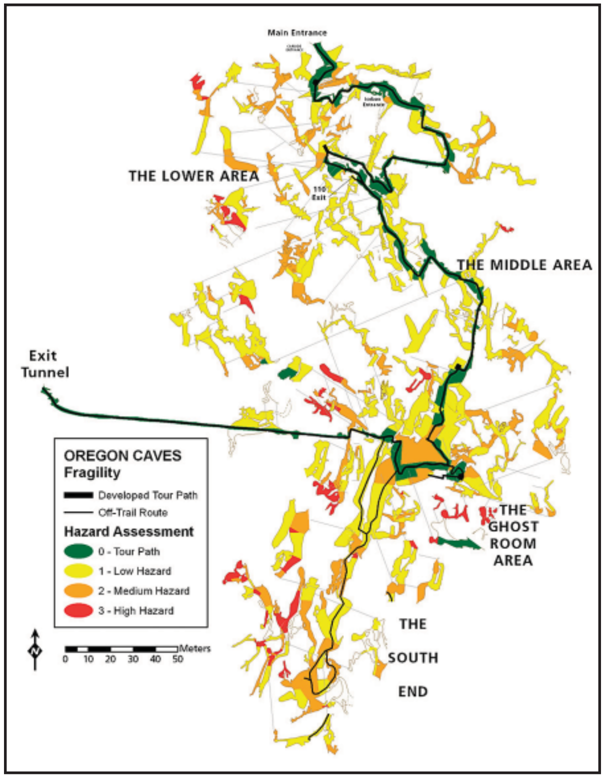
To eliminate this kind of subjectivity when determining whether to issue caving permits, GIS was used to produce hazard and fragility maps from a criteria-based assessment to clearly and objectively display the hazardous and fragile areas of the cave.

ArcPad mobile GIS software on a Pocket PC in a rugged case was used to conduct the hazard-fragility assessment. Based on the GIS line layer of survey shots, cave passages were attributed with a rating for hazard and fragility. Factors considered for a hazard rating included potential falls, loose ceiling rock, mazy passages, and required caving gear. Fragility was assessed as the average of four equally weighted ratings: resource condition, proximity to fragile resource, resource value, and density of breakable formations. To design hazard and fragility maps with ArcGIS Desktop (ArcMap) software, the GIS layer of cave walls was divided into polygons to represent areas encompassed by individual survey shots, as the assessment was conducted on a shot-by-shot basis.

Combined hazard and fragility ratings were used to categorize areas of the cave into caving zones. Permits to enter areas of the cave beyond the tour path are now issued based on the requirements of the caving zone being visited, as defined by the monument's subsurface management plan.

Keeping Track of Paleontological Resources

Oregon Caves contains hundreds of animal bones, some of which are very old or fragile yet well preserved in the cool and dark passages of the cave. Bones were inventoried in a nonspecific way in the 1990s, resulting in a rough map of where they were found throughout the cave. More recently, a site-by-site paleontology survey was undertaken to compile precise locations and descriptions of bones.



The hazard of cave passages in Oregon Caves was systematically rated between zero and three.

In the subterranean passages of Oregon Caves where GPS cannot be used, survey station markers—often a labeled strip of aluminum or piece of surveyor's tape—serve as points of reference. Paleontology sites were surveyed from the nearest survey marker with a laser distance meter, compass, and inclinometer. Additionally, sites were described systematically, photographed with an object for scale, and flagged when in danger of being disturbed. COMPASS was used to create a GIS layer of paleontology sites from survey measurements. Attribute data is managed in a table that can be queried, sorted, and joined to the GIS layer.

As of mid-March 2008, more than 180 paleontology sites had been documented. The staff at Oregon Caves works with professional paleontologists to identify and study these paleontology sites. Approximately 30 vertebrate species have been identified.

Managing and Retrieving Photos for Monitoring

Photo monitoring is perhaps the most common approach to keep track of the impact of visitors to the cave. Photo monitoring involves repeatedly photographing a site from the same distance and angle to detect changes in its condition. There are 19 sites along Oregon Caves' tour routes that are photo monitored from fixed-point stations. However, many other sites and features of interest or concern have been photo documented casually (without a specific distance and angle), which has resulted in a larger set of photos that can become unwieldy without naming conventions and methods for retrieval.

To make the cave photo collection more usable, old and new photos were sorted by location and a GIS layer was prepared so that a wide range of photos can be retrieved by selecting any area of the cave. To do this, the photos were named according to a specific format and organized by the closest survey station marker. The GIS layer of cave walls was divided into polygons to represent areas defined by their proximity to survey station markers. Then a text field in the attributes table was set up so that when hyperlinks are enabled for this layer, photo sets can be accessed with the hyperlink tool.

GIS layers for photo-monitoring stations and paleontology sites were also set up so that photos could be hyperlinked from individual stations and sites.

Planning Low-Impact, Off-Trail Tours

In summer 2007, the National Park Service offered a public, off-trail caving tour in Oregon Caves for the first time. Data on the off-trail tour route was gathered from cave-resource and visitor-impact inventories, as well as the hazard-fragility assessment and paleontology survey. These datasets helped identify every hazardous area and fragile resource so that each could be addressed with protective flagging, rerouting, and/or training for tour guides. The visitor-impact inventory was analyzed to predict how the caves would be affected by visitors who take the tours.

The polishing and darkening of rocky surfaces caused by touching was one expected impact. As there are many tight passages along the off-trail route, this is largely unavoidable, though all visitors wear gloves. Photos were taken to monitor polishing and darkening of several areas along the route.

Accumulation of hair was also expected to occur. People who visit the caves all leave behind some skin flakes, hair, or lint, which can build up and create unnatural deposits of organic material. These deposits, besides being unsightly, can have an ecological impact.

Survey Station Markers Key

Survey station markers were an important component of the approach that Oregon Caves took to use GIS to help monitor and limit visitor impacts. Otherwise, a completely different scheme would have been needed to reference assessments, surveys, and photos to physical locations. The efforts described here can be applied at other caves and carried out even when staff members have only a basic knowledge of GIS.

About the Author

Elizabeth Hale is a physical science technician with the Resource Management division at Oregon Caves National Monument. Her duties include monitoring cave processes and fauna, managing GIS data, and coordinating cave cleanup and restoration.

