CHAPTER 9

GIS in Action

Let observation with extensive view
Survey mankind, from China to Peru.
—*Samuel Johnson*, The Vanity of Human Wishes *(1749)*

It is a map that moves
faster than real
but so slow;
only my watching proves
that island has being,
or that bay.
—*May Swenson*, The Cloud Mobile, *1958, 2nd verse*

"It's all fine you saying we're no longer in Kansas, but lets try to be a little more scientific about this..."

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ORNIA'S COASTAL

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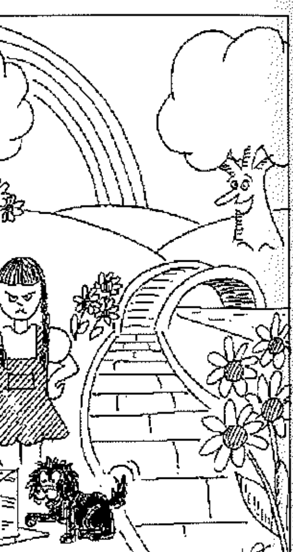

we're no longer in Kansas,
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9.1 INTRODUCING GIS IN ACTION

As much as knowledge and understanding of the principles behind GIS are critical to getting started with GIS, the technology's true strength is and will always be in the power of its applications. In this chapter, five GIS case studies are presented. Each is unique in its own way, and the reader should pay attention to differences in data structures, software, procedures, and directions as the GIS systems we have discussed in theory now move out into the real world. What is also impressive is the extreme breadth and versatility of these applications. GIS is a tool that crosses disciplinary and professional boundaries with ease. Nevertheless, each field of expertise has an angle on GIS use and brings to the application a fresh set of approaches. The five applications cover oceans, rural, suburban, deserts, and urban areas, they encompass forestry, geology and ecology, public health concerns and insects, storms and runoff, and mysterious rocks, and also how GIS assisted at the site of the tragedy in the nation's worst terrorist attack. These five applications do not pretend to be comprehensive. Each has been contributed by the GIS experts in question as a summary of a broader-scale work that they have either completed or that remains in progress. Nevertheless, these applications are a perfect starting point from which to examine GIS in action.

9.2 CASE STUDY 1: GIS FIGHTS THE GYPSY MOTH

A Case Study of the Use of GIS to Understand Population Dynamics of the Gypsy Moth in Michigan

9.2.1 Contributors: Bryan Pijanowski and Stuart Gage, Michigan State University

The Entomology Spatial Analysis Laboratory in the Department of Entomology at Michigan State University is devoted to the spatial analysis of insect pests and the assessment of risk to Michigan's forests, among other projects. The laboratory is directed by Dr. Stuart Gage, who has conducted research on the spatial distribution of forest and crop pests for over 25 years. Dr. Bryan Pijanowski is an ecologist, and an associate in the laboratory. He has specialized in the use of GIS, such as Arc/Info and IDRISI, to model insect and human populations. The laboratory currently contains several Pentium computers, four Sun workstations, and a Silicon Graphics workstation for visualization of spatial data. The staff uses Arc/Info, IDRISI, ERDAS, ER-Mapper, and Atlas*GIS for research.

9.2.2 Background

The use of GIS to study the gypsy moth in Michigan provides an excellent example of the applicability of this tool in the biological sciences and for resource management. The gypsy moth (Figure 9.1) is an introduced forest pest that consumes the leaves and needles of nearly 300 woody plants. The insect was first discovered in the state 40 years ago, and outbreaks of the pest have been occurring in Michigan since the mid-1980s. Severe defoliation (i.e., loss of leaves) of oaks, aspens, and other tree species preferred by gypsy moth caterpillars has occurred throughout the northern Lower Peninsula, and

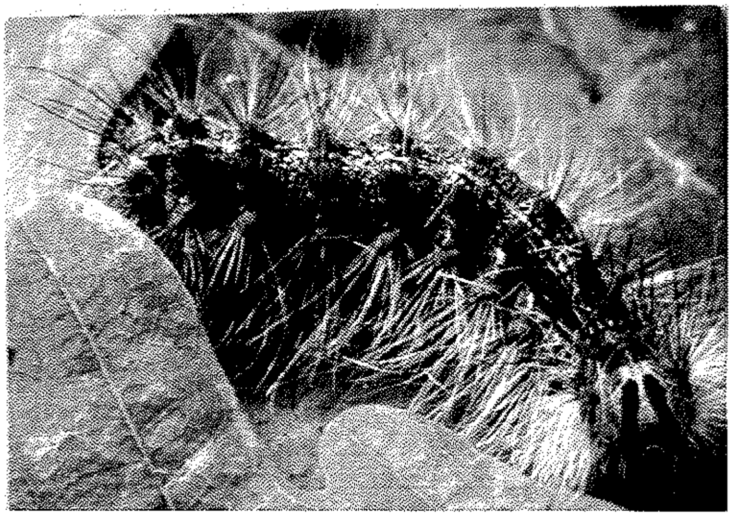


FIGURE 9.1: A gypsy moth caterpillar, shown against an oak leaf. (Photos in this section are courtesy of Dr. Bryan Pijanowski. Used with permission.)

populations continue to expand into southern Michigan and into the state's Upper Peninsula. Defoliation has increased from 2800 hectares in 1984 to over 280,000 hectares in 1992.

Unlike many native forest insects, the gypsy moth is a problem in both urban areas and forests. Multitudes of large, hairy caterpillars, abundant frass (fecal material), and loss of leaves on shade and ornamental trees create much annoyance for people in wooded residential and recreational areas. Management of the gypsy moth is carried out by aerial spraying of a biological insecticide called *Bacillus thuringiensis* (Bt) from helicopters or planes (Figure 9.2). This biological insecticide kills only moths and butterflies that eat the Bt from tree leaves and it degrades in the environment in a few days.

9.2.3 The Monitoring Program

In 1985, a statewide gypsy moth monitoring program was implemented to characterize this pest's population dynamics. Because the male is attracted to the female through the use of a pheromone that is emitted by the female, populations of male moths have traditionally been monitored through the use of pheromone-baited traps (Figure 9.3). A small pesticide strip is placed at the bottom of these traps to kill the moths once they enter. The statewide program entails the monitoring of 3000 pheromone traps placed in a grid-like design (Figure 9.4) with a 6-mile intertrapping distance. Several agencies have been involved in this monitoring effort, including the Michigan Department of Agriculture, Michigan Department of Natural Resources, the USDA–APHIS, Animal and Plant Health Inspection Service, and USDA Forest Service. Funding for the project has come from the Michigan Department of Agriculture.

Every year, these pheromone-baited traps are placed in designated locations in the spring. In the fall, trap tenders visit each location and record the number of moths contained in the trap. Trap catch data are recorded on specially designed forms and are

FIGURE 9.2: Helicopter with spray boom, spraying trees with the Bt biological pesticide to kill the gypsy moth.

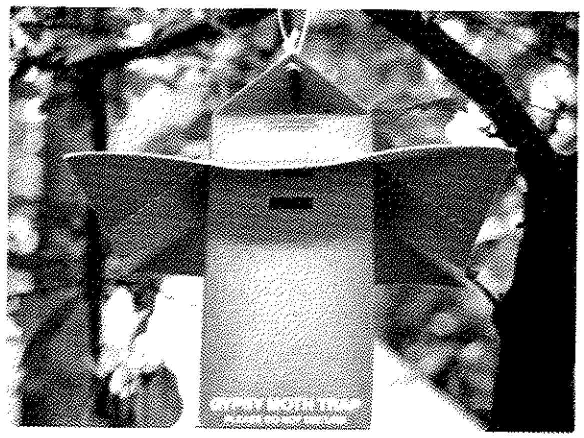


FIGURE 9.3: A milk carton trap used by the spatial monitoring program for the gypsy moth across the state of Michigan.

sent to the state survey coordinator at Michigan State University for data entry and management. Trap locations are geocoded at Michigan State University's Entomology Spatial Analysis Laboratory by linking permanent site numbers to geographic coordinates. Data are then placed into a geographic information system for spatial analysis and association with other information, such as previous years' moth estimate, host distribution, and tree defoliation.

Once the data are brought into a GIS, the numbers of moths captured per year, initially represented as point data, are converted to a raster format using various interpolation methods. The most common interpolation method that is used is the inverse distance squared (IDW) method (we use a weighting of 2), which is available in both IDRISI and

FIGURE 9.4: Gypsy moth trap sample locations in Michigan.

Arc/Info. Interpolation of these trap data are conducted to obtain a raster layer of gypsy moth trap numbers at 1-km cell resolution. Once the raster data layer is developed for trapping results for each year, the data are reclassified into population-size categories For example, raster maps of moth counts of 1–25; 26–100; 101–200; 201–300; 300–400; and 400 or more moths are used frequently as starting maps for analysis and overlay with various other GIS layers, such as forest cover.

9.2.4 GIS Use and Data Analysis

The use of GIS to assess risk to Michigan's forests from the gypsy moth is one example of a case study that has special interest to both resource analysts and to biologists interested in studying the interaction of insects and forests. The main objective of this study, partly funded by the Michigan Department of Agriculture, is to determine areas where the most susceptible tree species, oak and aspen, may undergo defoliation. We approached this study by developing annual gypsy moth population-size category coverages (Figure 9.5). Annual high-risk population coverages, which we determine to be 400 moths or more, are created as simple binary maps; a "1" is coded as the presence of 400 or more moths and a "0" as locations of the state that contain fewer than 400 moths for that year. Susceptible forest data were obtained from a statewide 1-km resolution forest-type map (dominant tree species only) that was developed from a multitemporal analysis of AVHRR data and various forest cover maps from the Michigan Department of Natural Resources.

This forest cover map contains information for several classes of forests (e.g., oak–hickory; spruce–fir); we used GIS to extract only susceptible forest types (i.e., oak and aspen forests) from this database. To perform the final analysis, we coded all oak forests with a "2" and all aspen forest with a "1" and multiplied the high-risk population coverage with the susceptible forest coverage.

