A New World of Maps

The tools of geographic information sciences help researchers to visualize, analyze, and discover new meaning in their data.

MAPS are one of society's most valuable tools. A new generation of maps, capable of housing vast amounts of data, is being created with the tools of geographic information systems (GIS). The relatively new field marries the power of computers with the ever-increasing amount of information that is geospatially based.

GIS tools organize, relate, analyze, and visualize data to help discover new meanings and insights and support important decisions. A GIS-based map can combine information that is found in hundreds of traditional maps. Data can be added with the click of a mouse, and new mixtures of data can be visualized on a screen or printed out.

What distinguishes GIS from other forms of information systems, such as databases and spreadsheets, is that GIS deals with information that is related on the basis of location, such as longitude and latitude or Global Positioning Satellite coordinates. GIS maps let users visualize this spatial information in ways not possible with spreadsheets, databases, or charts.

GIS maps are composed of superimposed layers of geographic data that allow analysts to handle and visualize large amounts of information simultaneously. There is no limit to the number of layers that can be visualized simultaneously. A user can "drill down" through data layers to discover all the data associated within a certain distance of a designated location—for example, all the schools and hospitals located within 16 kilometers of an earthquake fault line.

"GIS tools create a new visual language," says Livermore GIS analyst Lynn Wilder. She adds that researchers have jumped out of their chairs when she showed them how GIS maps allowed their research data to be almost instantly understood.

GIS has been traditionally confined to the computer screen or a printout of one or more map layers. Recently, Livermore GIS specialist Lee Neher and Web designer Marisa Price have been developing Web-based versions so researchers can access and manipulate data while working anywhere in the world.

Stunning Breadth of Applications

"The field has a stunning breadth of applications," says Charles Hall, leader of the five-year-old Livermore Geographic Information Sciences Center. The group is working with Laboratory researchers from many disciplines and has been particularly successful in combining GIS with computer models. A user can select or remove data to analyze quickly how different factors affect the model. Dave Layton, Health and Ecological Assessment division leader within the Energy and Environment Directorate, says that GIS maps aid modelers by taking advantage of the enormous amount of geospatial information that is available. Layton, who helped establish Livermore's Geographic Information Sciences Center, notes that much of the information is available from aircraft and satellite imaging. This information, when digitized, forms one of many GIS layers.

The GIS group often supports the Department of Energy's National Atmospheric Release Advisory Center (NARAC), located at Livermore, that models atmospheric releases. The GIS group has also mapped factors affecting international security for a number of Livermore researchers.

Closer to home, GIS analysts have done emergency planning for local governmental agencies in showing the best emergency response routes. The group has also mapped seismic activities and fault lines to help Livermore geologists and engineers understand the relationships among the occurrence of earthquakes, location of faults, surface topography, and underlying geology, which will be used to develop models of future tectonic activity.

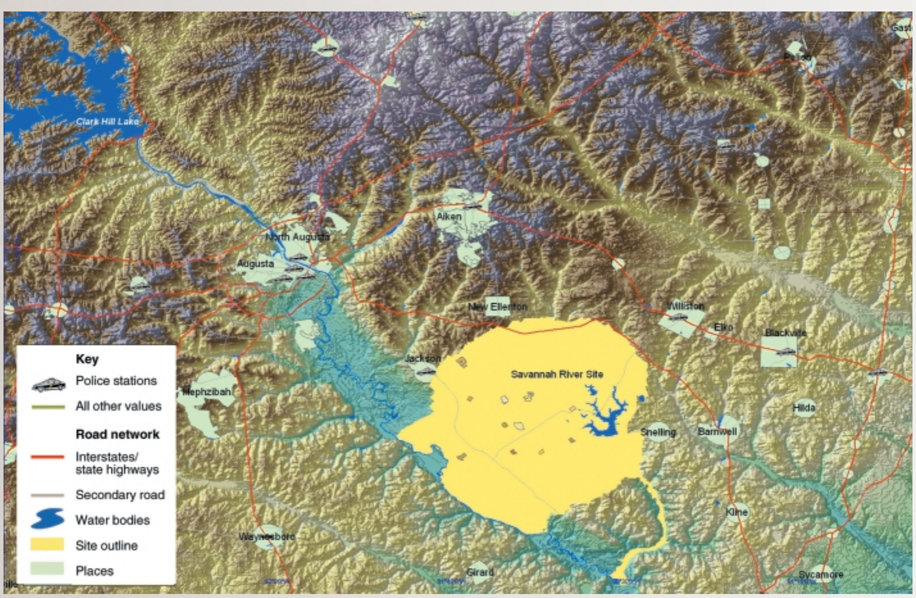
The group built an interactive Web site for the California Energy Commission to help site future power plants. Using a menu of options together with 30 layers of data on California, a user can request the location of prisons, canals, urban areas, railroads, watersheds, oil and gas fields, earthquake faults, and many other features, all within a specified distance. Each of the options corresponds to a separate GIS layer.