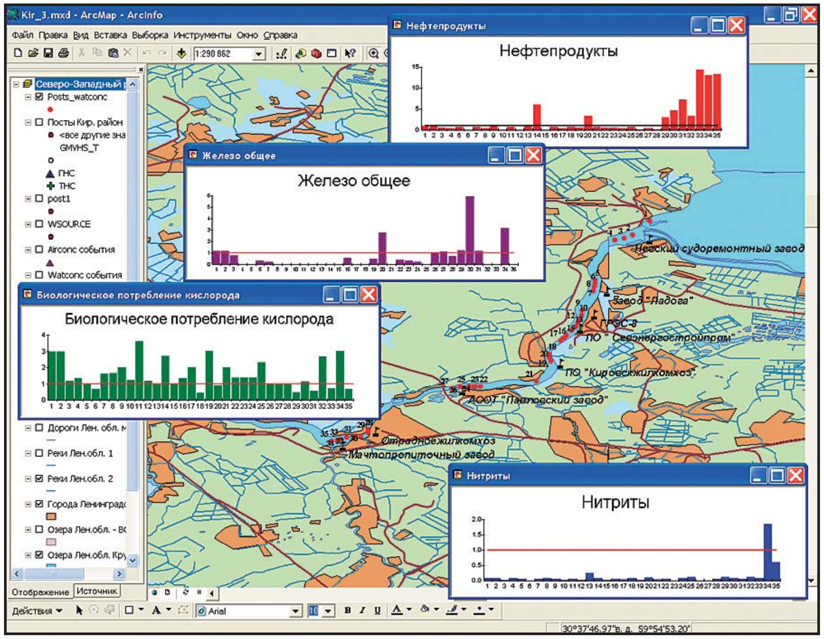
(Reprinted from the Summer 2008 issue of *ArcNews* magazine)

River Pollutants Monitored with GIS

Analyzing the Environmental Impact of Water Bodies in Russia

By Natalia Kurakina, Saint Petersburg Electrotechnical University, Russia

A crucial aspect of environmental policy is to review and assess human impacts of all types. GIS plays an important role in achieving this task when monitoring and analyzing the adverse environmental impact on water bodies, such as lakes, rivers, and bays. For example, a GIS can facilitate an evaluation of pollution sources by generating reports and managing data about polluters, results of measurements, reference materials providing classification of hazardous groups, and concentrations of hazardous substances in a specific river or an entire aquatic system. A GIS can also provide the tools to identify the most hazardous contaminants with regard to ecological regulations and contribute to effective decision making to ensure that natural resources are preserved and utilized correctly.



Data translated into charts shows that the Neva River is polluted with petroleum products, nitrites, and iron salts.

Due to the advanced spatial visualization and analysis capabilities of GIS, researchers at Saint Petersburg Electrotechnical University (ETU) in Russia are able to map and study natural water bodies; their polluters; the source, location, and levels of polluting agents; and the content of the pollutants. Their analysis of natural water bodies and industrial enterprises provides the opportunity to predict the level of industrial impact and study various scenarios to make recommendations for rational use of natural water resources.

For the purpose of its water bodies study, ETU's GIS incorporates databases, models, calculation methods, and directives in the form of an integrated information medium for obtaining integrated data. This system design enables researchers to review and perform the following tasks:

- Assess water body quality.
- Review activity of water users.
- Rank water users by the degree of their impact on the environment.
- Evaluate environmental load on a water body taking into account a basin-based approach.
- Produce reports.

The GIS interface is designed by means of ArcView software with spatial and attribute data stored in a local geodatabase.

A Water Body of Investigation

The GIS-based monitoring system was established on part of northwest Russia's Neva River, located in the Kirovsky District of Leningrad Oblast. The Neva River is an integral part of the region's aquatic system, which also includes Onezhskoe Lake, the Svir River, Ladozhskoe Lake, Nevskaya Guba Bay, and the eastern part of Finsky Bay. This entire aquatic system is affected by an industrially developed area that serves as the main source of pollution. The comparative analysis of the values of some chemical parameters of water in Ladozhskoe Lake, Nevskaya Guba Bay, and a northeastern part of Finsky Bay clearly showed that the Neva River is subjected to the greatest load compared with the other water bodies in the aquatic system. The Neva River receives wastewater discharged from municipal wastewater treatment plants, untreated wastewater, and effluents coming from industrial and agricultural enterprises located near its banks.

Information Medium Assessment System

Data from the Neva River findings is stored in a GIS-based information medium assessment system, which is designed to perform hydrochemical analysis of water body quality to assess the adverse impact produced by humans and to set permissible levels of the ecological load on water resources. Its ArcGIS Desktop platform provides integration and use of the distributed information, while enabling users to process the data depending on which sphere (geographic or administrative) it relates to. The information medium consists of a topographic base arranged in the form of GIS layers, a model base of natural bodies and enterprises, databases with the results of monitoring, and analyzing activities and a regulatory framework.

The topographic base of the assessment system is intended for visualization of the results of investigation and spatial analysis. Each GIS layer contains a group of single-type components, such as rivers, lakes, roads, woods, and monitoring checkpoints. These components are arranged in separate folders.

Basis of Models: Natural Water Bodies and Polluters

Depending on their type (rivers, lakes, seas), water bodies are clustered into GIS layers, containing a geographic description of the object and its key characteristics. Smaller rivers are presented as polylines while bigger ones are described as polygonal objects. More sophisticated objects, such as big rivers, are divided into several sections so that one object has several records in the tables with parameters. The information is kept in two files: a graphic description of the object and midchannel areas with major hydrological characteristics (width, depth, and flow velocity).

Databases of ecological control keep data about monitoring stations and the results of measurements performed. The location of monitoring stations is in a shapefile, and the characteristics of the stations are presented in the attributive file, including the name of the station, to what authority it belongs, type of observation network, name of the water body, and other related data. The results of measurements are accumulated in the database in .dbf format and contain the date of measurement, code and name of the observation station, and values for each measured parameter.

Assessment of Water Quality and Industrial Loads

The ArcGIS software-based information medium assessment system enables its users to make analyses in time and space and assess the quality of a water body in different measuring points. For example, a report visualizes average annual values of pollutants in the checkpoints of the Neva River compared with the maximum permissible concentrations (MPC). Another report demonstrates that the river is polluted with petroleum products, nitrites, and iron salts. It is obvious from analyzing the data in each report that the content of harmful substances on the border of the Kirovsky District is higher than that at the river's head.

The tasks of industrial load assessment are to identify key critical substances, define major users who are responsible for these pollutants, and rank the water users in order to give recommendations for making managerial decisions.

To determine critical parameters in the measuring point, the user shall select in the database a number of measured parameters—the results of hydrochemical status control. For each substance from the selected list, it is necessary to calculate the impact coefficient (concentration compared to MPC value). The substances are ranked by the level of the impact. All the substances for which the impact coefficient is more than one are arranged into a group of critical parameters.

For each substance included in the list of critical indexes, the enterprises are identified that discharge this substance, among others, into a water body. Then the extent of the enterprise contribution to the pollution is to be determined. The identified critical water users are then grouped by the different harmful substances they produce. The impact degree of each water user is determined, and the enterprises are ranked by hazard degree of each substance. The results can then be presented in the form of tables and diagrams in an ArcGIS Desktop (ArcMap) interface.