9.2.5 Summary

The Michigan Department of Agriculture has used these map series to help manage the state forests that are located in the western portion of the Lower Peninsula of Michigan. Analysis of these data could not be accomplished easily without the use of a geographic

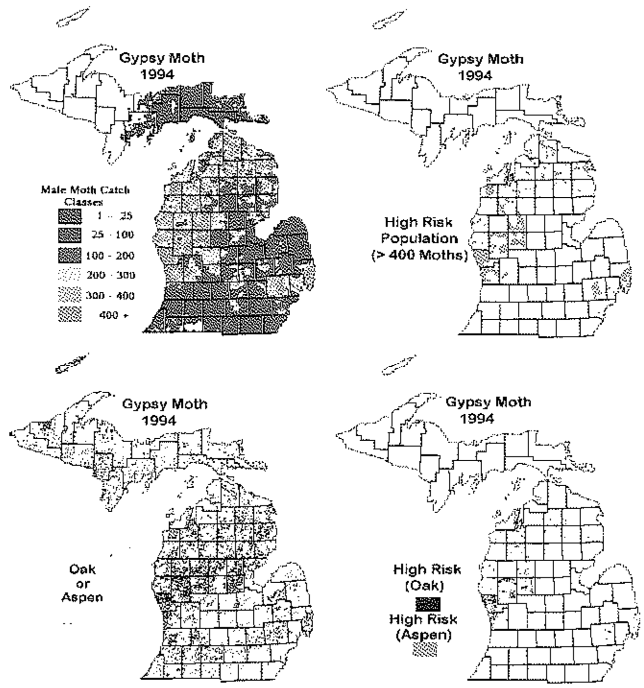


FIGURE 9.5: Upper left: Sample annual map for 1994 with seven density categories. Upper right: High-risk population map; area with greater than 400 moths trapped. Lower left: Susceptible forest types (i.e., oak and aspen forests) from the database. Lower right: Risk areas from an overlay of the data.

information system. Results of spatial analyses are generally easy to interpret and are thus powerful tools for use in resource management and policy development. Furthermore, because the results can be displayed as a colorful map, posting the maps and associated text on the World Wide Web has become a very effective communication device as well. The Entomology Spatial Analysis Laboratory in the Department of Entomology at Michigan State University maintains a World Wide Web site at `http://www.ent.msu.edu`.

9.3 CASE STUDY 2: GIS AND ROAD ACCIDENTS IN CONNECTICUT

Case Study of the Use of GIS to Inventory and Understand the Pattern of Traffic Accidents in Connecticut

9.3.1 Contributor: Ellen Cromley, University of Connecticut

Ellen Cromley is a medical geographer who studies geographical patterns of health and disease and the location and use of health services. Mapping has long been an important part of medical geography, and most mapping activity now uses GIS. Dr. Cromley has been involved in several public health GIS projects, including working with the Connecticut Department of Environmental Protection to develop a GIS for the Water Supplies Section of the Health Department, the unit that regulates public drinking water in the state; developing a GIS for statewide surveillance of Lyme disease and identification of risk areas; using GIS with a community planning group to evaluate health services to prevent HIV/AIDS; and compiling GIS databases for environmental health assessments. Graduate students in the Department of Geography at the University of Connecticut have examined exposure to electromagnetic fields from power transmission lines, accessibility to mammography services in the state, and Emergency services (911) coverage areas. Contributors to the Connecticut CODES GIS include Mary Kapp, Connecticut CODES Project Director; Brian Pope, Graduate Assistant, the Accident Records Section of the Connecticut Department of Transportation (ConnDOT); and the Connecticut Health Research and Education Foundation (CHREF).

9.3.2 Background

CODES stands for *Crash Outcome Data Evaluation System* and Connecticut is one of 20 U.S. states participating. CODES evolved from a national need to report on the benefits of regulations requiring automotive protection systems like seat belts and bicycle helmets. States are funded by the National Highway Traffic Safety Administration (NHTSA) to link motor vehicle crash data with medical outcome data to develop a better picture of the problem of motor vehicle injury and the effectiveness of protection systems. The linked database is the primary product of a CODES project, and a public-use version of the database is also required by NHTSA. In addition, CODES projects are allowed to develop state-specific products. The Connecticut CODES GIS is an example.

The Connecticut CODES Project links statewide automotive crash data from police accident reports for 1995 and 1996 (the two most recent complete years at the time the project began) coded by the Accident Records Section of ConnDOT to trauma registry, emergency department, and inpatient records maintained for the project by CHREF (an arm of the Connecticut Hospital Association), and mortality records maintained by the Vital Records Section of the state health department. The data include all collisions reported to police that occurred on Connecticut's state or federal roads in 1995 and 1996 and all collisions that occurred on local roads if the police report indicated a fatality or injury. There is one database for each year of collision data. The number of crashes is alarming: 72,672 involving 190,143 people in 1995 and 78,407 involving 202,792 people in 1996. This resulted in a linked accident-hospital database with 28,913 records for 1995 and 37,124 for 1996. All have spatial location of the accident as part of the record.

9.3.3 The Connecticut CODES GIS

The purpose of the Connecticut CODES GIS is to create a viewing environment for the linked motor vehicle crash records so that users can find collisions of interest and obtain data on their attributes and locations. CODES users can easily display, query, and map data. These capabilities are especially important for the public-use version of the databases, with which the GIS works. The CT CODES GIS is a combination of Microsoft Access databases and an ESRI ArcView application modified with Avenue scripts to create a GIS specifically for the project. Users can search the CODES databases by *WHAT* and by *WHERE*. In Access, users can perform detailed queries to identify *what* collisions are of interest, report them, and add them as a user-defined collision data layer in the GIS to see *where* the collisions occurred. In the GIS, users can find *where* a place of interest is, and then identify and report collision attributes to find out *what* kinds of collisions occurred in that place.

The Access databases contain related tables of collision attributes, traffic unit attributes (a traffic unit is a pedestrian or a combination of a vehicle and an operator), and involved person attributes including individual data on operators, pedestrians, and passengers. Every collision is assigned a unique identifier. Specially designed Access queries and reports allow users to find collisions of interest and either print reports or export a table of collision identifiers for the user-defined collisions to the GIS. DBase tables of collision, traffic unit, involved person, and user-defined collision attributes are exported from Access. They are automatically linked to ArcView point shape files of collision locations when the GIS user selects a database to view in the application (Figure 9.6).

Users open the GIS application by clicking a shortcut icon on the computer desktop. The application automatically adds data layers to the application and applies legends (Table 9.1). These data layers create the context for viewing the collision data. Users of CT CODES GIS can pan and zoom to locations of interest in a number of ways. They can enter a CODES_Id and the view zooms to display the collision location in the center of view at a scale of 1 : 24,000. Users can select from a tool menu of common map scales, click a point on the screen, and zoom to display the location where the user clicked in the center of the view at the selected scale. Users can select a type of place from the *PanTo* menu, scroll through the list of names for that type in the annotation

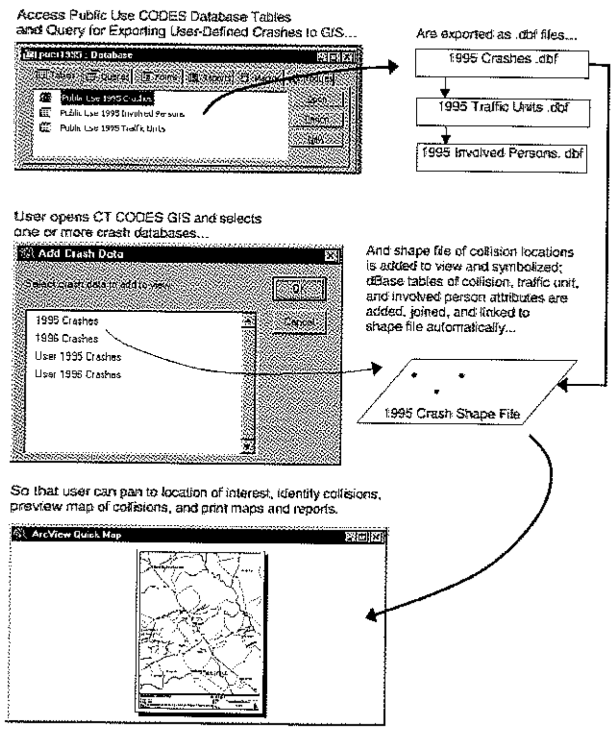


FIGURE 9.6: Process flow for queries in the Connecticut CODES GIS. (Courtesy of Ellen Cromley.)

TABLE 9.1: Data layers in CT CODES GIS

Data Layer and Source	User Action	Range of Map	Scale
Town names Connecticut DEP	Added when application is opened	1 to 125 000	400 000
Town index Connecticut DEP	Added when application is opened but not visible	1 to 125 000	400 000
Quadrangle index Connecticut DEP	Added when application is opened but not visible	1 to 125 000	400 000
Boundaries Connecticut DEP	Added when application is opened	1 to 6 000 35	0000
Roads ConnDOT	Added when application is opened		1 to 6 000 125 000
Annotation	Added when application is opened; user can turn off and on as needed		1 to 6 000

data layer, and zoom to display the location of the annotation the user selected. Finally, users can load the address-ranged street network database for a town of interest and enter an address or street intersection to zoom to that location.

Once locations of interest are in the view, users can graphically select collisions and open joined and linked tables of the collision, traffic unit, and involved person attributes from which selected records can be printed as reports or exported to files. The Map and Report menu makes it easy to preview and print color maps and reports of collisions in the view. Users can enter titles for maps and reports, but other elements of the layout like scale, north arrow, legend, and date printed are handled by the GIS application (Figure 9.7). These functions support data distribution and analysis.