A similar Web site is being created for the federal Nuclear Regulatory Commission, which must evaluate applications for new operating licenses for nuclear power plants as well as for license renewal for each of the nation's 103 nuclear power plants. With the click of a computer mouse, the location of endangered species, low-income populations, past hurricane and tornado routes, seismic fault lines, highways, cities, and many other factors are shown within a user-specified radius of a given power plant.

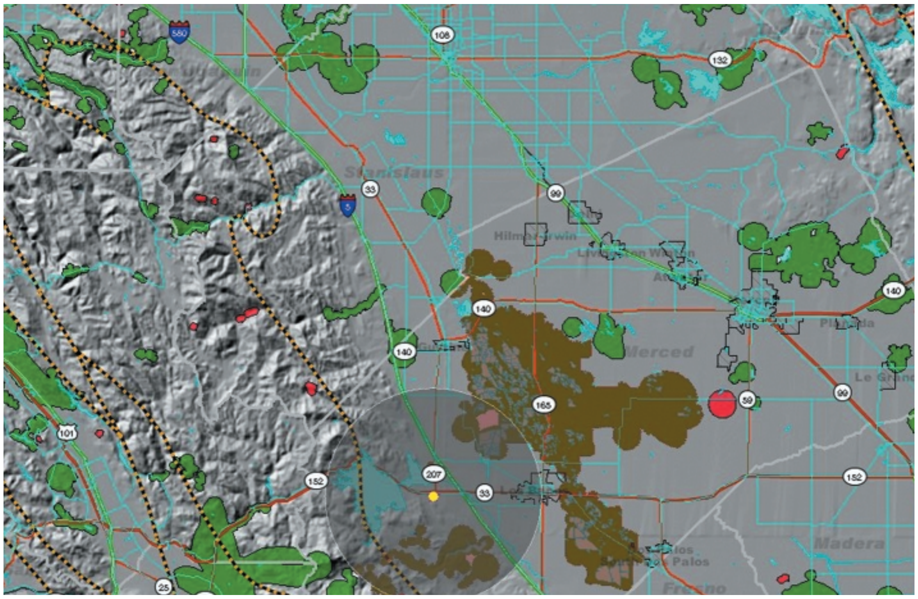
Modeling the Tallgrass Prairie

GIS tools are particularly helpful to people who do environmental and ecologic modeling. The Geographic Information Sciences Center is helping to develop an Internet-based, interactive site to help assess the ecologic risks of oil exploration and drilling for vegetation and wildlife located in the Tallgrass Prairie Preserve in Oklahoma. The modeling project, funded by DOE's National Petroleum Technology Office, is a collaboration among the Laboratory, Oak Ridge National Laboratory, and oil industry partners.

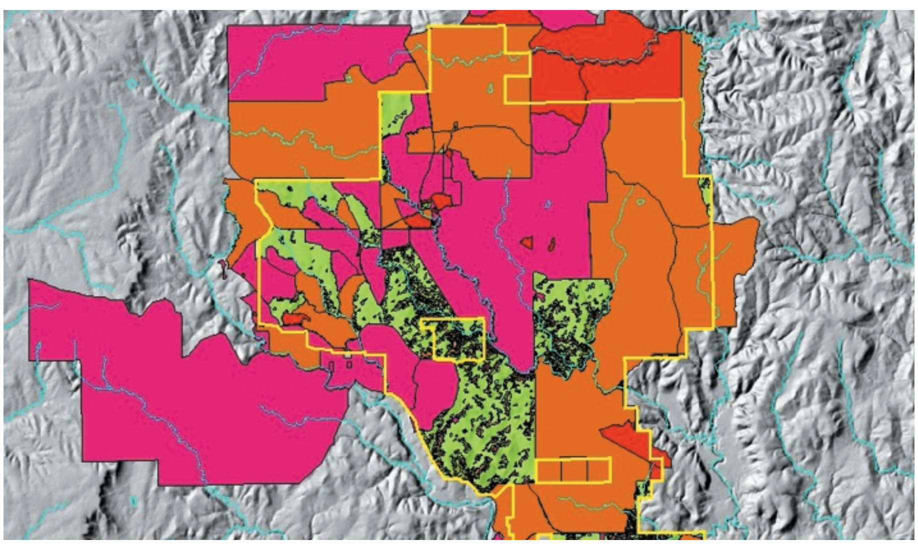
The reserve consists of 152 square kilometers of rolling prairie in northeastern Oklahoma and is owned by The Nature Conservancy. The reserve plays host to a variety of plant and animal species, including bison, and is one of the last substantial remnants of the tallgrass prairie ecosystem that once covered large areas of the United States and Canada. The reserve has over 600 nonworking wells and 120 active wells, and a number of oil and brine spills have occurred in the preserve over the years. As a result, says



