# Using GIS in Emergency Management Operations

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**Abstract:** The purpose of this paper is to describe the use of a geographic information system (GIS) in emergency management efforts for disaster preparedness, mitigation, and response, and summarize an ongoing effort to build a GIS-based decision support system for the Douglas County Emergency Management Agency in the state of Kansas. Emergency management historically has focused on the immediate and urgent aspects of a disaster, response, and post-disaster recovery. However, there is a growing awareness that emergency management is much more complex and comprehensive than traditionally perceived. The primary function of government is to protect life and property. This involves not just crisis-reactive responses to emergencies, but also finding ways to avoid problems in the first place and preparing for those that undoubtedly will occur. The aim of this project is to build a database in a GIS frame that helps emergency management officers in decision making, focusing on Douglas County's preparedness, mitigation, and response efforts for its most common disaster, flooding. The system will lead to better flood management by automating the task of determining the probable flood-affected areas and integrating the results with other spatially distributed information. This will enable county emergency management officers to make more informed decisions before, during, and after a flood situation.



## INTRODUCTION

Disasters are defined as threats to life, well-being, material goods, and environment from the extremes of natural processes or technology. Although disaster management is a national concern, at the most basic level it is the responsibility of county emergency management agencies to cope with disasters. Their efforts focus on lessening the impacts of the disasters on human lives as well as property with mitigation and preparedness, and managing disasters with response and recovery work. The problem in this system is that most county level emergency management agencies have very limited resources, both in manpower and in equipment. They need help to successfully accomplish their mission. To develop a better emergency management effort at the level of county emergency management agencies, these agencies must be equipped with tools that help them to overcome their resource shortfalls. These tools must allow them to not only reach information about the geographical, geophysical, and socioeconomic characteristics of their county, but also to determine, visualize, and analyze the possible extent of disasters. Efficient management of potential risks can only be accomplished if the emergency managers are aware of the extent of the possible effects of disasters. Such tools can be developed to act as a decision support system for emergency management agencies, through the use of a geographic information system (GIS). Disaster management consists of various cyclical phases: mitigation, preparedness, response, and recovery. Because each phase is geographically related to where people, places, and things are spatially located, GIS can be a valuable tool for analysis purposes throughout each cycle.

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## EMERGENCY MANAGEMENT

The Federal Emergency Management Agency (FEMA) classifies overall emergency management into four categories: mitigation, preparedness, response, and recovery. Mitigation can be described as the efforts that reduce the degree of long-term risk to human life and property from natural and man-made hazards. Preparedness is the activities that develop operational capabilities for responding to an emergency. Response covers the efforts taken immediately before, during, or directly after an emergency that save lives, minimize property damage, or improve recovery. Recovery includes the activities that restore vital life-support systems to minimum operating standards and long-term activities that return life to normal.

Each of the 50 states has its own state level emergency management agency. Where it is located in the state organization varies from state to state. Some agencies are independent, and others are part of larger organizations. The chain continues down to the county level in most states.

Over the past few years there has been an increased interest in the emergency management system. A significant amount of this interest is due to the seemingly increasing frequency of disasters and their coverage by news media. In the past it could take days or weeks for people to learn of disasters in other parts of the country. Today, it takes only seconds. This effect heightens our awareness of the problems and also provides some ability to deal with disasters that move over time.

## GIS IN EMERGENCY MANAGEMENT

A GIS can be a very powerful tool in emergency management. This technology has the ability to capture the data by digitizing, scanning, digital imagery, or aerial photography; to store the data; to manipulate the data; to form data queries; to analyze the data; and most importantly, to visualize the data. In other words, GIS technology brings to the user the ability to integrate, store, process, and output geographic information. This system takes a multitude of data from numerous sources and graphically displays the information.

To make the right decisions, emergency management personnel need accurate information quickly and in the right form. They need projections about what may happen and information about what has happened and where, and what resources are available to respond. They need plans that help them anticipate contingencies, assess developments, and direct effective response and recovery operations. One use of GIS for emergency management officers is displaying information regarding various conditions, such as

- Disaster forecast—information concerning the possible extent of a particular disaster; used to determine which areas include critical facilities that would be subject to the potential hazard
- Vulnerability analysis—information on critical facilities (hospitals, shelters, police and fire facilities, dams, trauma centers, etc.) that can be used for mitigation efforts
- Damage assessment—reports of the actual impact of hazards; speeds applications for federal aid with electronic reports based on FEMA, Small Business Administration, and Farmers Home Administration forms
- Hazardous materials—identifies material types and quantities, storage locations, and potential threatening situations



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- Personnel resources—location, contact information, and relevant skills and/or experience of potential disaster response personnel; improves deployment by keeping a running log of each member's latest action, shift, and availability
- Resource inventory—vital information concerning supplies, equipment, vehicles, or other material resources as well as mutual aid availability from neighboring companies
- Infrastructure—shows transportation networks (roads, railroads, bridges, traffic control points, and evacuation routes) as well as complete utility grids (electric, gas, water, and sewer)
- Mass care/shelter status—monitors the movement of people to and from government or voluntary agency shelters by providing information on capacity, availability, supplies, and suitability to victims' needs