9.3.4 Making Connecticut CODES GIS Accessible

The CT CODES GIS resides on a dedicated PC in the Department of Health in Hartford, Connecticut (CT). Health department staff use the system for their own analyses and they can extract data, maps, and reports based on requests. Individuals can also make appointments to use the system at the department. Public Use Access and CT CODES GIS User Guides are also available. At the conclusion of the first phase of the project, free hands-on training sessions were held in a GIS teaching laboratory at the University of Connecticut's Hartford regional campus. Participants included local health directors, EMS personnel, DOT staff, public-safety professionals, and public health researchers from around the state. The CT CODES GIS has been used to provide data for specific towns and regions, for local child safety seat campaigns, for evaluation of traffic calming devices by DOT, for studies of elderly drivers in one Connecticut county, and for research on fatal motor vehicle collisions in the state. Data for 1997 are now being added to the system. Attribute tables and shape files of collision locations for each of the 3 years of data available to date will be distributed for the entire state and for individual towns

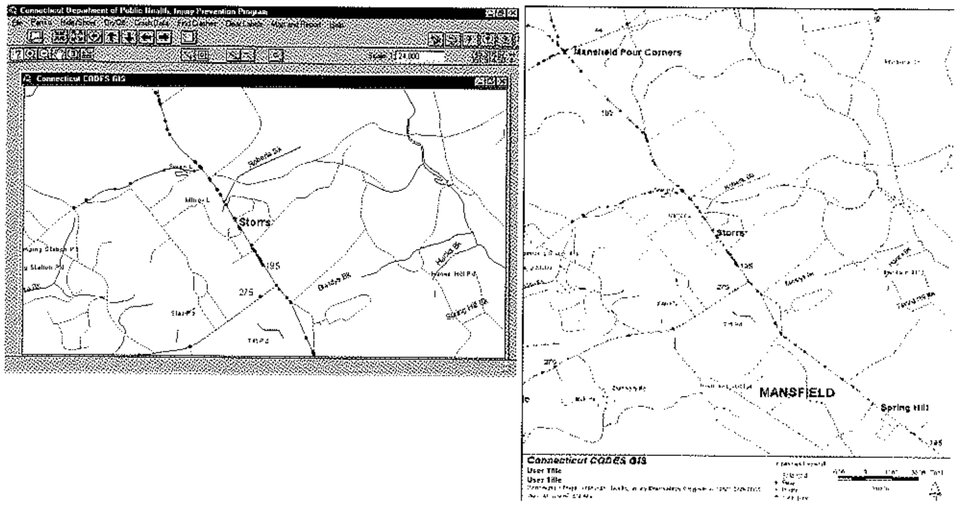
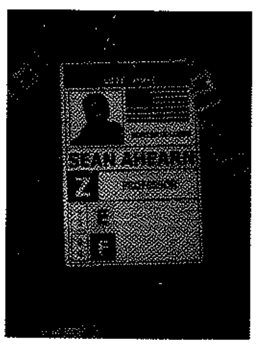


FIGURE 9.7: Map displays created by the Connecticut CODES GIS. Left: Screen query. Right: Automatically generated printed map. (Courtesy of Ellen Cromley.)

through the MAGIC (Map and Geographic Information Center, of the University of Connecticut libraries), which distributes digital geospatial data for the state through its Web site at `http://magic.lib.uconn.edu`.

9.4 CASE STUDY 3: GIS AT THE WORLD TRADE CENTER AFTER SEPTEMBER 11, 2001

How GIS Helped in the Rescue and Clean-Up Operations after the World's Worst Terrorist Attack



9.4.1 Contributor: Sean C. Ahearn, Hunter College–CUNY

September 11, 2001 saw the greatest peacetime tragedy of the recent era, the combined suicidal attack on the twin towers of New York City's world trade center (WTC) and the Pentagon by four hijacked planes. At Hunter College's CARSI (Center for the Analysis and Research of Spatial Information) laboratory, GIS was put to immediate and effective use in dealing with the aftermath. Fortunately, Geography Professor Sean Ahearn was ready and able to assist, having worked on the NYCMap, New York City's comprehensive GIS. The CARSI played a critical role, partly because the permanent New York City Emergency Operations Center had been located in the WTC complex, and was destroyed. This case study is dedicated to all of those who helped, but also to those who died, and especially to Geographer Robert LeBlanc of the University of New Hampshire who was on United Flight 175 on the way to a Geography conference in Santa Barbara when it was crashed into the WTC's south tower.

9.4.2 Getting the Call

The call came at 4 P.M. on September 11, 2001. It was from Alan Leidner, head of New York City GIS, "Get your staff together and start creating maps, your lab is the only operational GIS Center in town, everything else is destroyed or inaccessible, I'll be there within the hour." Everyone who didn't live in Manhattan had gone home except me. I called up the only two people on my staff from Manhattan, Ji Ding and Jeffery Bliss and they rushed over to the CARSI Lab at Hunter College. Leidner showed up soon after.

Maps of ground zero were needed for command and control of the operation. Rescue workers from around the country would be pouring in and they would all need detailed site maps. Fortunately New York City had recently created a "base-map" called NYCMap, consisting of 30 cm resolution orthophotography and planimetric map data with an absolute spatial accuracy of half a meter. NYCMap has over two dozen geographic map features including building outlines, curb lines, street centerlines, parks, subway stations, rails, towers, and so on. Over the next four hours, the Hunter College team worked to create a baseline set of maps using just the planimetric data (Figure 9.8), and maps showing the orthophotographs with planimetric overlays (Figure 9.9).

At about 10:30 P.M. on September 11, Leidner and Bliss headed downtown to the Emergency Operations Center (EOC) on 21st Street with armfuls of maps of the WTC site. The city virtually empty, the next morning at 7:00 A.M. the Hunter team piled three computers loaded with the NYCMap database into the back of a police car and sped down to the EOC. The data on these machines was to form the kernel of what would become a

FIGURE 9.8: Plot of the planimetric data from the NYCMap GIS. Figures in this section by Sean Ahearn. (Used with permission.)

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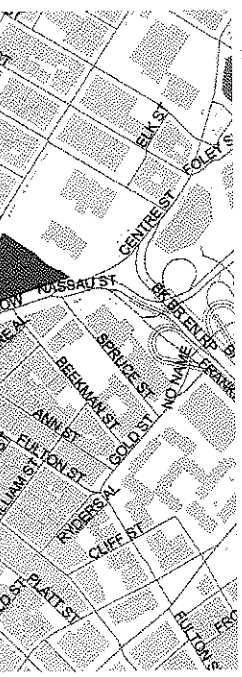

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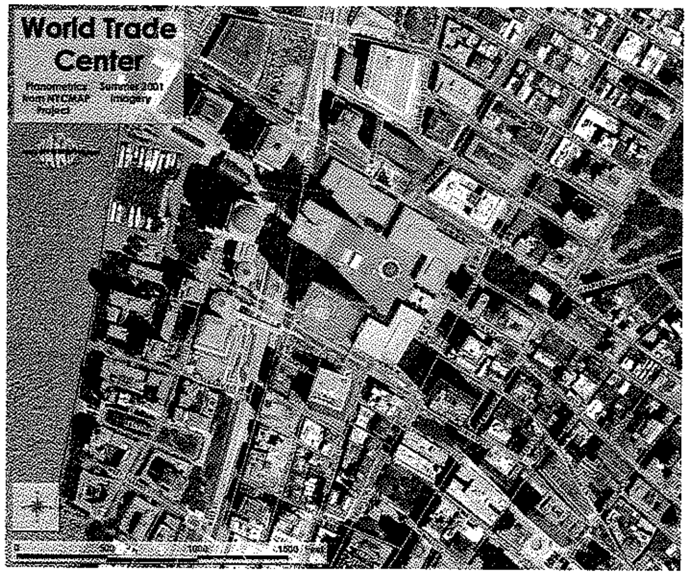

FIGURE 9.9: Orthorectified photography overlain with vector data from the NYCMap. WTC area prior to 9/11/02.

twenty-four hour a day, seven days a week operation involving over fifty GIS professionals and lasting for over two months. The full range of mapping science technologies would be deployed: GIS, GPS, and remote sensing. Cartographic representation of data would prove to be critical in an environment in which the consumers of maps (such as firefighters and rescue workers) had never seen the likes of the data that we would be providing, including thermal imagery and Light Detection and Ranging (LIDAR).

9.4.3 Damage Assessment

Damage assessment and infrastructure status were the first tasks. Bruce Oswald from the New York State Office of Technology called the EOC on the morning of September 13 to discuss possible remote sensing instruments to be deployed. Since my background was in remote sensing I took the call. We decided on orthophotography with an accuracy of plus or minus 70 cm, a thermal sensing instrument and Bruce suggested LIDAR. We ended up by going with all three. Earth Data Holdings out of Maryland would fly the plane, man the instruments, and pass on the data to the CARSI Lab at Hunter College and the GIS team at the EOC. Earth Data would create an all-digital system with a turnaround time of less than 12 hours.

The first orthophotographs were shocking. Even the rescue workers who saw them were startled. This was the first synoptic view of the entire site and it was horrific (Figure 9.10), showing 16 acres of total destruction. The smoke from the fires still obscured a portion of the site confirming the need for the LIDAR system. LIDAR is an "active" remote sensing device, one that relies on its own energy for creating an image, in this case a laser with a wavelength of 0.9 micrometers. I was familiar with the technology because one of my classmates while I was a graduate student at the University of Wisconsin-Madison, Gordon McClean, did some of the early research on

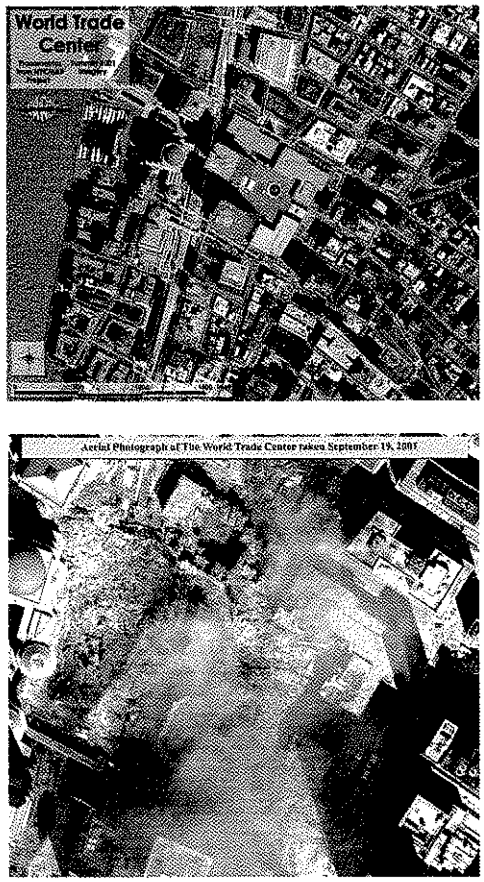

FIGURE 9.10: Orthorectified photography from September 19th.