Geographic information systems (GIS) maps are composed of layers of geographically superimposed data. There is no limit to the number of layers that can be visualized. Such capabilities are particularly valuable to researchers working at the National Atmospheric Release Advisory Center, located at Livermore. In the example above, the Geographic Information Sciences Center assembled layers of data about natural and human-made features, including geography, topography, demography, roads, railroads, surface water, and facilities.



An interactive Web site built for the California Energy Commission was developed to help the state to locate sites for future power plants. Users can request to view the location of prisons, canals, urban areas, railroads, watersheds, oil and gas fields, earthquake faults, and other features, within a specified radius. This image shows selected features within 16 kilometers of a proposed power plant near Merced.



Livermore's Geographic Information Sciences Center is supporting ecologists studying the Tallgrass Prairie Preserve in Oklahoma. The center's tools allow ecologists using the Internet from anywhere in the world to access and manipulate numerous layers covering the prairie and to model hypothetical conditions in the preserve. The layers show vegetation, bison grazing areas, elevation, oil well locations, access roads, slope, drainage basins, streams, soil type, precipitation, contaminated areas, and the location of past years' prescribed burns.

Livermore ecologist Tina Carlsen, the land is characterized by small patches of contaminated or otherwise affected areas.

The project's approach takes an ecosystem perspective rather than relying on traditional organism toxicity studies. "In this project, we're working as traditional ecologists using state-of-the-art tools to determine the effects on the prairie vole and the short-eared owl of removing them from their habitat because of an oil spill or the construction of a new access road," Carlsen says.

GIS tools allow ecologists to access and manipulate numerous data layers covering the prairie as they model hypothetical conditions in the preserve. The layers show vegetation, bison grazing areas, elevation, oil well locations, access roads, slope, drainage basins, streams, soil type, precipitation, contaminated areas, and the location of past years' prescribed burns. Hall notes that this work should allow the models to run from the Web site, with the results displayed over various layers. "GIS has become essential to ecological work," says Carlsen.

Supporting Livermore's Site 300

In other environmental applications, the center is supporting the Environmental Restoration Project at Site 300, Lawrence Livermore's remote 18-square-kilometer test facility. The group has developed sets of data describing the topography, facilities, utilities, roads, groundwater contamination, population, zoning, and digitized aerial photographs. The data, organized as GIS layers, are helping researchers to place wells that extract and treat contaminants. The work also helps biologists to estimate the remedial work's effects on native species.

In another project, the group is also assisting Lawrence Livermore's Fire Department and Site 300 managers to conduct annual prescribed burns. Such burns prevent an accumulation of wild grasses that could pose an unacceptable risk of wildfires. To understand better the atmospheric dispersion of smoke from prescribed burns at the site, NARAC researchers simulated the smoke dispersion from eight prescribed burns, four in June 1999 and four in July 2000.

The Laboratory's Fire Department provided information on the area of each burn plot, the time of ignition, the duration of the burns, how much fuel was burned, and the estimated plume heights. Using this information, the NARAC researchers estimated the smoke emission rate for each burn.

The GIS team analyzed the smoke dispersion simulations, importing the data into GIS software and then superimposing it over a satellite image of the area, which constitutes another layer. Data layers were also developed that corresponded to the location of nursing homes, schools, hospitals, day-care centers, and other facilities, called sensitive receptors, that might be affected by the smoke. Other layers corresponded to streets and highways, towns and cities, and county boundaries.