As GIS technology has become more affordable, emergency management personnel are able to enhance their efforts to understand and manage the magnitude of and mitigate the potential damage of natural and artificial disasters. Emergency managers can achieve a variety of efficiencies and gains in productivity by employing GIS technology. Some of the major categories are

- Efficiencies gained from automating tasks previously done manually
- Efficiencies realized through the reduction, elimination, and/or coordination of tasks previously done that currently are duplicated by multiple individuals in different organization units
- Efficiencies obtained when GIS performs tasks that are too time consuming and costly to be done manually or with current outmoded technologies
- Enhancements provided by GIS technology in productivity that other, more traditional technologies do not provide

## DOUGLAS COUNTY EMERGENCY MANAGEMENT AGENCY'S (DCEMA's) GIS-BASED DECISION SUPPORT SYSTEM

The DCEMA is responsible for developing, maintaining, and implementing an integrated emergency management system that strives to protect lives in Douglas County, Kans., in the event of a disaster. This is accomplished through the maintenance and exercise of an emergency operations plan; education and training of the public, government officials, and emergency responders; and promotion of mitigation and self-protective measures that lessen the possibility and/or impact of disasters.

To increase the efficiency of DCEMA in its emergency management operations, a joint research effort is under way involving Douglas County and the University of Kansas, Lawrence, Kans. The objective of the research program is to use GIS technology to develop a flood impact assessment methodology for DCEMA. This methodology will be used to improve the current emergency response methods of the agency. It will work as a computer-based decision support system that integrates data, information, and models for the purpose of identifying and evaluating solutions to complex problems involving spatially distributed information for the emergency management agency.

The goal of this research is to develop a tool to maintain an integrated

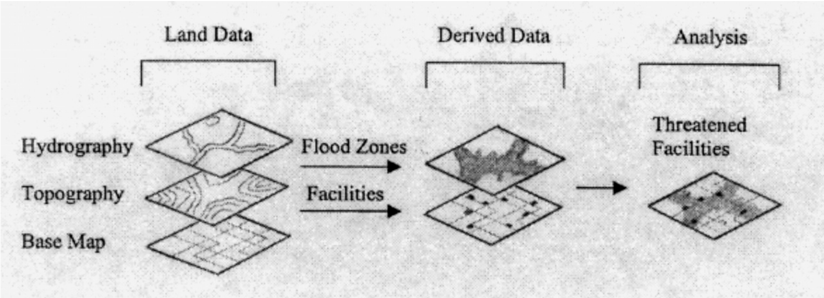


**FIG. 1. GIS**

emergency management system that enables the emergency manager to visualize and analyze flood situations more accurately. A major impact of this tool in current disaster response efforts will be its ability to determine potential and actual flooded areas more accurately by means of GIS technology. Use of GIS in this research is summarized in Fig. 1.

This research will outline ways for developing damage functions, which better describe the flood hazard conditions, provide a means to quickly address implications of changes in land use policy, and produce hazard maps that provide a new perspective of modeled data. This, in turn, will lead to better protection of lives and property in the county in the event of a flood, which is the major responsibility of any emergency management agency.

The specific GIS package used in this project is Environmental Systems Research Institute's (Redlands, Calif.) ArcView 3.1 with the Spatial Analyst extension. The Spatial Analyst extension supports a system based on raster data types [digital elevation models (DEMs) in this case]. ArcView is the base software used to integrate data that is needed by DCEMA in its emergency management operations with the data geographically. Selection of any package depends on the availability of the digital data to be used in the development of the system. In this case, compatibility of the package with the other units of Douglas County, the capability to support the purposes of the whole project, and being user friendly for emergency management personnel were also important.

Douglas County is located in eastern Kansas within Zone 15 of the Universal Transverse Mercator (UTM) grid (Fig. 2). To provide a detailed spatial analysis, 1:24,000 scale digital maps are used in this project. Larger scale allows seeing the land data more clearly as well as giving the opportunity to determine the possible flood zones more accurately within more precise elevation difference ranges. Digital data for Douglas County exists in 1:24,000 scale quadrangles. These quadrangles can be seen in Fig. 3.

Early efforts of this research include the gathering of digital data for the whole county. For the time being, for the hydrography and orthophotos of the county, all of the digital data is available and used in the project. However, some of the DEM quadrangles, namely DC1654, DC1655, DC1656, and DC1754 are still not available.

All the digital data, including maps and photos, used in that project are provided by Data Access and Support Center of the state of Kansas. Information about the different file types follows.