LIDAR. The systems had come a long way in 20 years and the new ones could fire over 10,000 pulses per second. More importantly their spatial accuracy was about 9 cm vertical and 30 cm horizontal. These incredible accuracies are made possible with the help of an on-board GPS that provides three-dimensional locational coordinates and an inertial navigation unit which provides angular orientation of the platform. The LIDAR system measures the time each pulse takes to hit an object on the ground and return to the sensor. By knowing the speed of light the travel time can be converted to a distance. Because we know the location of the sensor, the orientation of the platform and the scan angle of the sensor, we can derive a precise location of the object reflecting the LIDAR pulse. The result is a blanket of points of the "terrain" with precise X, Y, and Z coordinates (Figure 9.11). These points can be converted to a Triangulated Irregular Network (TIN) by fitting each set of three points with a triangular facet (Figure 9.12). The TIN is essentially a "wire frame" similar to those created in movie animations. It can be viewed in 3-D by adjusting the viewing azimuth and angle, and the sun azimuth and angle (Figure 9.13).

The first LIDAR image was captured on September 19, 2001. This was the first clear image of the site because LIDAR penetrates clouds and smoke (Figure 9.14).

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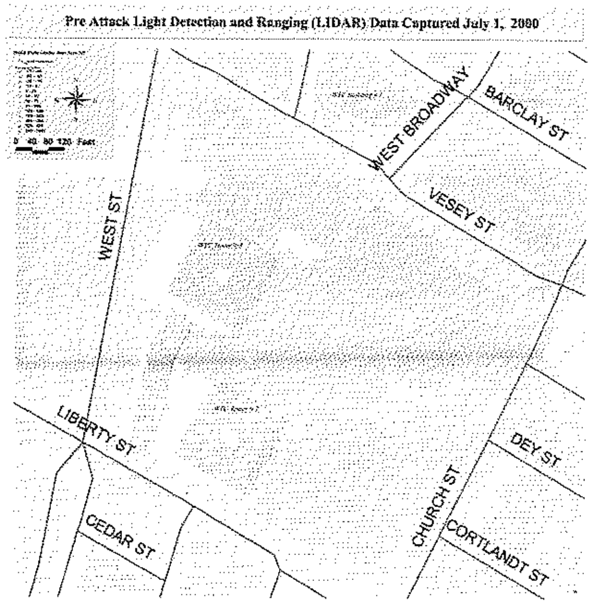

FIGURE 9.11: Point-based LIDAR height data collected before the attack.

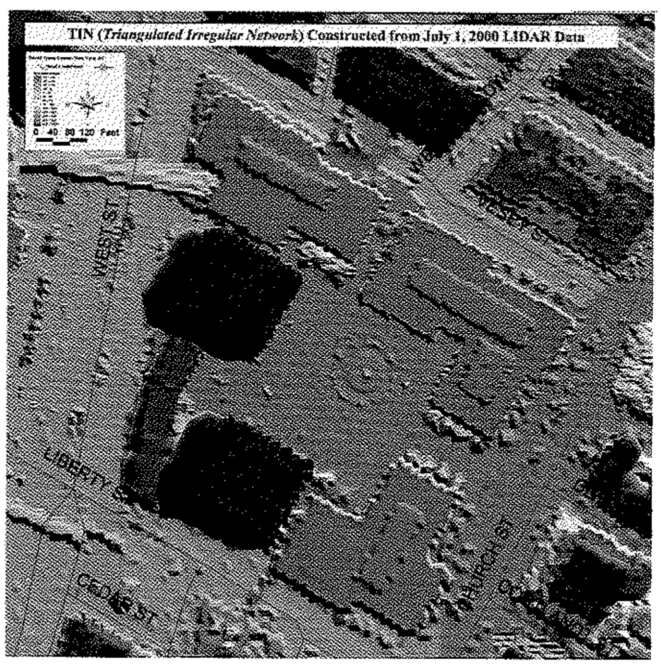

FIGURE 9.12: Elevation data from a TIN derived from the LIDAR data in Figure 9.11.

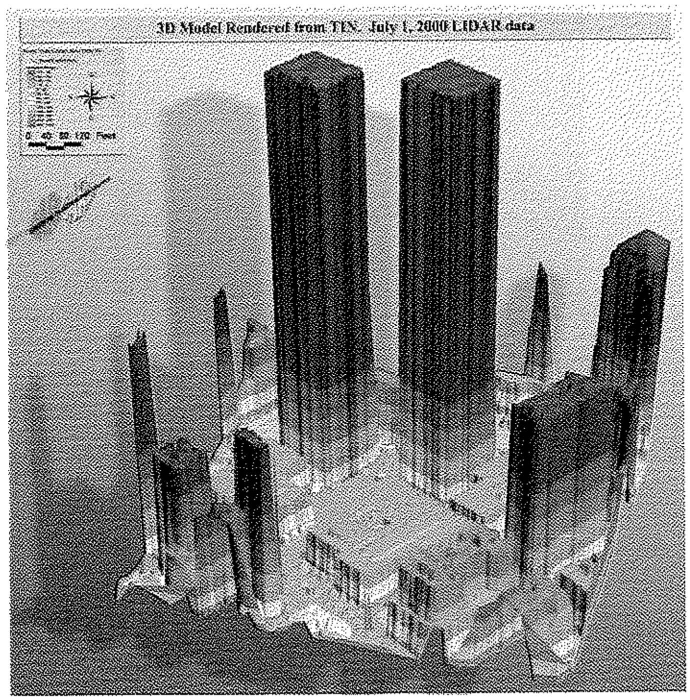

FIGURE 9.13: Three dimensional GIS-based rendering of the LIDAR elevation data.

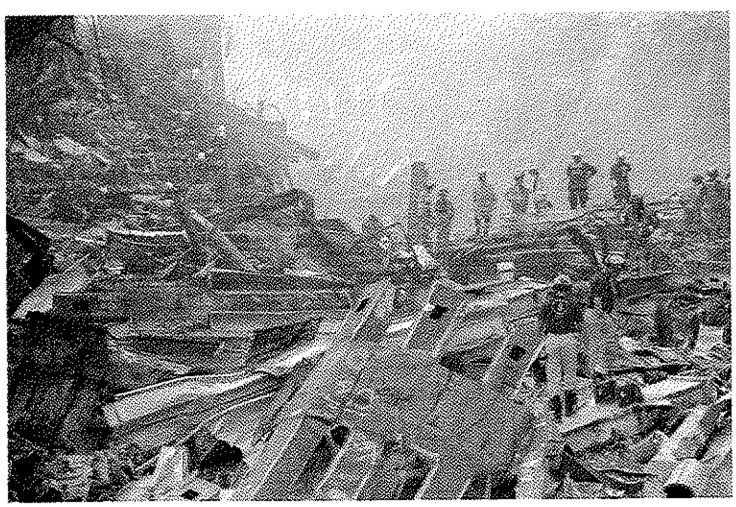

FIGURE 9.14: LIDAR was able to penetrate the pervasive smoke that hindered imaging.

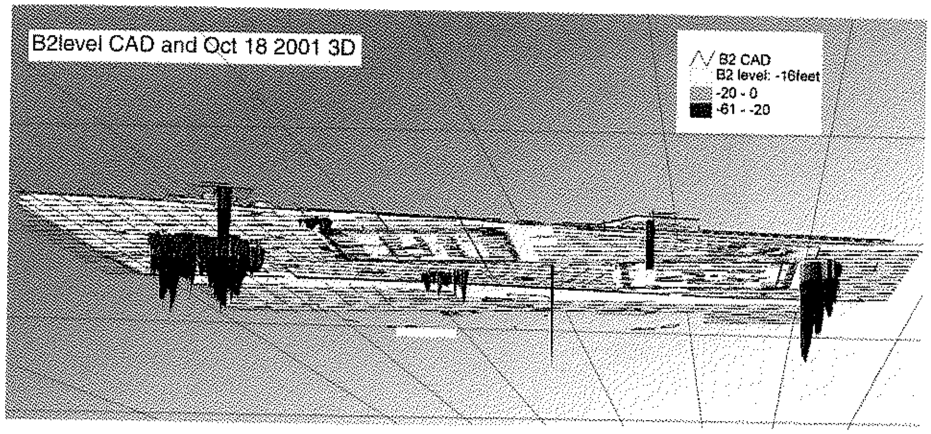

FIGURE 9.15: LIDAR elevations overlain with CAD-based building and room layout levels at the second level of basement, showing debris penetration.

The team at the CARSI Lab at Hunter College struggled to get the right cartographic representation for communicating the maximum amount of information while insuring that the image was interpretable by nongeographers. I still remember rolling out that first 50-by-60-inch LIDAR image of ground zero in front of a half dozen firemen and waiting for their response. After about two minutes of silence it "clicked" and they simultaneously began relating the image to their ground experience "oh my guys were working on that pile yesterday," "that's what's on the other side of that pile," and so on. The LIDAR proved to be a very valuable tool not only for damage assessment but also for getting a better understanding of the site. One of the real unknowns was the damage done to the underground infrastructure. By geometrically rectifying the CAD drawings to the NYCMap building outlines and incorporating the LIDAR TIN models the amount of surface penetration into the subsurface could be analyzed (Figure 9.15).

The thermal systems deployed were probably the weakest link in the remote sensing suite. The problem was that they were thermal videography systems that provided information on relative not absolute temperatures (Figure 9.16). It was good for seeing where the hotspots were but not good for knowing how hot something was. After three weeks a thermal system with on-board black body calibration was located and flown from a helicopter with GPS and inertial navigation systems after another week of bureaucratic approvals. Because it was a federal asset, owned by the Department of Energy, the request went from the City of New York to the State Office of Emergency to the Federal Emergency Management Agency, which made the request to the Department of Energy! By the time we got the data, it was too late as the fires had subsided and the threat to the underground Freon tanks had passed.

9.4.4 Infrastructure Status and the Role of Geographic Information

While the remote sensing efforts were underway the Emergency Mapping and Data Center (EMDC) under the leadership of Alan Leidner (Figure 9.17), had been set up on Pier 92 in the Hudson River, the new home of the Emergency Operations Center.

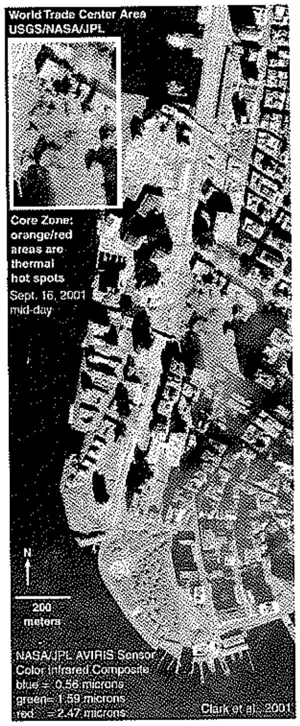

FIGURE 9.16: Thermal remote sensing data collected at the WTC on September 16th. Source: Roger Clark, USGS Open File report 01-0429.