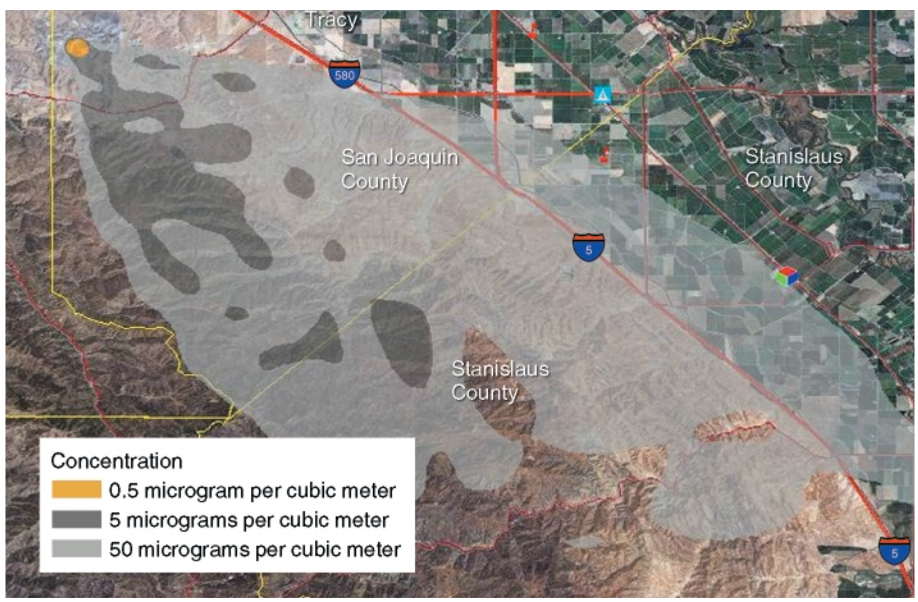
The simulations showed that for 24 hours after the burn, the simulated smoke concentrations were substantially below the legal limit of 50 micrograms per cubic meter, except directly over the burn area, as expected. Also, in no case did the simulated smoke plume drift over a sensitive receptor. NARAC meteorologist Mike Bradley says that the simulations provide persuasive evidence that the prescribed burns would cause no air quality problems. The study also confirmed that combining the modeling capabilities of NARAC with GIS provides a powerful predictive tool for evaluating the consequences of atmospheric dispersion of smoke from future prescribed burns.

Bradley is leading an effort that uses supercomputers and GIS to model wildfires more scientifically. The project, funded by the Laboratory Directed Research and Development program, combines NARAC weather prediction models with a physics-based combustion model developed at Los Alamos. Bradley is testing the model by reconstructing the early stages of the 1991 fire in the Oakland–Berkeley hills, which claimed 25 lives and destroyed 3,000 dwellings.

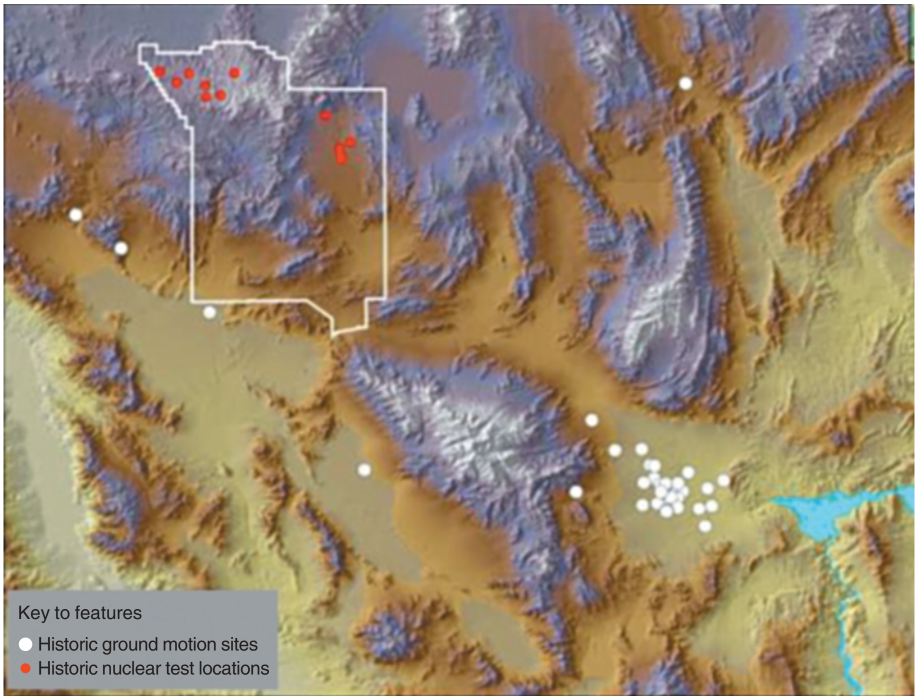
Hall explains that the Geographic Information Sciences Center assembles data describing topography, streets, houses, lot parcels, vegetation, transmission lines, population, and aerial imaging. Topographical and vegetation (fuel) data are fed to the combustion model, which simulates the spread of the fire from its origin. The simulation results are displayed with GIS over the topography and lot parcels to assist in calibrating or checking the accuracy of model resolution. Eventually, this system could be used to manage vegetation, assess risks and consequences of wildfires, and plan and manage evacuation.