About the Author

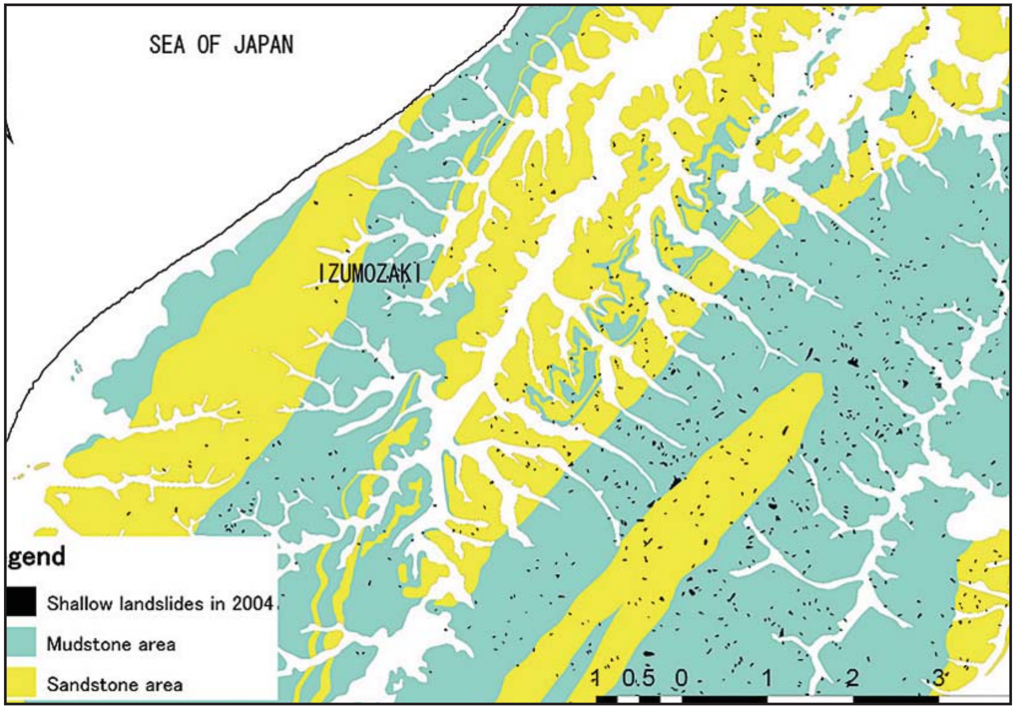
Natalia Kurakina is an associate professor in the Information System and Technology Department at Saint Petersburg Electrotechnical University, Russia. In addition to writing more than 90 subject-related papers, Kurakina has written a book titled Measurement System and GIS Technology

(Reprinted from the Summer 2008 issue of *ArcNews* magazine)

Landslides Studied by Japan Researchers

Causes Analyzed with GIS—Geology and Geomorphology Probed

Mountainous, rocky terrain is characteristic of Japan's landscape. Also characteristic of Japan are frequent downpours and severe earthquakes. In the summer and fall of 2004, this combination created ideal conditions for an October series of landslides in the mid-Niigata region. Specifically, the heavy rainfall on July 13 flooded two major branches of Japan's longest river, the Shinano-gawa, and three months later, on October 23, intense earthquakes rocked another hilly area just south of the area of summer rains, triggering about 4,000 landslides. Using GIS technology to analyze these landslide triggers, so common for mid-Niigata and the rest of Japan, were Hiromitsu Yamagishi from Niigata University, Junko Iwahashi from the Geographical Survey Institute, and Toko Takayama from Asia Air Survey.



July 13, 2004, landslide distribution is shown on an outline geologic map.

"Different triggers brought about the various landslides in the hilly mountains," the research team writes in its analysis. "Therefore, these two events [of July 13 and October 23] are very useful for clarifying the difference in features of the landslides between the two events. We have been researching both landslide [events] in the field, just after both occurred, and later analyzing air photographs using GIS."

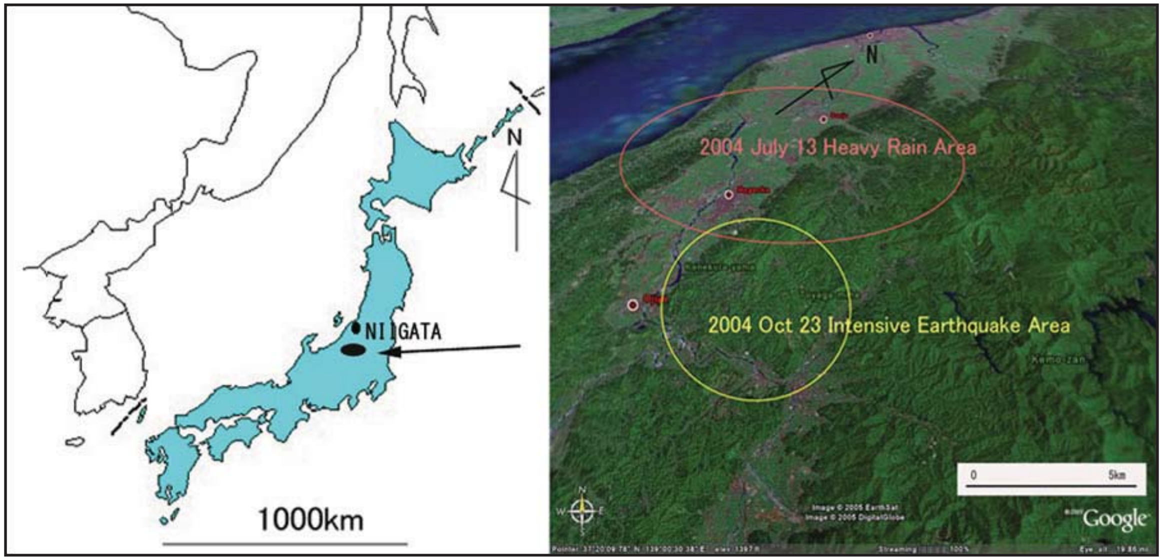
In their analysis, the researchers used ArcGIS Desktop software (through Niigata University's ESRI University Campuswide Site License Program) and geological data sources to explore the number and severity of the landslides in relation to their being rainfall or earthquake induced. GIS is used to generate thematic maps, which help illustrate patterns that a researcher might not be able to easily identify by just looking at data tables. The team also used GIS maps to see if the area's geology and geomorphology, or landforms, played a part as well. By mapping and charting the two landslide triggers and geological features, the researchers were able to visualize what affected the density and severity of the landslides, providing valuable findings that could be used for future disaster mitigation.

Izumozaki and Tochio: Rainfall-Induced Landslides

To begin examining how many and what type of landslides the heavy rainfall caused, the researchers looked at the July 13 precipitation level for mid-Niigata's Izumozaki and Tochio regions. The Automated Meteorological Data Acquisition System (AMeDAS) station in Tochio City recorded almost 17 inches of rainfall starting the evening of July 12 and ending early the next day.