Every part of the infrastructure was damaged and the GIS professionals at the pier, who consisted of a mix of Government, Industry, and Academia, were busy gathering information and creating maps of infrastructure status. These included utilities (such as gas, water, electric, telecommunications), building, transportation, and storage tanks (Figure 9.18). These maps were updated daily, posted on the Internet, passed on to city officials, and released to the news media. There were also a host of special use maps for a variety of local, state, and federal agencies.

One of the biggest problems was managing the building status database. While NYCMap had all of the building outlines delineated, these geographic features had yet to be tied to the attribute databases that described them. Additionally, the identifier used for the inspection of buildings was a street address, which was not unique! A building can span a whole block and can have one or more address for each block face. Fortunately through the foresight of Richard Steinberg of the Department of City Planning, buildings were assigned a unique Building Identification Number (BIN). In response to this need a project team was set up at the Pier to assign each of the building features of NYCMap for the area below Canal Street with a BIN.

The next problem was going from the paper inspection data to a map of building status. This process was fraught with all kinds of problems from a lack of consistency of the data collected, to data integrity, to the timeliness of the process. A team from IBM and Linkspoint Inc. stepped in and created a wireless hand-held inspection application.

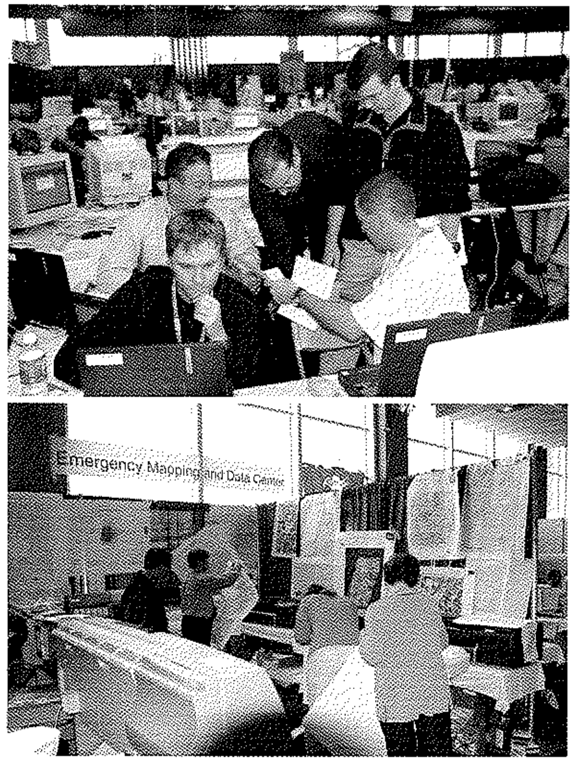

FIGURE 9.17: The Emergency Mapping and Data Center established at Pier 92 on the Hudson River.

The application enabled inspectors to access NYCMap wirelessly from a handheld iPAQ, click on a building to see the previous inspection (and make sure they were in the right place), fill out a new inspection, and then send it to the database. The Chief Inspector in the office could monitor which buildings were inspected that morning (or in the last minute) and create a map of building status at the stroke of the mouse. A process that up until then had taken three days and was fraught with problems had been reduced to a matter of minutes!

9.4.5 GPS Field Application

Firefighters' boots were literally melting as they stood scribbling down information on equipment and body parts recovered at ground zero and doing their best to estimate where they were on the 16-acre pile. A better methodology was needed to increase data integrity, obtain a more accurate location for the objects found, and reduce the time of collecting data in the severe environment confronted by the firemen. The solution was a ruggedized handheld computer with a barcode scanner, a Linkspoint GPS hardware attachment, and software. Extensive testing and the use of a specialized GPS antenna for the Linkspoint system in the second week after September 11 helped reduce the problems of multipathing due to the many pieces of metal on the site (Figure 9.19). The new process was as follows: The firemen would place the item in the bag, attach a barcode

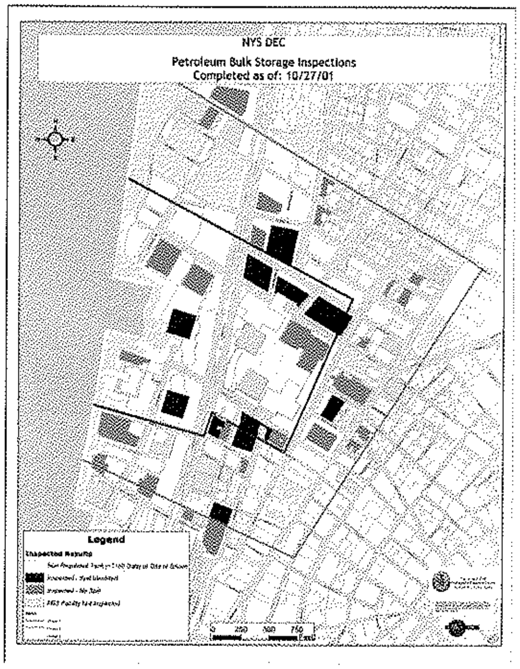

FIGURE 9.18: Infrastructure map products generated at the Emergency Mapping and Data Center for the New York City Department of Environmental Conservation. Locations and inspection conditions of gasoline storage tanks are shown.

to it, scan the barcode, select an item from a drop-down menu list, and the time and location was automatically captured. The technology reduced the whole process down to less than a minute, improved data accuracy and usability, and decreased firefighter exposure to the hazardous conditions they faced. The data would be mapped and used for victim identification and would provide information to loved ones on the location of victims bodies (Figure 9.20).

9.4.6 Lessons Learned

- New York City's GIS infrastructure played a critical role in the response to the WTC crisis.
- The federal government needs to provide options for available technologies (e.g., remote sensing).
- There were some severe data gaps:
  - The Census Bureau lists 1369 people as resident in the census tract containing the World Trade Center, but there was no daytime count of individuals who lived there.
  - Unique identifiers are essential for infrastructure management (such as the building IDs) but had to be added at the worst possible time.

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FIGURE 9.19: Hand-held GPS data collection suffered from multipath signal deflections from the considerable amount of metal.

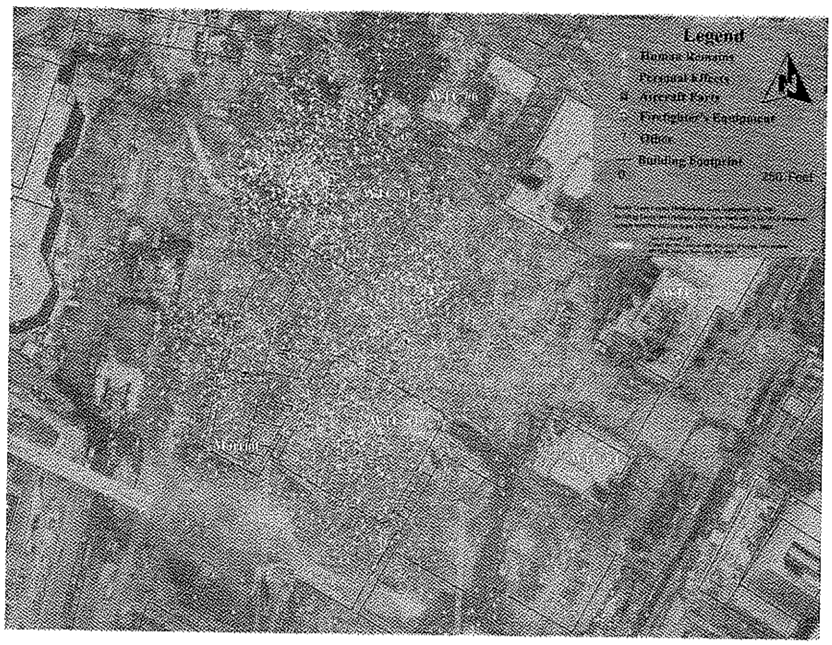

FIGURE 9.20: Map showing data collected from the mobile GPS and palmtop computer.

- Cities should make an effort to integrate their Geographic Information Systems into the rest of their management information system environments (i.e., connect spatial data to its attributes!).
- Cartographic standards for map production need to be established.
- Scenario development and exploration to anticipate data needs and modeling requirements should be planned in advance.
- Multiple levels of government involvement in scenario development are necessary to ensure cooperation in emergencies.
- Mobile access to GIS data is critical for "real-time" assessment and mapping of infrastructure
- Version management of data is a necessary tool for multiuser environments.

9.5 CASE STUDY 4: RESOURCE MANAGEMENT FOR CALIFORNIA'S COASTAL ISLANDS: THE CHANNEL ISLANDS GIS

Case Study Featuring a Collaborative GIS Helps in the Management of a Sensitive Coastline in the Santa Barbara Channel of California

9.5.1 Contributor: Leal A. K. Mertes, University of California, Santa Barbara

Dr. Leal Mertes investigates the processes responsible for creating wetlands and floodplains in large river systems and uses GIS and remote sensing in their analysis. The Channel Islands GIS (CIGIS) was created by undergraduate students, programmers with expertise in laboratory development for undergraduate courses, and GIS experts. The CIGIS is continuously being updated and used in teaching about the natural changes and ecosystems of the Channel Islands. Currently, new visualization interfaces are being created to enhance use of the database by managers and to provide educational materials to the general public. Contributors to the CIGIS include Ben Waltenberger, Ethan Inlander, Ceretha McKenzie, Amy L. Bortman, Melodee Hickman, John Dvorsky, and Olivia AuYeung.