Salton Sea Options

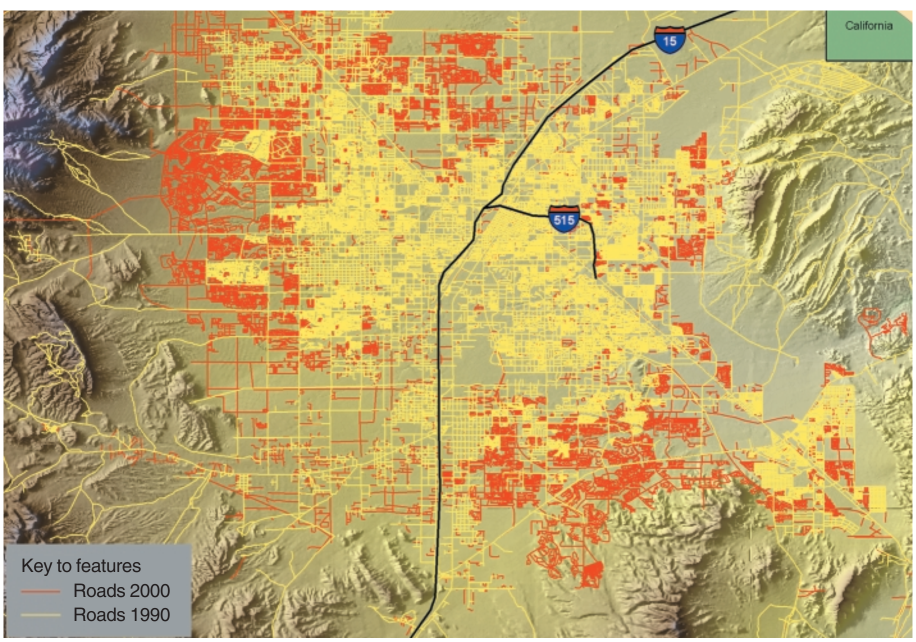
One of California's most threatened ecologic systems is the Salton Sea, an inland, 644-square-kilometer saline lake in the Sonoran Desert of southeastern California. It was formed between 1905 and 1907 when the Colorado River burst through irrigation controls south of Yuma, Arizona. Over the years,



A model of the June 10, 1999, 24-hour average of smoke concentration, summed for all three controlled burns that were conducted at Livermore's Site 300. The GIS team superimposed the simulated burn data over a satellite image of the area. Data layers were developed that corresponded to local nursing homes, schools, hospitals, day-care centers, streets and highways, towns and cities, and county boundaries. The model showed that 24 hours after the burn, the smoke concentrations were substantially below the legal limit of 50 micrograms per cubic meter except, as expected, directly over the burn area. Also, the simulated smoke plume did not drift over a sensitive receptor such as a nursing home, school, or hospital.



This geographic information systems image shows the locations of historic nuclear tests at the Nevada Test Site and the location of ground motion recording stations. The large number of ground motion sites in the lower right corresponds to the Las Vegas area.



Comparison of the number of roads in greater Las Vegas, Nevada, in 1990 and 2000 reveals that significant growth occurred in the area. This image combines three layers from the geographic information systems: roads, elevation, and highways.

much water has evaporated, leaving behind high concentrations of salt.