The team prepared GIS precipitation and contour maps of the area (approximately 777 square miles) depicting the landforms and identifying the flooding and landslides caused by the rainfall. Both deep and shallow landslides, as well as long mudflows up to several hundred yards in length, were made visible with colored lines indicating the type and size of the event. Most of the landslides were shallow, several yards wide and thick, and some were in close proximity to the mudflows.

With ArcGIS, a slope map was produced with landslide data from the National Research Institute for Earth Science and Disaster Prevention (NIED). The researchers could see from this map the number of rainfall-induced, shallow landslides in relation to older landslides virtually frozen in the earth. The region's hilly mountains are shaped by former events—old, deep-seated landslides that create slopes in the land, as seen in the team's stratum-dipping contour maps. The maps revealed that the rainfall-induced landslides were concentrated in these steeply sloped areas.



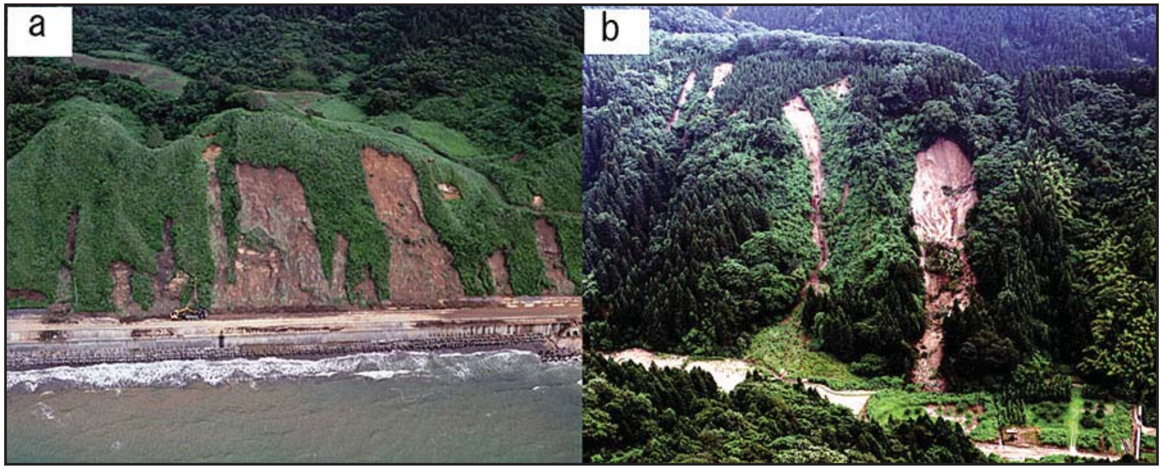
*The mid-Niigata region was affected by the July 13, 2004, heavy rainfalls.
Right: The area affected by the October 23, 2004, intensive earthquake.*

Surface materials were also considered in the analysis. A geological map modified with GIS was used to see how the rainfall-induced landslides differed in number depending on the area's geology. The affected region has a fairly equal amount of sandstone and mudstone surface material. However, where there was mudstone, there were more landslides.

When it comes to rainfall-induced landslides, the team's ArcGIS analysis unveiled some important observations related but not restricted to the July 2004 downpour. First, most of the Izumozaki and Tochio landslides were shallow rather than deep seated. Second, almost all the deep-seated landslides were closely associated with long-run mudflows. Also, the majority of landslides occurred along the ridges. Lastly, mudstone surfaces experienced more of the rainfall-induced landslides than the sandstone. These findings not only provide a better understanding of rainfall-induced landslides, but they also convey what geology and geomorphology are less safe for building roads and communities.

Yamakoshi: Earthquake-Induced Landslides

On October 23, 2004, the southern region of mid-Niigata was struck by an earthquake registering 6.8 on the Richter scale. A map created using ArcGIS was again used to compare landslide density in sandstone- versus mudstone-rich zones. The researchers found something different this time. The landslides caused by these earthquakes and aftershocks were concentrated along the mudstone and sandstone surfaces.



Shallow landslide examples from Nishiyama Hills. Left: Planar-type surface failure in Washima Beach. Right: Spoon-type failure in Aida, Izumozaki (Courtesy of Nakanihon Air Service Co. Ltd.).

Once more, the team turned to the contours of the land to further study the earthquake-induced landslides. A topographic contour line map, layered with a geologic stratum-dipping contour map, again showed a higher number of large-scale landslides in the areas of gentle stratum dipping. Also, when it came to the earthquake trigger, not only did the gradient affect the amount of large-scale landslides in the area, but the earthquake-induced shallow landslides were actually larger on steeper slopes.

Some of the October 2004 landslides were thought to even be accelerated as they ran their course. The hilly earthquake areas contain numerous paddy fields, flooded parcels of arable land used for growing rice. The researchers suggested that landslide flow could easily gain momentum by mixing with water from the paddy fields and ponds. GIS analysis did show a relationship between cracks caused by the earthquakes and paddy fields and ponds with or without water.

Yamagishi's team found both contrasts and similarities when comparing the earthquake- and rainfall-induced landslides. Mudstone, rather than sandstone, became the unstable surface during rainfall; more earthquake induced landslides overall were shown to occur in the sandstone-rich areas. In addition, water standing in surrounding paddy fields was also shown to create unstable terrain. Regardless of what triggered it, a landslide that mixes with water can gain deadly momentum.

The earthquake trigger in Yamakoshi proved just as dangerous as the rainfall in Izumozaki and Tochio. Where the rainfall occurs or earthquake hypocenter is located, what geology is involved, and whether there are steep slopes or paddy fields nearby, each affects how many and what types of landslides can occur. Yamagishi, Iwahashi, and Takayama used GIS to reveal these observations. Their work has shared vital information with their fellow researchers, the residents of mid-Niigata, and decision makers concerned with managing landslide hazards.