9.5.2 Background

Viewing the coastal system of California as an ecosystem that includes both marine and terrestrial inputs and outputs allows managers to take account of the composition, structure, and function of the entire range of processes influencing the area's environmental health. Environmental management in the rapidly growing coastal areas of Southern California is controlled by a unique set of political and scientific challenges that can partially be met through a combination of field data collection, spatial modeling, and information technologies. In particular, digital databases, remote sensing data, and spatial analysis tools embedded in a GIS allow analysis of relations among the environmental variables. In addition to scientific challenges, coastal regions

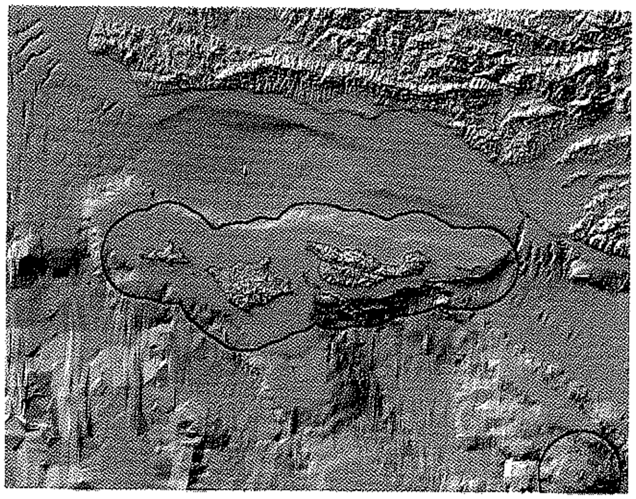

FIGURE 9.21: Topographic/bathymetric map of the area covered by the Channel Islands GIS. Area stretches from Point Conception to Ventura, California, west of Los Angeles. Image courtesy of Leal Mertes. (Used with permission.)

involve management by multiple agencies with distinct disciplinary and jurisdictional interests.

To meet the political and scientific challenges for management of the coastal region of central California, which includes the Channel Islands, the CIGIS was developed as a cooperative project among the University of California at Santa Barbara, the NOAA Channel Islands National Marine Sanctuary, the Channel Islands National Park, the Santa Cruz Island Reserve, the University of California Natural Reserve System, and the State of California Fish and Game Office of Oil Spill Prevention and Response. The area surrounded by buffers and covered by the database is shown by the topographic and bathymetric map (Figure 9.21).

9.5.3 CIGIS Users

As a resource management tool, the CIGIS provides information on flora and fauna (for example, kelp, sea grass, harbor seals, seabird colonies, shellfish), location of sensitive archeological sites, location and dimensions of sea caves, shipping lanes, oil platforms, bathymetry, geology, vegetation cover, soils, and topography. In response to the multiple roles it serves, CIGIS is customized to meet the needs of individual users. The master database is in Arc/Info and ArcView (Unix and PC version), while users receive versions with data relevant to the mission of the agency. For example, ArcView versions now reside at a field station and on a boat. Experience with multiple users shows that by promoting cooperation among agencies it is possible to create a database substantially more useful to the group as a whole than to have only emphasized the disciplinary or jurisdictional needs of an individual group. In addition, through pooling of resources, each agency has benefited from access to the entire database rather than only data explicitly related to their management mandate.

9.5.4 Using the GIS for Analysis

Success has been measured not by the size of the database, but rather by the new insight gained through spatial analysis of the environmental layers. Through analysis of a time series of Landsat remote sensing data (Figure 9.22) from 1972 to the present, Dr. Mertes and her collaborators have analyzed the characteristic patterns at the surface of the coastal waters of the Santa Barbara Channel.

More recently, shipboard measurements have been combined with water properties derived from advanced very high resolution radiometer (AVHRR) satellite data at a 1-km spatial resolution (Figure 9.22) During the El Niño storms of 1998, plumes were seen in these same positions from an airplane (Figure 9.23). In these images, the water color pattern in the ocean is dominated by the river plumes in the nearshore region that were generated by the Santa Ynez, Ventura, and Santa Clara Rivers. The surface pattern of the largest plume, which is the combined plume of the Ventura and Santa Clara Rivers is approximately 10 km long crossing the Santa Barbara Channel and is dispersed in different directions according to the season.

Digital terrain analysis of the watersheds of these three rivers shows that these rivers are the steepest and the largest of the rivers with input into these coastal waters and that the size of the river plume is correlated to storm size. To investigate the watershed characteristics associated with the smaller watersheds in the region, the surface expression of the plumes are under investigation. In addition, by analyzing properties of the watersheds using the cell-based modeling tools of the GIS, it is possible to compare features across the region in terms of watershed structure and the distribution of landcover types in different parts of the watershed. Watershed analysis was combined with analysis of the coastal geography (bathymetry and position of river mouths) to evaluate the potential impact of smaller rivers on the coastal waters (Figure 9.24).

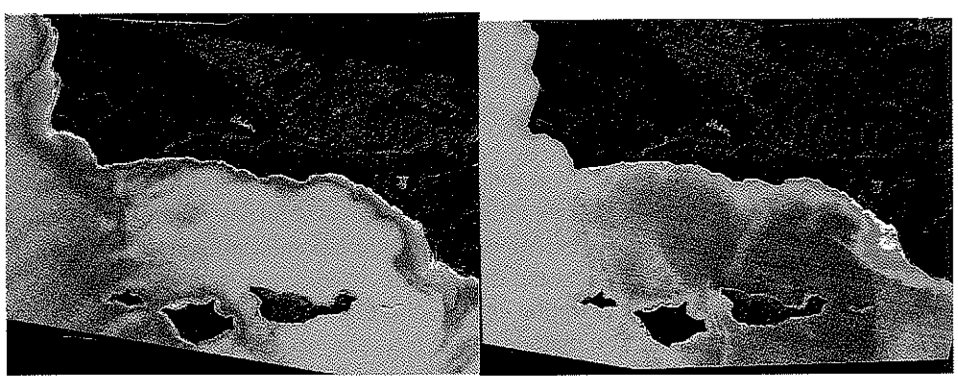

FIGURE 9.22: Sediment concentration from remote sensing of the Santa Barbara Channel. Ocean brightness indicates particulate concentrations, with brighter being higher. Left: Landsat 4 MSS image recorded 2/19/1983 after 28 cm of rain in the preceding month. Right: Landsat 5 TM image recorded 2/9/1994 after 10.5 cm of rain in the preceding month. Images courtesy of Leal Mertes. (Used with permission.)

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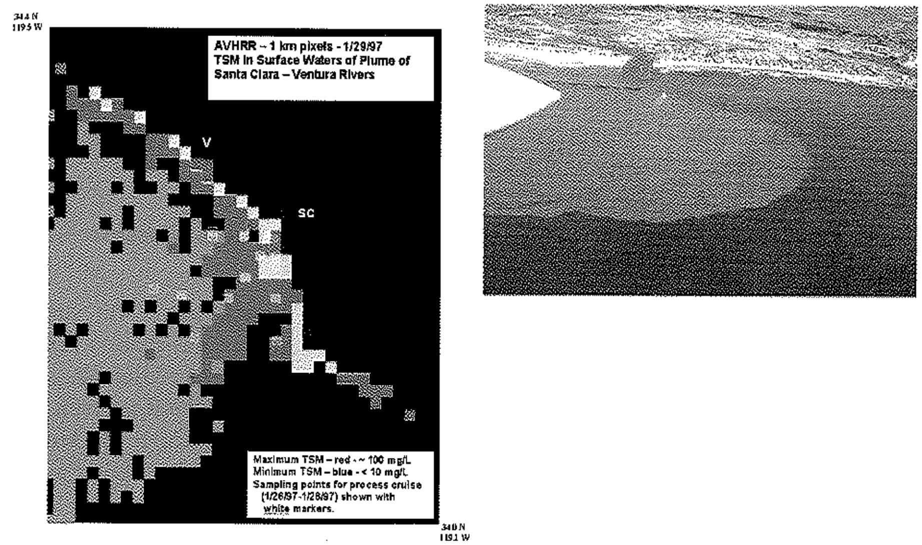

FIGURE 9.23: Left: AVHRR satellite image of the coastal region near the estuaries of the Ventura and Santa Clara Rivers during a typical storm event in 1997. Right: Oblique aerial photo taken of the Santa Clara River plume 2/10/1998, after El Niño-generated storms had resulted in 27 cm of precipitation in the preceding week. Images courtesy of Leal Mertes. (Used with permission.)

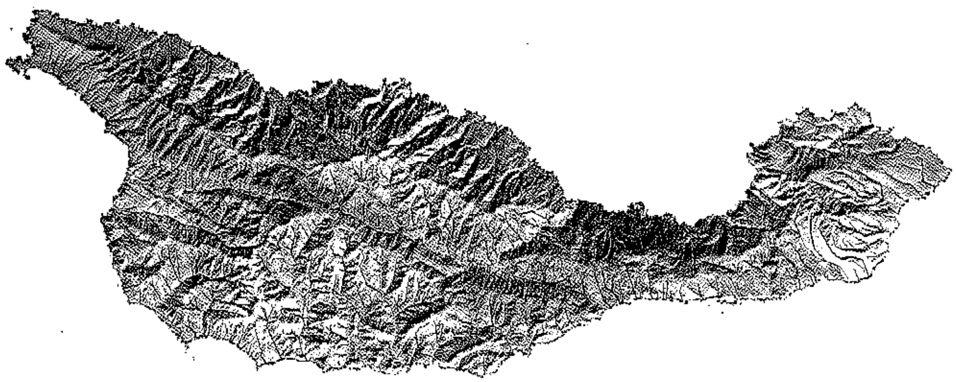

FIGURE 9.24: Streams on Santa Cruz Island, layer created using the DEM drainage functions in ArcInfo.

Conclusions from this research are that the greatest terrestrial influence on the Santa Barbara coastal waters is plumes, generated from the largest watersheds during and following significant (more than 3 cm of precipitation) winter storms. A second-order effect on the development of coastal plumes is the position of the watershed outlet with respect to the nearshore bathymetry and currents. Juxtaposition of smaller watersheds to shallow coastal waters may result in the appearance of anomalously large surface plumes.

9.6 CASE STUDY 5: USING GIS AND GPS TO MAP THE SLIDING ROCKS OF RACETRACK PLAYA

Case Study in the Use of Nonimpact GPS/GIS Research Methods to Map, Monitor, and Analyze the Activity of "Wandering Stones" in a Death Valley Wilderness Area

9.6.1 Contributor: Paula Messina, San José State University

Dr. Paula Messina investigates earth surface processes including the formation of desiccation features in desert regions, deflation of lacustrine sediments, and the unusual sliding rock phenomenon of the Racetrack Basin in Death Valley National Park. A graduate of Hunter College's Geology Program, she began her career as a high school Earth Science teacher in New York City. During a visit to Death Valley on a school break in 1993, she discovered the isolated Racetrack as a casual, but determined tourist. Upon observing the rocks—up to boulder in size—resting next to their enigmatic trails inscribed in the playa sediments, she was immediately captivated. She found herself returning repeatedly to try to understand how rocks could move along an almost perfectly flat dry lakebed, and realized the need for extensive spatial analysis of the area. As a graduate student of Keith Clarke, she pursued doctoral study that incorporated the use of Differential GPS, GIS, and terrain analysis techniques to explain the rocks' motions. She now teaches Geomorphology and GIS at San José State University, serves as a research associate for NASA Ames Research Center's Astrobiology Program, and still visits the Racetrack to monitor her rocks.