Preventing the sea's salinity level from rising is critical to the survival of many fish and to hundreds of species of birds that eat the fish and that depend on this oasis as a wetlands habitat. Livermore researchers have been studying options to ensure that the sea has a ready supply of fresh water. At the request of Congressman Duncan Hunter of California's 52nd District, which includes a majority of the Salton Sea, the researchers met with key stakeholders in May.

The Livermore research and the presentation to stakeholders were aided by GIS maps of the sea and the surrounding area. The many-layered maps created a virtual overview of the area, with layers corresponding to canals, farmlands, cities, power plants, rivers, and elevation.

Las Vegas on the Map

GIS is playing a role in determining the seismic effects on Las Vegas if the United States had to resume underground nuclear testing at the Department of Energy's Nevada Test Site (NTS). Livermore engineer Dave McCallen is developing a computer model that shows the structural responses of Las Vegas buildings, many of them highrises constructed during the past decade. The models are based on ground motion recorded by monitoring stations located throughout the area.

McCallen notes that Las Vegas, located some 90 kilometers from NTS, lies in a sedimentary basin that traps and amplifies seismic waves. The city has experienced dramatic growth since the United States last conducted an underground nuclear test in 1992. Much of the growth has occurred in the deepest part of the basin, where no monitoring stations were sited and where the strongest ground motions might be felt from an underground blast.

Geographic Information Sciences Is Advancing Many Fields

Although the field of computer-based geographic information systems (GIS) is about 30 years old, examples in the last 150 years predicted the utility of its powerful modern versions. For example, more than 500 people, all from the same section of London, died of cholera within a 10-day period in September 1854. John Snow, a local physician, constructed a map to show the distribution of the disease. The map helped authorities to conclude that the Broad Street water pump was linked to the outbreak. By removing the pump's handle, they stopped the epidemic.

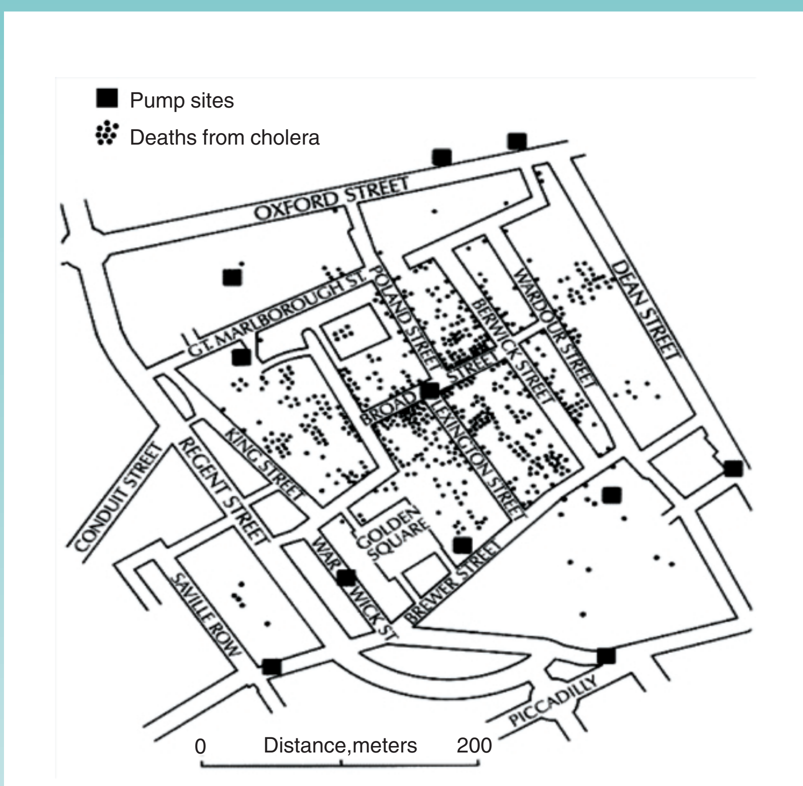
By the early 1980s, advances in computer hardware had made GIS cost-effective for many organizations. Today, GIS is growing rapidly and used by many government organizations and businesses. Some new cars are equipped with GIS and Global Positioning Satellite tools that show the driver the vehicle's exact location or the best route to a selected destination.

GIS has its origins in landscape architecture. It currently draws upon several related disciplines including cartography, cognitive science, computer science, engineering and land surveying, biology, environmental sciences, geodetic science (methods for determining precise positions on Earth's surface), and remote sensing. GIS applications span many disciplines, including anthropology, sociology, marketing, environmental science, health sciences, biology, planning, history, geography, geology, and climatology.