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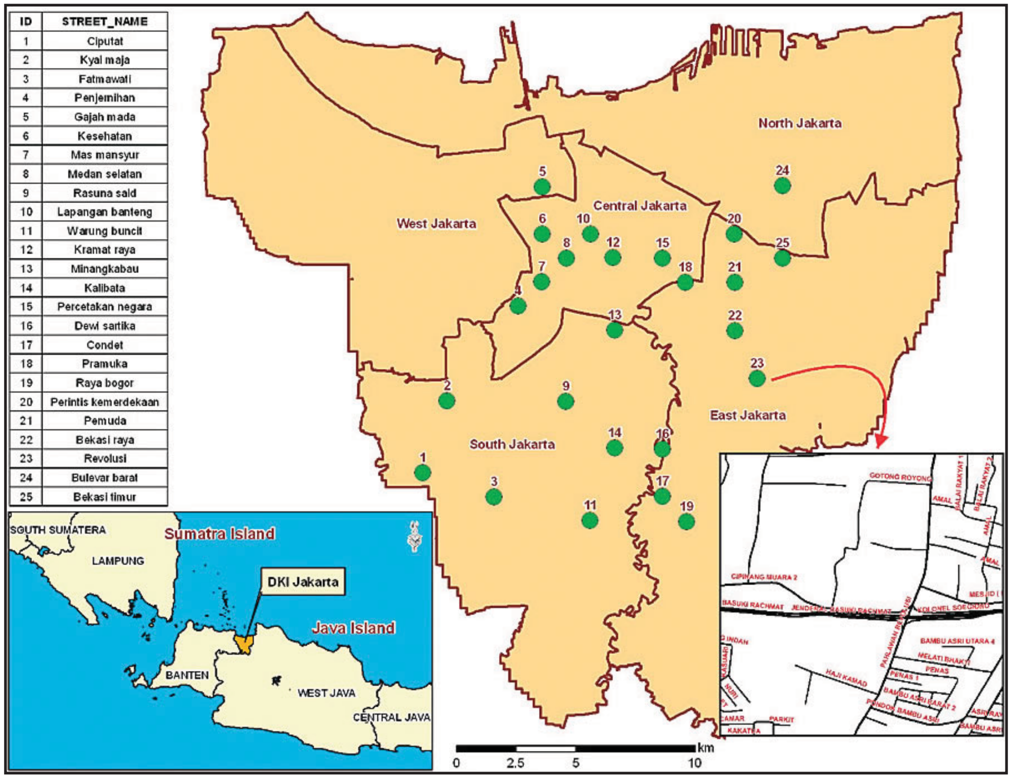
Addressing Ambient Air Pollution in Jakarta, Indonesia

GIS and GPS Help Isolate Problem Areas

Air pollution is a problem in big cities, including Jakarta province, the capital of the Republic of Indonesia. The pollution is due to increased human activities, population growth, the increasing number of industries, and transportation. Monitoring of ambient air quality parameters, such as total suspended particles (TSP), sulfur dioxide, nitrogen oxide, carbon monitrogen oxideide, hydrocarbons, and lead, in Jakarta indicates that the condition is concerning.



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2	Kyai maja
3	Fatmawati
4	Penjernihan
5	Gajah mada
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7	Mas mansyur
8	Medan selatan
9	Rasuna said
10	Lapangan banteng
11	Warung buncit
12	Kramat raya
13	Minangkabau
14	Kalibata
15	Percetakan negara
16	Dewi sartika
17	Condet
18	Pramuka
19	Raya bogor
20	Perintis kemerdekaan
21	Pemuda
22	Bekasi raya
23	Revolusi
24	Bulevar barat
25	Bekasi timur

Ambient air quality sampling locations in the DKI Jakarta area.

Transportation is the main source of ambient air pollution in Jakarta, which has 10 million people. It is larger than any other municipality in Indonesia with 15,000 people per square kilometer. According to the Statistic Central Agency, the number of vehicles in Jakarta in 2003 was 3.4 million motorcycles, 1.99 million passenger cars, 467,000 trucks, and 392,000 buses. Meanwhile, oil fuel consumption increased. In 2003, oil fuel use was 68 percent of total energy consumption. In 2004–2005, the demand for gasoline in Jakarta rose, resulting in increased air pollution. Ambient air pollution has a significant impact on the health and economic sectors. Health care costs increase by US$3.8 million per year. On average, people have only 18 "good air" days in a year. In 2004, 46 percent of all illness cases in Jakarta were respiratory related.

Recent Measurements

In June 2006, the Center for Health and Status Ecology Research and Development, National Institute of Health Research and Development, Ministry of Health, conducted research on this pollution. The aim of the study was to measure pollutant concentration, including TSP, nitrogen oxide, and lead. The measurements were conducted at 25 sampling points in five cities—West Jakarta, North Jakarta, Central Jakarta, East Jakarta, and South Jakarta. TSP was measured using a high-volume sampler, and nitrogen oxide was measured using a gas sampler. Lead concentration was measured using the atomic absorption spectrum. Sampling locations were chosen based on the density of vehicle traffic, and the measurement period was 24 hours at each sampling point. The sampling locations were recorded in GPS and moved to an attribute table to be visualized on a map using ArcView. The map also included information about the density of people in relation to building density; location of parks, which help minimize pollution; and road information, such as major roads and artery roads.

Data was mapped in two categories, threshold and upper threshold. The upper thresholds were defined as TSP concentration higher than 230 micrograms/m3, the standard quality determined by the government; nitrogen oxide concentration higher than 92.5 micrograms/m3; and lead concentration higher than 2 micrograms/m3.

The results show that the TSP and lead concentrations at some sampling points were upper threshold. Meanwhile, the nitrogen oxide concentration at all sampling points was under threshold. Specifically, TSP concentration ranged between 74.07 and 416.26 micrograms/m3, nitrogen oxide concentration ranged between 23.61 and 55.36 micrograms/m3, and lead concentration ranged between 0.00 and 3.88 micrograms/m3. The highest TSP concentrations were found in Central Jakarta and East Jakarta, which was consistent with Central Jakarta being an office area and East Jakarta being an industrial area.

The main purpose of the GIS was to describe and visualize the data, showing the current air quality conditions. The visualization and analysis of data using GIS are very useful for environmental researchers and the government, quickly providing pollution information and locations, and helping with the evaluation of air pollution reduction strategies in Jakarta.

As a result of this study, the government has carried out various efforts to overcome the problem, including producing the integrated *Local Strategy and Action Plan for Urban Air Quality Improvement in DKI Jakarta, 2006.* The action plan has focused on implementation of lead phaseout and low sulfur and on development of public transportation to decrease the number of private cars.

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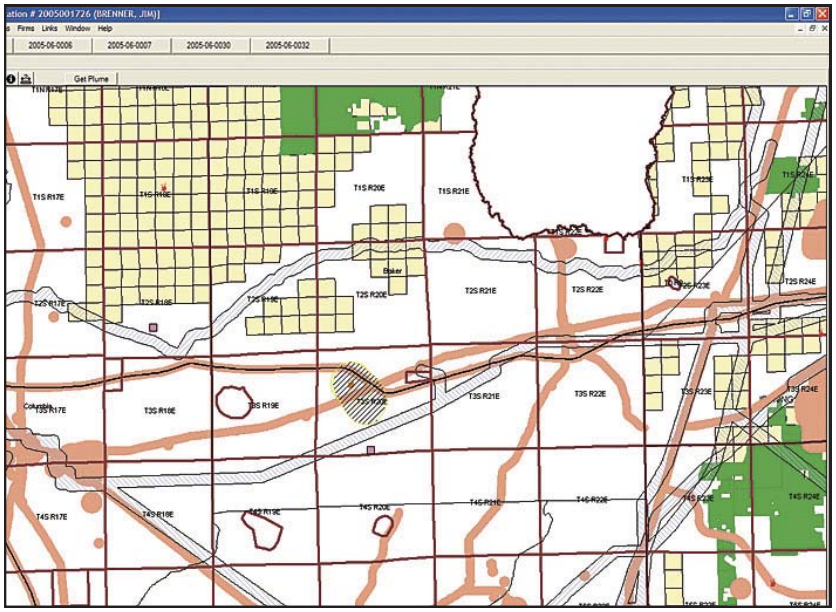
Modeling Potential Burn Hazards

GIS and Plume Modeling at the Florida Division of Forestry

Thinning and prescribed burning and combinations of both reduce fire range and intensity and improve forest health. If not properly managed, however, fire and the resulting smoke can have a negative impact that threatens public health and safety. GIS software is valuable for depicting plume smoke models and correlations drawn from forestry, meteorological, land base, and other pertinent information.



