In the summer of 1993, widespread continual rainfall in the Midwest transformed the normally placid Mississippi River into a raging torrent that flooded millions of acres of farmland and hundreds of towns.

The river overflowed its banks from St. Paul, Minnesota, to the southern tip of Illinois, affecting in some way almost everyone along its course. Unlike spring runoff, sustained rainfall kept the river at an exceptionally high level—from 25 to 35 feet above normal—for weeks. Numerous levees, which usually protect lowlands from flooding, were overtopped. Many others were breached under the sustained pressure of floodwater. The levees were highly saturated due to the unusually long duration of high water and some eventually failed.

As many as 16 cubic miles of additional water flowed past Quincy, Illinois, during the summer flooding, and the Missouri River added far more water at St. Louis. The river's flow was more than five times higher than normal in many areas. The river reached record flood stages at every reporting station south of Moline, Illinois. The Missouri, Illinois, and Des Moines river areas also experienced severe flooding.

The flood immersed entire communities—

By Thad Mauney and Harry R. Bottorff
The Federal Emergency Management Agency (FEMA) is the focal point of disaster assessment and assistance by the federal government and must respond quickly to aid persons in declared disaster areas. To evaluate conditions, FEMA must quickly and accurately conduct a pilot study in “rapid situation-assessment mapping” to take an inventory of the flooded structures in the area and to relay that information to GIS experts in Washington, D.C., and Rock Island, Illinois.

FEMA formed a team with the Rock Island District office of the U.S. Army Corps of Engineers, which had a GIS, and with GeoResearch Inc., a contractor to the corps. GeoResearch has developed a GeoLink GPS/GIS system to produce maps needed for disaster response, recovery efforts, and risk mitigation.

GeoResearch prepared Arc Macro Language (AML) programs. Those programs allow users of Arc/Info GIS software by Environmental Systems Research Institute (ESRI) to display digital pictures and data-base items in seconds when a mouse is used to choose a map feature on a computer screen. This permitted FEMA disaster assistance managers in Washington, D.C., to quickly examine the situation in the field. All observations are in digital form within the GIS, and they can be accessed for future analysis and map production.

This effort demonstrates that observations of disaster conditions can be quickly transformed to paper map products and computer data bases, which can then be used easily by other agencies concerned with the disaster.

AIRBORNE DATA ACQUISITION

During the last week of July, onsite observers started to map the condition of a 28- by 6-mile area flooded by the Mississippi River between Quincy and Warsaw, Illinois. A team from the corps, FEMA, and GeoResearch flew on an Army Reserve UH-60 Blackhawk helicopter to observe flooded dwellings and farm structures in the area. The aircraft and its crew came from the 102nd Army Reserve Command, A Company, 7-158 Aviation Battalion, stationed at Scott Air Force Base, Illinois.

FEMA and corps personnel informed observers of the features of primary interest and the type of data to be recorded. GeoResearch personnel acquired and converted the data. They recorded geodetic locations, types of structures, number of structures in a cluster, and apparent water depth. They also took videos as well as digital and film photographs.

In addition to recording information on flooded structures, the team recorded the actual interface of land and floodwater by flying directly along the waterline and continuously logging the GPS coordinates. Traveling by helicopter, observers could follow the shape of the waterline up along tributaries and around curved banks at 20 to 60 knots, with speed depending on the complexity of the waterline's shape.

Information on levee breaks in the area was gathered by tracing the actual levee lines and by noting in GeoLink the start and end of each break. This was done while the area was deeply flooded and water continued to flow through
The team converted its observations to GIS format and entered the data into the corps' GIS at Rock Island Arsenal on the same or next day and produced maps during the next several days. The data were then transmitted to decision makers at FEMA headquarters. The GIS computer software can be used not only to produce maps but to query the system interactively via map displays (which contain information on several themes, including flooded structures) and to display maps and digital photographs.

**FEMA's Inventory of Flooded Structures**

FEMA needed maps showing the locations of structures that may have undergone flooding and may have sustained damage amounting to more than 50 percent of their value. The building codes may require that owners elevate such structures above the 100-year flood level when they are rebuilt.

Throughout August, teams of observers, each consisting of one GeoResearch observer and one flood-insurance general adjuster, drove through every town along the Mississippi River flood zone in Illinois to record data on each flooded structure that met FEMA's inventory guidelines. The teams recorded data on all residential, commercial, and mixed-use buildings that were flooded by more than 1 foot above the main floor and that were located in communities with 20 or more buildings.

The floodwater depth criterion is based on the generally greater value of construction above the main floor level than in the foundation or basement.

Twenty counties were inspected in one month, which included a one-week delay to allow floodwaters to recede enough to give teams access to towns south of Quincy, Illinois. This area contains about 75 communities. The teams visually inspected thousands of structures and placed more than 1,500 in the inventory.