Local governments use GIS to update property boundaries, site new schools and parks, and calculate emergency response times and plan the best access routes. Livermore GIS researchers have worked with California's Highway Patrol to analyze highways with high accident rates. GIS is used by businesses to identify potential markets and determine where to locate new stores. U.S. military services rely greatly on GIS tools because geography is an important factor in military action, and analysts or commanders can quickly see the effect of the terrain on possible battlefield decisions.

Livermore GIS analyst Lynn Wilder notes that new GIS tools appear every few months, thereby increasing the power and utility of the discipline but making it difficult for analysts to keep current. Increasingly, colleges are offering GIS courses. Last fall, Wilder co-taught an introductory course at Las Positas Community College, near the Laboratory. She uses commercial software that takes at least two years to master fully. Her colleague, Lee Neher, develops software that permits users to manipulate their data with customized graphical user interfaces.

Neher says that the fields GIS can address have no limit, so long as data have an *x* or *y* coordinate. In that respect, GIS works equally well on an area of 10 square kilometers or 10 square millimeters. Livermore GIS researchers have worked on maps of the entire world as well as maps of small "worlds" of contaminants passing through rock strata.



More than 500 people, all from the same section of London, died of cholera within a 10-day period in September 1854. A map showing the distribution of the disease led authorities to close the Broad Street water pump, an action that stopped the epidemic. The map anticipated modern, vastly more complex, GIS analyses.

GIS maps include the entire basin and extend to NTS. The maps contain layers corresponding to streets, highways, railroads, fault lines, geology, elevation, ground motion stations, buildings, locations of past nuclear tests, and other features.

"With the GIS layers, we can see the relationship between geology and a building's structural response," says McCallen. "By mixing and matching the layers, we can understand a complex, large-scale problem, visualize the data, and gain insight. Without GIS, it would be difficult to get our hands around all of the data and explain our findings in a meaningful way, especially to nontechnical people." He notes that the research spinoff to Las Vegas residents is a better understanding of the area's general seismic hazards, especially from strong earthquakes centered in California.

GIS for Homeland Security

GIS has proved itself to be well suited to projects involving international and homeland security, especially when combined with modeling. Livermore scientists have developed two prototype programs called BIOURBAN and BIOBASE. Says Layton, "We wanted to answer two driving questions: Can we recreate the point of release and reasonably estimate the population at risk from a clandestine bioagent release days or weeks later on the basis of what happens to a few early victims? And can we analyze a facility's vulnerabilities to a chemical or biological release and evaluate ways to reduce the effects of an attack?"

BIOURBAN is a Web-accessible GIS-based program designed to back-calculate the point of origin of a clandestine biological release in an urban area in the U.S. and determine the size of the population at risk. The program reconstructs the probable time and location of biological agent attack from information including the location of victims, their activity patterns, the characteristics of the pathogenic organisms, disease latency, and meteorological data.

BIOURBAN contains data layers describing street and freeway networks, public places such as large arenas and auditoriums, public buildings, schools, hospitals, and mass transit systems. It can access meteorological data and dispersion models such as those used at NARAC.

A related prototype program, BIOBASE, is also Web-based. It is designed to investigate the potential vulnerabilities of a military base to chemical and biological agent attack and to evaluate alternative operating methods that could minimize exposure after such attacks.

The program uses GIS layers corresponding to roads, buildings, runways, topography, military personnel by function, local people employed on base, dependents, and citizens living in the surrounding area. It contains a database of historic meteorological conditions and a library of simulated plumes. The program also contains a database of potential biological agents and their potency, known health effects, time until onset of symptoms, medical intervention options, and other information.

Only the Beginning

GIS is helping a growing number of Livermore researchers understand and communicate their research data. "I'm very optimistic about the possibilities of GIS," says Hall. "At Livermore, we're only beginning to take advantage of its capabilities."

As NARAC researcher Bradley says, "GIS helps us to understand the meaning and significance of our data. Without GIS, it's just a bunch of numbers or pretty plots."

—Arnie Heller

Key Words: BIOBASE, BIOURBAN, geographic information systems (GIS), Geographic Information Sciences Center, National Atmospheric Release Advisory Center (NARAC), Nevada Test Site (NTS), Salton Sea, Site 300, Tallgrass Prairie Preserve.

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