A burn authorization showing the restrictions for that day along with what area (smoke sensitive) the plume was projected to hit.

The Florida Division of Forestry (DOF) Fire Management Information System (FMIS) is an essential tool for effective forestry management. Information supplied to FMIS comes from the DOF's communication centers, personnel at the scene of wildfires, and state and federal agencies. GIS plays an important role in FMIS by interfacing with data from a variety of sources, spatially representing that data, and creating correlations useful to research analysis and everyday workflow tasks. The agency's relational database includes incident data about wildfires, open burning/smoke complaints, on-site inspections, illegal burns, and so forth. FMIS uses an Oracle database managed with ArcSDE. DOF uses FMIS to process data; create reports; and perform services, such as issuing open burning authorizations, responding to wildland fires and other incidents, and recording law enforcement actions taken by DOF personnel.

Responding to a high demand for authorizations with sound judgment is a challenge that requires the support of an efficient system. Most requests to burn are call-ins to DOF communication centers. Duty officers issue 120,000 to 150,000 burn authorizations per year from 15 forestry offices. Approximately 80 percent of authorizations are generated between 7:00 a.m. and 9:00 a.m. On average, the duty officers have three minutes to respond to requests and provide authorizations.

FMIS provides smoke plume data that the duty officer uses to assess potential visibility hazards resulting from the smoke from prescribed burns. Using hourly weather data and the Mesoscale Model number 5 (MM5) weather forecast model, a plume prediction is intersected with a GIS layer of smoke-sensitive features (e.g., roads, airports, hospitals, schools). If a plume does intersect with a feature, supervisor approval is required for releasing authorization.

The smoke analysis model has continued to progress during the past decade. It now includes a component designed to track the potential impact of nuisance ash (e.g., from the burning of sugarcane fields in the southern part of the state). The model incorporates similar techniques used to study volcanic ash plumes in Hawaii and forest fires in other states. The model considers the burn request by creating trajectories that anticipate smoke layer movement at different heights in the atmosphere every hour. Along each trajectory, the perpendicular spreading of the plume is determined using a Gaussian distribution, then initial emissions are calculated. A polygon representing ground-level particle concentrations is constructed and returned to FMIS for determining intersection with layers containing smoke-sensitive features. Initial vertical velocities and terminal velocities are assigned for a representative particle; this particle is then transported in a two-dimensional (height-distance) plane using weather forecast information to determine how far along a trajectory ash is likely to travel during a time span.

U.S. Department of Agriculture Forest Service meteorologist Scott Goodrick used the National Oceanic and Atmospheric Administration HySplit trajectory/dispersion model to develop the smoke plume projection component of the system as a Web service that is integrated into the FMIS application through MapObjects. Goodrick explains, "Bringing weather forecast data into the model was essential. Smoke plume modeling works in a very limited time window, and the ability to access and compute the data requires fast turnaround. The MM5 used for performing weather predictions produces gridded datasets of time-varying weather at resolutions of seven kilometers for Florida. These datasets contain wind, temperature, and atmospheric stability."

When the Florida Division of Forestry receives a request for an authorization, the duty officer enters the address information into the GIS interface, which tabulates it as latitude-longitude coordinates. Based on the vegetation information in the database for that area, the model predicts how much smoke would be released by that burn and how it will move through space and time.

Jim Brenner, Fire Management administrator for DOF, says, "The smoke-modeling component of FMIS supplies the Florida Division of Forestry personnel with a quick way to determine potential hazards from prescribed fires as an integrated part of its authorization process."

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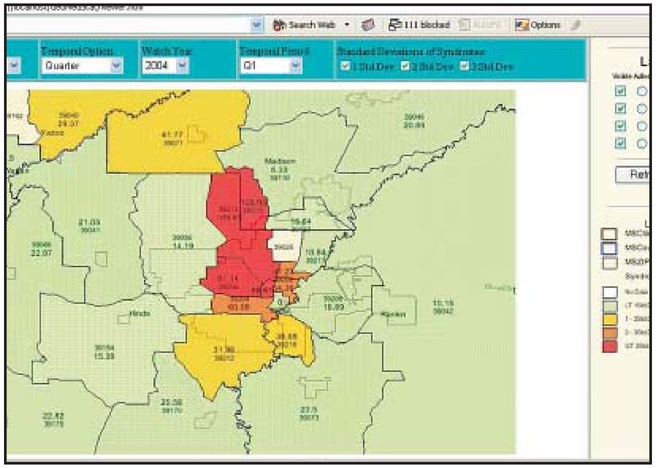
Real-Time Syndromic Surveillance

By Hui Li, Fazlay Faruque, Worth Williams, and Richard Finley

Editor's note: The authors, staff members at the University of Mississippi Medical Center (UMMC), have developed a syndromic surveillance system with GIS disease mapping capabilities. The GeoMedStat system incorporates real-time discharge data from an urban teaching hospital, syndrome classification, dynamic spatial mapping, and query capabilities. GIS disease mapping is a Web-based tool of value to epidemiologists and public health officials for the interpretation and analysis of both routine and outbreak-related health data.

Syndromic surveillance is the utilization of crude health data for the rapid detection of disease outbreaks or bioterrorism attacks. These systems have been deployed using routinely collected laboratory, pharmacy, or clinical data such as a patient's chief complaint on arrival at an emergency department. Existing systems have focused on data collection methods, characteristics of the data collected, and analytical methods to detect disease outbreaks. Beyond actually detecting an epidemic, the availability of additional demographic information—such as age, sex, and location—is valuable for understanding the etiology and dynamics of an outbreak.



GeoMedStat user interface.

The interpretation of such large datasets is difficult. GIS can play an important role in surveillance systems and help decision makers interpret and analyze this data. In particular, geographic information about the location of cases and their temporal evolution would be invaluable to those responsible for identifying and controlling an outbreak. The use of these systems for routine health and disease surveillance may be even more useful than monitoring for disease outbreaks or bioterrorism attacks.