Teams took about one minute to observe each structure, a process that consisted of entering data, taking photographs, and automatically recording the GPS coordinates. Where flooded structures were dense, information on several hundred could be recorded per day. Where most of the homes were above the flood level, information on far fewer was recorded each day, but all of the towns had to be inspected to create a true record of the situation.

The resulting data base on the buildings compiled, and maps were produced by GeoResearch consultants and corps personnel at the Rock Island facility. For each affected county, they produced one county map and a map of each affected municipality. In addition, an 8 1/2- by 11-inch data sheet containing a data base record, a digital photo, and an area map was printed to assist local building inspectors and FEMA's insurance adjusters. About 70 E-size maps and more than 1,500 supporting data sheets were produced.

The maps must be digitized and georeferenced to integrate FIRMs with data in a GIS. FEMA has been digitizing FIRMs for parts of the United States, but the daunting task is far from complete.

Because FEMA needed composite maps immediately to respond to Midwest flooding, corps personnel skipped the backlog to integrate FIRMs of affected parts of Illinois.

Illinois state agencies had digitized flood-zone maps of unincorporated areas and provided them to ARC/INFO coverage to the corps. Unfortunately, digital data for the municipalities were not available. Consequently, the Rock Island District corps office digitized municipality FIRMs manually for about a third of the state. The coordinates were scaled off from the quad sheet or digital coverage and used to translate the digitizer units to world coordinates—a useful to building and zoning authorities who write building codes to minimize the risk of future flood damage, as well as to insurers who estimate risk.

FIRMs at several scales have been developed over many years by different engineering teams using a variety of base maps. Therefore the map series is printed without horizontal coordinate references. Many base maps appear to have been derived from enlarged parts of U.S. Geological Survey (USGS) topographic quadrangles, but coordinate tics were omitted.
tedious but not difficult task. To expedite the process for the rest of the Illinois’ Mississippi River flood zone, the corps scanned the maps and used GPS to collect geodetic coordinates of features.

About 60 maps were sent to ESRI in Redlands, California, to be scanned and converted to ARC/INFO. At the same time, GeoResearch teams used CPS with GeoLink to record the geodetic coordinates of key streets, intersections, and reference points in towns. These data were converted to ARC/INFO and transmitted to ESRI to be used as the ground control needed to georeference and rectify the scanned maps.

GIS Teamwork Makes a Difference

The Mississippi River, a lifeline connecting people and regions, had turned into a 500-mile path of destruction. The river, a great natural interstate that conveys 15 percent of the nation’s cargo from grain to iron ore, coal, and fuel oil, had overflowed its banks from St. Paul to St. Louis. So had the Missouri River and many other rivers in the region.

Tens of thousands of people were homeless. Crop and property damage in nine midwestern states is estimated in the billions of dollars. Airports were flooded, bridges were out, and countless miles of roadways and railroads were disrupted. “We’ve never seen anything like this before,” says Ron Fournier, spokesperson for the U.S. Army Corps of Engineers in Rock Island, Illinois.

Many in the GIS community have responded to the emergency by supporting the Federal Emergency Management Agency (FEMA) Emergency Response Team. FEMA’s ability to respond to a disaster depends, in part, on how quickly it can collect and process information. “The agency has had to determine the extent of the flooding and to assess damages in the flood area,” says Dan Cotter, who is leading FEMA’s GIS effort. This requires up-to-date roadway and transportation data, point elevations, satellite imagery, and other feature information.

Coming to the aid of FEMA—and pulling out all the stops to help—were members of the GIS community. “The response has been remarkable,” says Cotter. Numerous state agencies, local governments, and universities have offered to make their GIS data bases available for disaster assessment.

The U.S. Army Corps of Engineers, Rock Island District (Illinois), helped FEMA by funneling a variety of shared data from Illinois, Missouri, Wisconsin, Minnesota, and Iowa that included TIGER files, railroad data, and point elevation information for water treatment plants along the Mississippi. In two days, the corps, GeoResearch, and FEMA, using a GPS unit mounted on a helicopter, inventoried 200 houses and farms located between Quincy and Warsaw, Illinois. An additional 1,500 structures were similarly mapped by observations from cars. To map submerged structures, they downloaded data in ARC/INFO format to a Sun workstation. In August, FEMA used the information to assess damage before the water completely receded, speeding up aid.

Also assisting FEMA by gathering data were corps personnel in Omaha, Nebraska; St. Paul, Minnesota; and Chamberlin, South Dakota. Satellite data were also collected and analyzed by the staff of the corps’ GIS and Remote Sensing Center at the Cold Regions Research Engineering Lab in Hanover, New Hampshire.