9.6.2 Background

The Racetrack Playa, at an elevation of 1131 meters, is a pluvial lake within the Panamint Range of Death Valley National Park, California. As the topographic low of the Racetrack Basin, rocks of various sizes tumble onto the dry lakebed from abutting cliffs and surrounding alluvial fans. Since the beginning of the twentieth century, prospectors, park rangers, and geologists have noted and described evidence of dynamic traction events that apparently occur once the rocks are deposited on the playa. Recessed furrows, up to two centimeters deep, suggest that rocks glide along the surface, a near-perfectly horizontal plane; in fact, rocks skid slightly *uphill* since most rocks are found on the ends of trails closer to the 5-centimeter-higher northern "shore." Trails are defined by lateral ridges, similar to scaled-down river levees, suggesting that the surface is saturated and pliant when the rocks move (Figure 9.25). Some trails exhibit evidence of splash marks, wakes, and bow waves, indicating that the rocks are propelled at speeds of about 2 meters per second, or even more. The longest trail, over 800 meters, is fairly straight, but others record extremely chaotic activity. The largest boulders are estimated to have masses up to 320 kilograms (Figure 9.26), and contrary to logic, their trails are by no means the shortest. To date, no one has witnessed the rocks in motion.

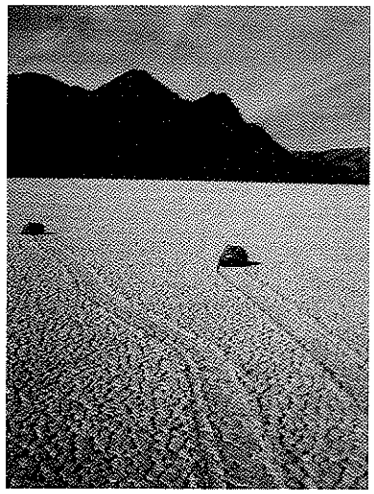

FIGURE 9.25: Two rocks, "Ellen" and "Bessie," apparently slid to the northwest, imprinting trails as evidence of their unusual activity. (Photograph by Paula Messina. Used with permission.)

FIGURE 9.26: Paula Messina stands next to "Karen," one of the largest boulders on the playa. The GPS antenna protrudes from Paula's backpack, where the receiver is carried during field mapping. (Photograph by Paula Messina. Used with permission.)

Scientific investigations of the phenomenon commenced in the 1950s, when several researchers visited the basin, described a few of the rocks, and mapped some of the trails. Survey chains, pacing, and compasses were their only tools. Maps of a few selected trails showed significant parallelism, suggesting that rocks may move while entrained in a cohesive wind-propelled ice sheet. Temperatures do indeed reach the freezing point on the Racetrack: The Playa has been blanketed with snow, and ice sheets up to 8 centimeters in thickness have been reported.

While some trails are parallel, most are not. Robert P. Sharp of Cal Tech tested the ice hypothesis in the1970s by constructing a "corral" composed of seven iron stakes encircling three rocks; he was surprised to see, upon a return visit, that although two rocks remained within the circular space, one rock had slid out beyond the stakes, leaving a trail as evidence of its route. Sharp, who assigned women's names to the rocks during his seven years of monitoring visits, concluded that ice is not a requirement for rocks to move, and that the wind alone, acting over a surface "lubricated" with wet clay, may provide enough force to set the rocks in motion.

If *some* trails are parallel, does that imply that ice moves only *some* rocks? Are there any trails preserved within the space *between* two highly parallel ones, and if so, are they congruent, too? Why were only *some* trails mapped, while others ignored? No doubt, part of the answer to this last question rests in Death Valley's isolation, extreme environmental conditions, and the time commitment required of traditional survey methods and the long journey to the Racetrack. The lack of complete trail network maps made it impossible to settle the "ice versus wind alone" argument. Research on the playa became more restricted with the passing of the 1994 Desert Protection Act, which designated the Racetrack as a wilderness area. After 1994, only noninvasive, nonpermanent instruments could be used for scientific investigations.

9.6.3 GPS and GIS to the Rescue

Having reached full operational capacity in April 1995, the global positioning system (GPS) provides surveyors with a new non-impact tool for constructing highly accurate maps in little time. Differential correction of GPS data can achieve centimeter-level accuracy for point and line features. The exact locations of all rocks and precise plans of all trails on the 667 hectare playa were captured by a field crew of two in July, 1996, requiring only ten days' time. Data were exported to ArcView GIS, and analyzed using a variety of spatial and statistical methods.

The resulting map (Figure 9.27) shows the point locations of every rock ($N = 162$) and polylines of trails. Measurements taken in the field indicated no correlation between the size, shape, or lithology of a rock and the length, or straightness of its resulting trail. Ice floes may explain parallel trails, or similar but divergent trails (should an ice sheet shatter while in motion), yet the complete trail network, as mapped in 1996, shows virtually no parallelism among trails, suggesting that ice may not play a role in this phenomenon. In fact, two highly convoluted trails (Figure 9.28) show a great degree of congruence while continually *converging*. It is impossible to describe these features using the ice floe model. And yet, while it seemed that the wind alone may be the mechanism responsible for this activity, the lack of obvious relations within the data set remained problematic. Why did some rocks move, independent of their weight or shape, while others remained motionless—in a single event?

9.6.4 Terrain Analysis

With no smoking gun there were still many questions left unanswered. The GIS did present some spatial patterns worth investigating. It seemed that straighter, longer trails were concentrated on the eastern margin of the playa, but those near the playa's center were sinuous or chaotic. Analysis of the surrounding terrain, using the USGS digital

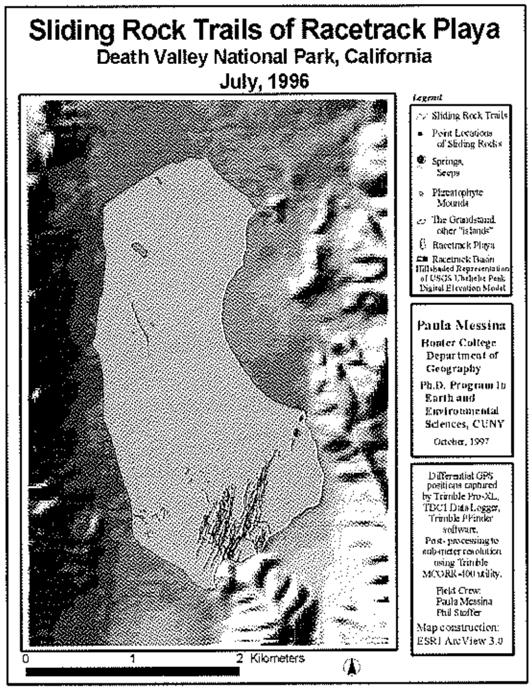

FIGURE 9.27: July 1996 map of the Racetrack's sliding rock network, as mapped by Trimble Pathfinder files, exported to ArcView. (Used with permission.)

elevation model (DEM), provided the clue that had remained hitherto elusive: The slope and aspect of the basin directs airflow along specific vectors (Figure 9.29). Direct measurements of the wind conducted with handheld anemometers revealed that wind speeds up to six times faster, and up to 50 degrees deviant in heading occurred synchronously at locations only 400 meters apart. Therefore, the nature of a trail has more to do with the location of the rock that inscribed it than to the physical characteristics of the rock itself. Follow-up visits to the Racetrack confirm these conclusions, since the rock that has slid farthest since the 1996 survey ("Diane") is the one that previously carved the longest trail (881 meters).

It was previously estimated by Sharp and Carey that rock sliding events occur with a frequency of every year or two. While this may have been the case in the 1970s, Messina's recent monitoring visits show a lower periodicity. For five years (1996–2001) most rocks remained in place. Sometime between February and May 2001, a storm propelled over 70 rocks to new locations, leaving fresh trails. The Racetrack may be thought of as a mosaic of microclimates, with different wind regimes in adjacent locations. A few days after a rain, when fine, saturated clays coat the surface, a "near-Teflon" state supports mobilization of Racetrack Playa's rocks by wind. *Where* they wander is a function of the conditions at their instantaneous locations (or perhaps of their whim!).

For more information and individual maps and photographs of the entire original data set, visit `http://geosun.sjsu.edu/paula/rtp`.

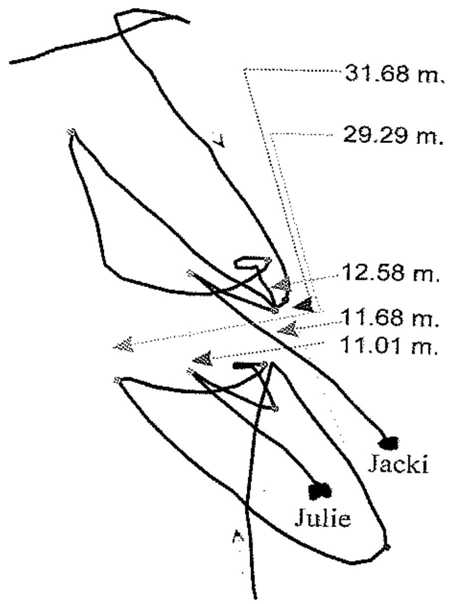

FIGURE 9.28: The trails of "Jacki" and "Julie" suggest a high degree of similar motion. However, although somewhat congruent, the rocks apparently converged during their calligraphic journeys. Trails such as these and the absence of ice-gouging features on the playa suggest that rocks are not driven lockstep within a sheet of ice. (Used with permission.)

FIGURE 9.29: USGS aerial photograph of Racetrack Basin draped over a TIN based on the 7.5-minute Ubehebe Peak Quad DEM. The terrain channels air—generating turbulence resulting in erratic rock movement, and this explains the presence of convoluted trails in the playa's central region.