The authors' research focuses on implementing Web-based GIS functions into a real-time syndromic surveillance system. The system includes four major components: real-time data collection, syndrome classification, dynamic spatial mapping, and query capabilities. Query functions allow filtering of the data by syndrome and demographic variables such as age and sex. Queries can focus on particular geographic areas, such as ZIP Code or county, and permit analysis of temporal trends using user-determined dates. The Web-based nature of the system will allow anyone with access privileges to query the system for epidemiological analysis.

Implementation

GeoMedStat can map the spatial distribution of infectious diseases of interest in any given time period and query disease-related information in spatial data layers. ArcIMS delivers dynamic maps and GIS data and services via the Web. For rapid application development, ArcIMS includes Designer, a component to create ArcIMS viewers using prebuilt templates. However, the ArcIMS prebuilt viewers support only limited customization capability so a customized viewer was developed using JavaScript, HTML, and DHTML to support flexible mapping functions in this system.

Data Source

Health care encounter data (i.e., data about interactions with the health care system), particularly emergency department (ED) data, is readily available and well-suited to syndromic surveillance. ED discharge diagnosis data from May 2000 to February 2005, consisting of a total of 87,350 records, was obtained from UMMC's emergency department patient database. These records were collected and used in this study.

ED data is acquired using an electronic medical record in real time, and the discharge diagnoses (or ICD-9 codes) are coded automatically at the time the patient leaves the ED. ICD-9—an abbreviation of the International Classification of Diseases, Ninth Revision, Clinical Modification—was developed to allow the assignment of codes to diagnoses and procedures associated with hospital utilization in the United States. The ICD-9 codes represent ED patients' final diagnoses. One patient visit may have multiple diagnoses and associated ICD-9 codes, and each ICD-9 code in a visit was ranked in order, with the primary diagnosis first and additional diagnoses listed in rank order.

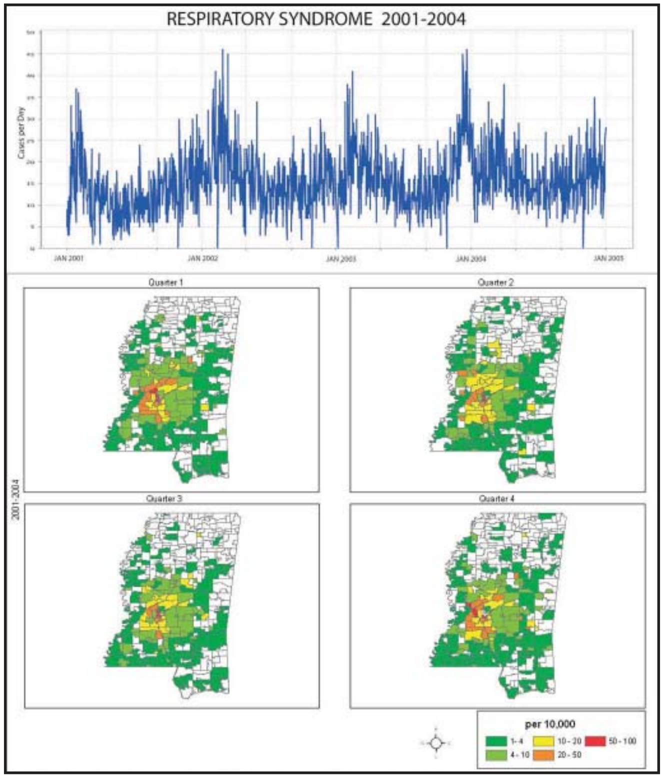
The use of ICD-9 codes obviates the need to use the much less specific chief complaint data that is used in many other syndromic surveillance applications. Data elements imported from the ED database include encounter date, patient ZIP Code, city, sex, age, ICD-9 code, ICD-9 code description, and ICD-9 rank. Patient identification information is excluded.

ICD-9 codes were mapped to different syndrome categories. The data could be imported from the ED database into the surveillance application at arbitrary time intervals. However, for practical reasons, in the current implementation, a time interval of 24 hours was chosen based on ED census data. Shorter intervals did not seem to offer any significant advantage.

Syndrome Classification

Architects of the Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE) system developed a mapping of ICD-9 codes to syndrome categories that has been widely distributed. The Centers for Disease Control and Prevention (CDC) identified 11 syndrome categories and the corresponding ICD-9 codes that can be used in syndromic surveillance programs.

Syndromic surveillance systems have used ED chief complaints or ED discharge diagnosis data for syndrome categorization. Free-text chief complaints can be grouped into syndromes using a statistical model such as Complaint Coder (CoCo), a Bayesian classifier. Studies have shown that ICD-9 codes more accurately classify patients into syndromes than chief complaints. However, ICD-9 codes are often not available in a timely manner; therefore, many systems use chief complaint data. One GeoMedStat advantage is the rapid availability of specific ICD-9 discharge diagnoses.



Temporal and spatial variation of the data for respiratory syndrome over the years 2001 through 2004.

Although seven syndrome categories (gastrointestinal, botulism-like, hemorrhagic, respiratory, neurological, rash, and constitutional) were selected for monitoring, the system can be easily modified for any combination of ICD-9 categories. The ED discharge diagnosis data was automatically grouped into the seven syndromes based on corresponding ICD-9 codes.

Two kinds of redundancy in ED data need to be considered when data is classified in the syndromic surveillance system. One is that multiple ICD-9 codes for a single patient visit may belong to the same syndrome group. This redundancy will overestimate the number of cases in a syndrome category. It is removed programmatically to eliminate multiple insertions found in 18.9 percent of the records. Second, multiple ICD-9 codes for a visit may belong to different syndrome groups because a patient's symptoms may fall into more than one syndrome. This redundancy includes important information and is left intact in the database.

Spatial Distribution Mapping

Disease mapping is a major focus of spatial epidemiology. It provides insight into possible causes of a disease, clusters of disease outbreaks across a geographic area, and the evolution of disease outbreaks. In this study, one of the goals of spatial mapping was identifying regions with unusually high numbers of cases during disease outbreaks or a bioterrorism attack (also referred to as "cluster detection"). Another goal was determining high-risk areas for a disease of interest. This information could be related to other factors such as environmental pollution, weather conditions, or demographic factors. Visits for each syndrome are used to map syndrome distribution at the ZIP Code level. To evaluate dynamic spatial patterns over time, the system supports disease mapping over any given time frame.

Query Functions

To help users interpret disease patterns, the system supports query capabilities. Users can select different data layers to query for disease-related information by clicking on a geographic area of interest. JavaScript is used to collect query parameters and transfer them into ArcXML format that is then sent to the ArcIMS server for further processing through .NET link using ASP.NET.

Discussion

Syndromic surveillance is a rapidly evolving discipline that is driven by timely concerns about emerging disease outbreaks or bioterrorism attacks. Most published literature emphasizes early detection of outbreaks, and this is certainly a worthwhile goal. Possibly even more important is the use of associated monitoring tools to analyze an outbreak that has already been detected. This would be an invaluable epidemiological tool to aid in understanding and controlling such an outbreak.