State agencies helped with the initial emergency response to the flood, including the Illinois Department of Energy and Natural Resources, the Illinois Environmental Protection Agency, and the Minnesota Pollution Control Agency, which keep data on sites they regulate in the region affected by the flood. The Environmental Management Technical Center of the U.S. Fish and
A two-person team completed observations on the ground in one week. One person drove the car while the other navigated and operated the GeoLink data acquisition system. They used differential GPS to obtain an accuracy equal to or greater than that of the USGS quadrangle maps from which the FIRM data had been derived.

**GPS AND GIS TOOLS USED FOR MAPPING**

In this mapping project, GeoLink version 3.0 GPS/GIS software from GeoResearch was used to acquire, edit, and convert data for use in the GIS. ASCII was used to integrate and display the data and to produce maps. ARC/INFO and ARCView were used to query the system interactively, and to produce maps.

For the differential GPS work during helicopter trips, the aircraft was equipped with small, lightweight Army SLGR GPS receiver manufactured by Trimble Navigation. The observers used a Trimble 4000 SE 9-channel precision GPS receiver, taking advantage of its internal data-logging capability for the differential base station.

Inventory observers on the ground obtained GPS coordinates by using LTG 1000 GPS receivers manufactured by Motorola. Base station data for differential GPS were also obtained by using those receivers and GeoLink GPS/GIS data acquisition software on notebook computers.

Data were entered and maps were displayed in real time by using GeoLink on a variety of conventional IBM-compatible, notebook computer systems. The systems had 1 to 4 megabytes of random access memory, 20- to 120-megabyte hard disks, 80386 central processing units, 80387 math coprocessors, and either color or monochrome graphic displays.

The ARC/INFO GIS software was installed on SUN Sparc (Sparc 1-, Sparc 2, and Sparc 10 models) and IBM RS 6000 workstations in Ethernet local area networks. Internet was used extensively to transmit data quickly between offices, and data on diskettes and 8-millimeter tape were shipped by express mail parcel services, as the many participants around the country teamed up to respond to a national need.

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Wildlife Service offered its large data base on the condition of the river system before the flood (from St. Paul, Minnesota, to Cairo, Illinois).

The disaster has established new lines of communication between many organizations, including many in the GIS community. Environmental Systems Research Institute (ESRI), publisher of ArcData, provided on-site technical support to the Corps. Many other ArcData users offered and provided data used to manage the emergency. VISTA Environmental Information pulled together environmental data on the St. Louis and Des Moines areas. Earth Observation Satellite Company (EOSAT), which has been acquiring satellite imagery for the U.S. Department of Agriculture, offered to provide imagery to FEMA. SPOT image offered to collect multispectral and panchromatic information on the area with each pass of its satellite and to provide FEMA with up-to-date information as it became available. Environmental Data Resources volunteered all their data on states affected by flooding.

ESRI provided ArcView software and ArcUSA data, which includes information on state and county boundaries, cities, roads, rivers, and statistical attributes. Additionally, ESRI provided on-site technical support to Dewberry and Davis, which uses ARC/INFO in providing data automation and processing services at FEMA headquarters in Washington, D.C. The National Park Service is working with the corps to map historic sites affected by the floods.

The need to respond has opened new lines of communication between FEMA and many organizations. The emergency has been a catalyst for cooperation and data sharing in the area. Publishers of ESRI's ArcData have offered and provided GIS data for use during the emergency. Geography Data Technology offered the use of its comprehensive topological files, called Dynamap 2000, which contain street names and types, political boundaries, railroads, and water features. Donnelly Marketing Information Services supplied point location data for features in the affected areas.

Using the shared data, as well as FEMA's own data base of point location information, such as airports, hospitals, and refineries, analysts are assessing the extent of the disaster. Computer Sciences Corporation, using ARC/INFO, assisted with maps, coverages, and reports needed by state and federal agencies to expedite aid. Analysts processed information from the Thermal Infrared Observation Satellite (TIROS), GPS, and aerial photography using an IBM RS 6000 workstation; turned images into grids; and produced polygon data roughly indicating flooded areas. This was valuable in preparing preliminary reports on the infrastructure such as roads, railroads, nuclear power plants, airports, and bridges. By using census data, FEMA was able to assess precisely the features and populations affected by flooding. This kind of information is critical in responding to such a disaster: "The GIS is providing extremely valuable information, which we would have to otherwise collect in the field," says Cotter. "Not only is GIS maximizing resources, it is helping the agency respond more quickly in a changing situation."

Recovery efforts will continue long after the flood waters retreat, and much of the work will be done by the organizations that have already responded to the disaster. "No one let us down," says Harry Bottorff of the U.S. Corp of Engineers.

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