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9.7 STUDY GUIDE

9.7.1 Summary

CHAPTER 9: GIS in Action

- **Use of GIS is best understood by examining case studies.**
- **Five case studies in this chapter cover desert, coastal, rural, suburban, and urban GIS applications.**

Case Study 1

- **In Michigan, GIS has been used by Michigan State University to monitor the spread of the gypsy moth.**
- **The gypsy moth has spread over the state from the north and east and defoliates trees.**
- **Information from the monitoring program, via a GIS in Arc/Info and IDRISI, is used to direct spraying trees with Bt.**
- **A statewide monitoring program uses milk carton traps in trees dispersed over a spatial grid.**
- **Data are aggregated annually in a central GIS; forms are entered and locations geocoded.**
- **Statewide gypsy moth infestations are interpolated using inverse distance squared weighting and are mapped.**
- **An overlay of tree species data is then used to map the trees at risk of defoliation and therefore to be sprayed.**
- **Results are used in resource management, policy development, and are posted for information on the WWW.**

Case Study 2

- **In Connecticut, a GIS has been developed to track automobile accidents.**
- **A key element in the GIS has been linking spatial data and maps showing locations of accidents with hospital information about injuries.**
- **A public access version of the GIS has been constructed for easy access to the information.**
- **Data include all collisions reported to police on state or federal roads in Connecticut in 1995 and 1996 and on local roads if the police report indicates a fatality or injury.**
- **GIS users can pan and zoom to locations of interest and select from a tool menu of common map scales.**
- **GIS users can select collisions and open tables to print reports or export these to database files.**
- **A Map and Report menu allow previewing and printing of color maps.**
- **ESRI's ArcView Avenue scripts allow users to enter titles for maps and reports, and to automate map layout.**
- **Training and workshops have produced system users, and the system is available to the public and community groups in the state capital.**
- **Additional data for more recent years are being added and analyses conducted.**

Case Study 3

- Hunter College's CARSI laboratory came to the aid of New York City after the 9/11/01 destruction of the World Trade Center.
- Fortunately, New York City had a recently completed GIS-based digital map, the NYCMap with over two dozen mapped feature themes.
- The distaster relief effort was supported by a GIS operation involving over 50 GIS professionals that operated around the clock for two months.
- Data from remote sensing proved useful, including orthophotography, thermal imagery, and LIDAR.
- LIDAR allowed a TIN to be generated that helped relief workers in navigating and removing debris in the rescue and recovery efforts.
- Emergency crews used plotted GIS maps and new data in their work.
- Maps of infrastructure and building status were especially important.
- Each building had to be assigned a Building ID number in the GIS.
- A GPS-based field computing system proved effective in the recovery work.
- A series of lessons were learned that should be read by other communities around the country.

Case Study 4

- At the University of California, Santa Barbara, a GIS has been developed to provide data for environmental analysis of the Channel Islands in Southern California's Santa Barbara Channel.
- The GIS was built by collaborative efforts from several agencies, and included database assembly by both undergraduate and graduate students.
- Data layers assembled included information on topography, bathymetry, flora and fauna, archeological sites, sea caves, shipping lanes, oil platforms, geology, vegetation cover, and soils.
- The GIS has a master database and smaller, specialized subsets in use in different places and using different ESRI GIS products.
- The system has met operational, educational, and modeling needs.
- Analyses have included work incorporating remote sensing of sediment plumes, terrain analysis, and watershed modeling.

Case Study 5

- Studies of the mysterious Sliding Rocks of Racetrack Playa in Death Valley have been conducted using GIS and field GPS.
- The rocks sit on a flat playa, and have irregularly shaped trails indicating that the rocks have moved or slid up to 800 meters at a time.
- Research on the rocks dates back to the 1950s, with a leading theory being related to ice flow.
- Since the 1994 Desert Protection Act, intervention with the rocks has been illegal.
- A total of 162 rocks were inventoried and mapped over a period of 10 days in 1996 using differential GPS.
- Some of the mystery of the rocks' movement seems to be related to topographic forcing of winds. GIS mapping has shown how this could occur.

- **Continued mapping has confirmed that the rock movement is wind driven and depends on the slick playa surface being wet from rain events.**

9.7.2 Study Questions

Case Study 1: Gypsy Moth

For this case study, make a flow diagram containing the following major boxes: data, data conversion, analysis, software, output. Work through the section, filling in the boxes with notes summarizing the project's stages.

What software packages were used in the study, and how well do the project's needs and characteristics suit the functional capabilities of the software?

Gypsy moths have been spreading slowly across the United States ever since a known accidental release of some moths over a century ago in Boston. The spatial process at work is called "spatial diffusion," the same process that occurs when smoke spreads in the air. What spatial analysis tools and quantitative measurements might suit the analysis of spatial diffusion?

Case Study 2: Traffic Accidents

For this case study, make a flow diagram containing the following major boxes: data, data conversion, analysis, software, output. Work through the section, filling in the boxes with notes summarizing the project's stages.

What software packages were used in the study, and how well does the project's needs and characteristics suit the functional capabilities of the software?

In this case study, an obviously important element is placing useful information into the hands of the public. What decisions might be made given the availability of the spatial information? What is added by having the linked hospital data? How can the GIS help in doing an analysis of the spatial patterns of accidents and injuries? Who might be the interested parties that could make productive use of the GIS?

How might this GIS application be said to be consistent with Chrisman's definition of GIS from Chapter 1?

Case Study 3: World Trade Center Aftermath and GIS

Which were the key layers in the WTC aftermath? Make a timeline of what data were used and when.

Call your local City Hall or County offices, or search their Web sites, and see if the NYCMap data equivalent exists for your own community. Is your city or community GIS-prepared for a major disaster?

Search the available literature about the 9/11 terrorist attacks at the World Trade Center, the Pentagon, and in Pennsylvania. How did the media cover the role that GIS played in the relief efforts?

Make a list of the barriers that might prevent the effective use of GIS in an emergency situation.

Write a short story about a "scenario" that could occur in your community. How might GIS help in planning and recovering from the situation? How might it prevent it from happening?

Case Study 4: Channel Islands GIS

This GIS contains a large suite of data layers with lnks to the environment. Make a list of the data layers. Which of them could be supplied from public-domain sources, and which would require additional data entry or acquisition of new data sets?

Several different user environments exist for the CIGIS, including the classroom and onboard research vessels at sea. Make a list of the user interface characteristics that would be best in each setting.

Make a flow diagram of the steps necessary for a GIS to translate digital topography, such as in a DEM, into the boundaries of watersheds.

Case Study 5: The Racetrack Playa and the Sliding Rocks

This GIS pivots on data collected in the field with GPS. Make a list of the data layers. Which of them could be supplied from public-domain sources, and which would require additional field data entry?

What might be some of the concerns if you had to conduct a GIS assembly operation entirely in the field? In Death Valley?

Suggest ways that the line information in the GIS about the rock trails might be described and summarized statistically.

How might DEM-based topography be used to prove that wind causes the rocks to move?

9.8 EXERCISES

1. *Use one of the sources of information in Chapter 1 to find out about a GIS application of interest to you. Find data on the application that may be publicly available on the Internet or elsewhere. Use the data input capabilities of your GIS to input the data used in the application. Make a concise listing of the problems you encounter, what data structure conversions are necessary, and a full listing of the suite of data formats that you had to deal with. If either the data or the software is not available, find a well-documented GIS applications project and try to surmise the information from the documentation and reports that accompany the study.*
2. *Choose a particularly simple applications study with a well-defined public-domain data set that uses your GIS software. Science dictates that experiments be repeatable. Try to repeat the application in exactly the same way as the original GIS expert. Are your results the same? If not, can you find where your results diverge from the reports or write-up that you are using as information?*
3. *If you are a student, ask your faculty or counselor about internships. Is a GIS company willing to give you a summer or part-time job (for college or school credit) for getting some real GIS hands-on experience? Find out about funding and awards to support internships. Remember, there is only so much that can be learned through books and manuals, even this one!*

9.9 REFERENCES

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9.10 KEY TERMS AND DEFINITIONS

AVHRR (advanced very high resolution radiometer): An instrument on NOAA orbiting polar satellites that returns 1- and 4-km resolution data about the earth in four wavelengths. Used extensively for large-area land-cover and vegetation mapping and weather prediction.

base layer or map: A GIS data layer of reference information, such as topography, road network, or streams, to which all other layers are referenced geometrically.

biology: The study of living organisms and their vital processes.

defoliation: The removal of the healthy leaves of a plant or tree.

ecology: The science concerned with the interrelationship between organisms and their environments.

empowerment: Placing power in the hands of the citizen by providing effective and timely information.

entomology: The branch of zoology that deals with insects.

epidemiology: The science that deals with the incidence, distribution, and control of disease in a population.

GRID: The raster module of ESRI's Arc/Info GIS software.

gypsy moth: A tussock moth introduced into the United States in Boston about 1869. The early stage is a gray-brown mottled hairy caterpillar that defoliates trees.

Landsat: A U.S. government satellite program collecting data about the earth's surface in the visible and infrared parts of the spectrum. Two instruments, the multispectral scanner (79-meter resolution) and the thematic mapper (30-meter resolution), have been used. Landsat 7 is the next to be launched, for which the data will return to the public domain.

layer: A set of digital map features collectively (points, lines, and areas) with a common theme in coregistration with other layers. A feature of GIS and most CAD packages.

municipality: An administrative division of geographic space, usually for the purposes of election or service delivery.

Murphy's law: "Anything that can go wrong will go wrong." Long linked to the public use of computers.

parcel: A land surface partition recognized by law for the purpose of ownership.

pheromone: A hormonal substance excreted by an individual that elicits a response in the same species.

raster: A data structure for maps based on grid cells.

resource management: The intentional control or influence of environmental elements to accomplish particular goals.

TIGER: A map data format based on zero, one, and two cells, used by the U.S. Census Bureau in street-level mapping of the United States.

toxic release: Release of a toxic substance into the environment, such as the venting of a poisonous gas into the atmosphere.

unsupervised classification: The grouping of pixels by their numerical spectral characteristics without the intervention of direct human guidance.

UTM (universal transverse Mercator): A standardized coordinate system based on the metric system, and a division of the earth into sixty 6-degree-wide zones. Each zone is projected onto a transverse Mercator projection, and the coordinate origins are located systematically. Both civilian and military versions exist.

vector: A map data structure using the point or node and the connecting segment as the basic building block for representing geographic features.