Health officials and epidemiologists must consider such problems as the dynamics of spread, associated ecological or climatic factors, possible quarantine decisions, and resource allocation. For this reason, a real-time geographic picture of the situation is essential. A more prosaic, but probably ultimately more useful, task for such a real-time GIS tool would be for routine epidemiological studies. If such a tool were Web-based and widely available to epidemiologists with differing interests, it would certainly augment public health analysis immeasurably and point to unsuspected problems much more rapidly than currently possible.

The development of such a tool is beset with several difficult but not insurmountable challenges. The first is data acquisition. In the past, epidemiological studies have relied on classical methods of physician and hospital reporting, chart reviews, and patient interviews. This is an expensive and time-consuming method that limits data collection in both time and scope. The final release of the data is often delayed by months or years. This is unacceptable when dealing with rapidly evolving situations, for example, emerging infectious disease epidemics such as severe acute respiratory syndrome (SARS) or a bioterrorism attack with smallpox.

Electronic hospital administrative records have allowed the rapid retrieval of simple information, such as presenting chief complaint and demographic information, that can be used for analysis of real-time disease trends. Because this data is usually collected by nonmedical personnel, algorithms are applied that attempt to determine the related diseases. The gradual deployment of complete electronic medical records has improved the information available with timely and specific diagnosis information.

The authors have the advantage of working in a hospital where a completely electronic medical record has been in place in the emergency department database for the past four years. This data is available, can be imported into GeoMedStat on a real-time basis, and includes the relevant clinical and demographic information enabling mapping to appropriate syndromes.

Using GeoMedStat, real-time syndrome data can be mapped at the ZIP Code level within the state over a Web-based interface. Current research is focused on the best methods for automating the presentation and interpretation of this data. A major problem with the interpretation of spatial mapping is data normalization. There is a large amount of both temporal and spatial variability that must be taken into account. For example, a known temporal variability is the seasonal variation in respiratory diseases with increases during the winter months.

Spatial variability is even more problematic. UMMC is centrally located and draws patients from the entire state. However, the number of patients seen and the severity of their illnesses are associated with the distance the patient must travel to reach the hospital. Rural areas also have large variations in population density that must be considered.

These normalization issues are a complex topic. Implementation of algorithms to study the advantages and efficiency of different techniques is currently under active research using tools such as time series analysis, cluster analysis (including spatial scan statistics), neural networks, and simulation modeling.

Conclusion

GIS can play an important role in disease outbreak surveillance systems and help decision makers interpret and analyze both routine and outbreak-related health data.

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Richard Finley is a professor of medicine and emergency medicine at the University of Mississippi Medical Center. He has a master's degree in theoretical physics from the University of Colorado, Denver, and a medical degree from the Tulane School of Medicine in New Orleans, Louisiana. His areas of interest include bioinformatics, epidemiology, and the dynamics of infectious disease utilizing real-time monitoring, spatial statistics, and GIS.

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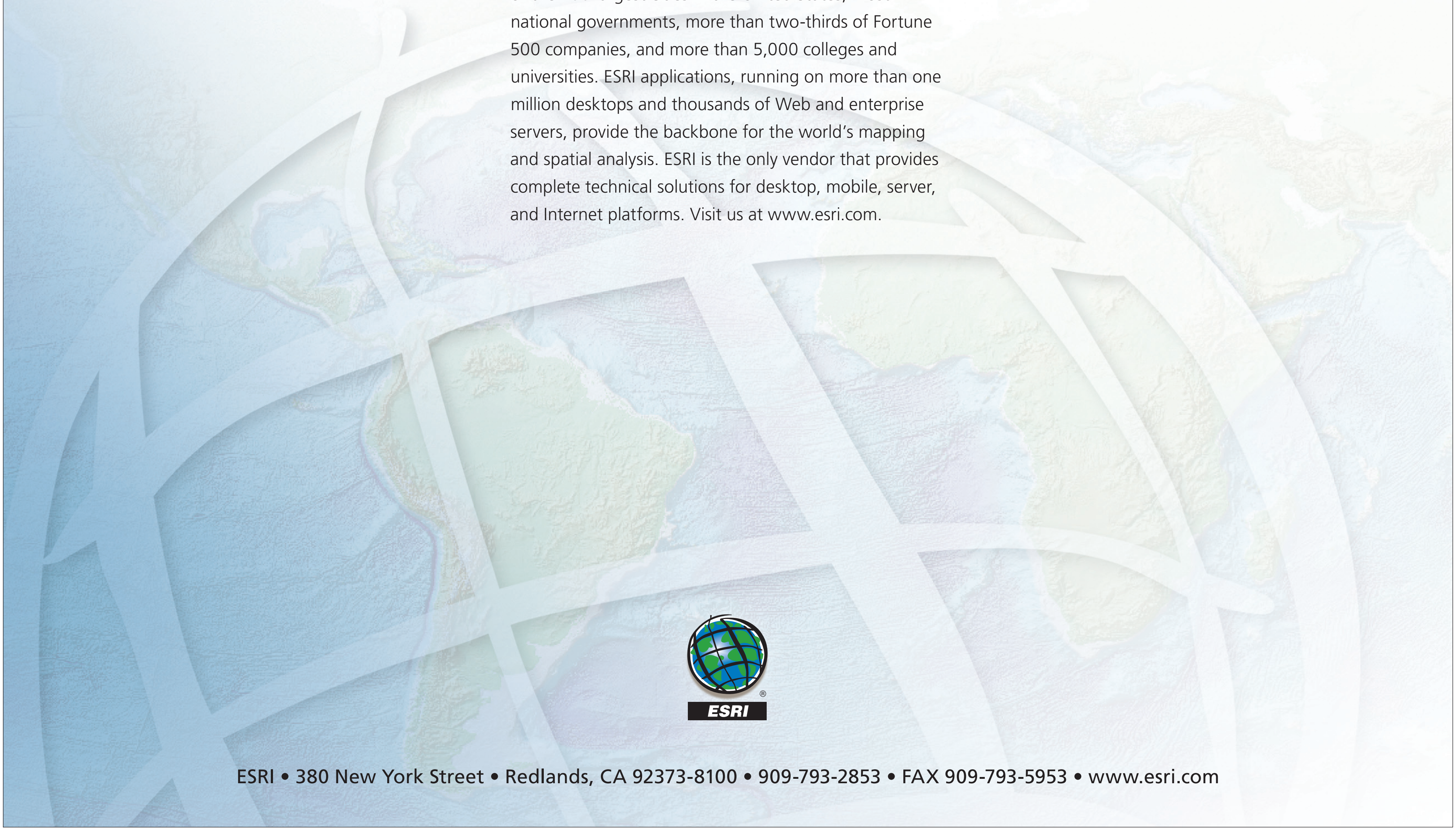

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