## 1:24,000 Scale DEM

"Digital elevation model" (DEM) is the terminology adopted by the U.S. Geologic Survey (USGS) to describe terrain elevation data sets in a digital

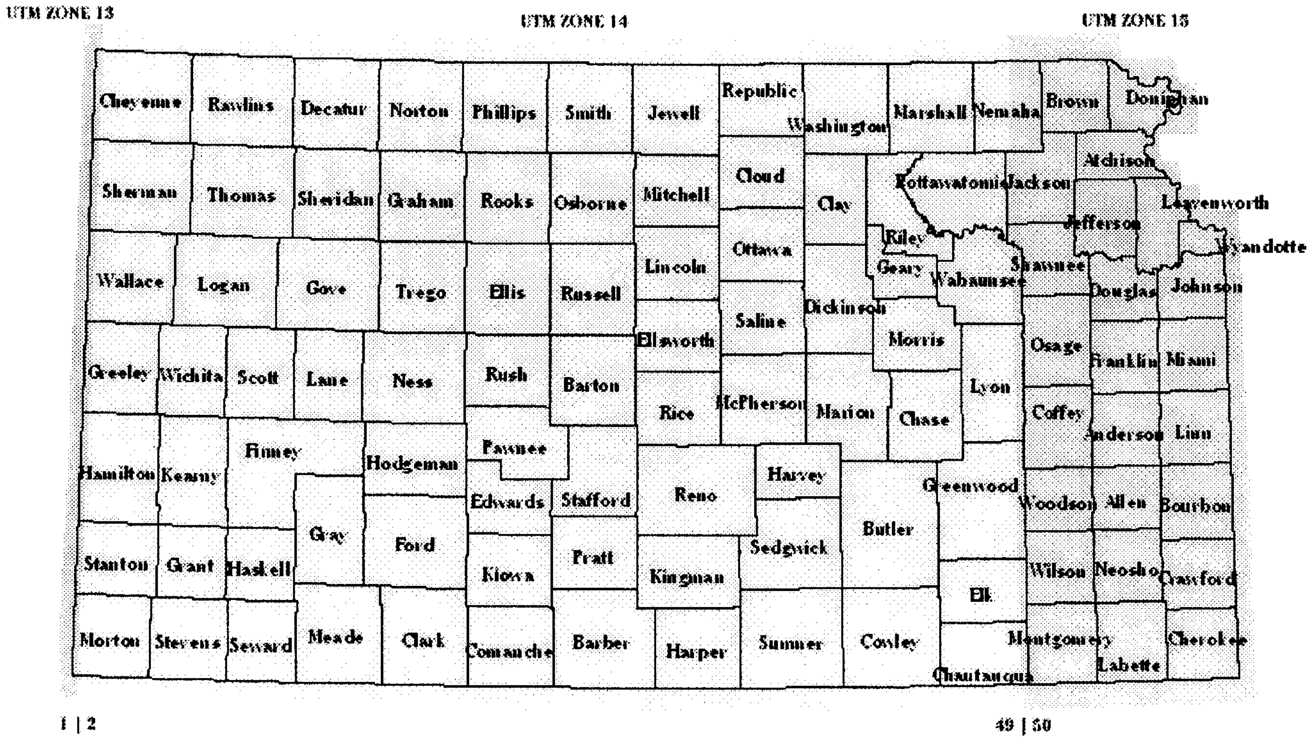


FIG. 2. UTM Zones, Kansas

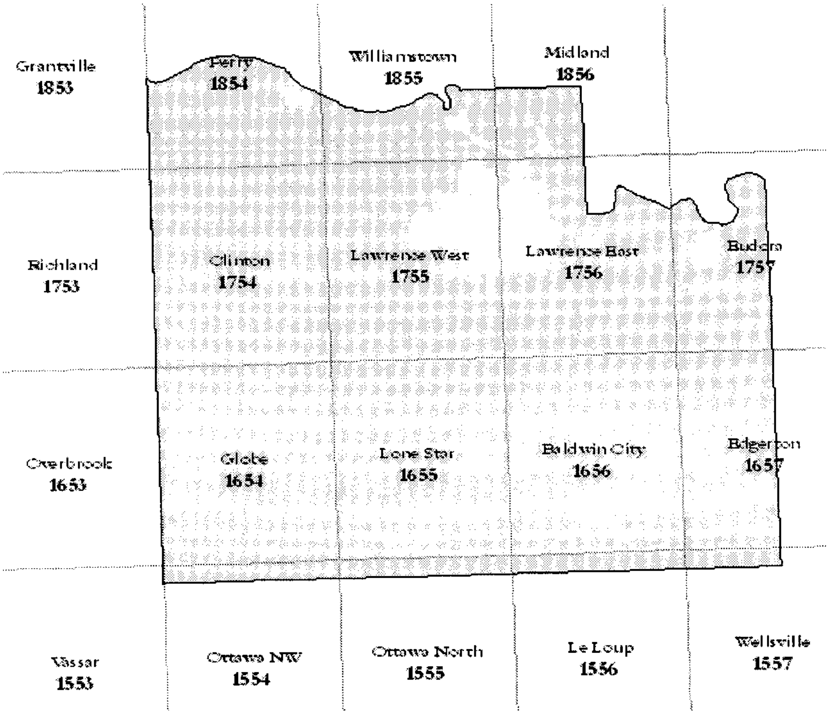


**FIG. 3. Douglas County, Kans., 1:24,000 Quadrangles**

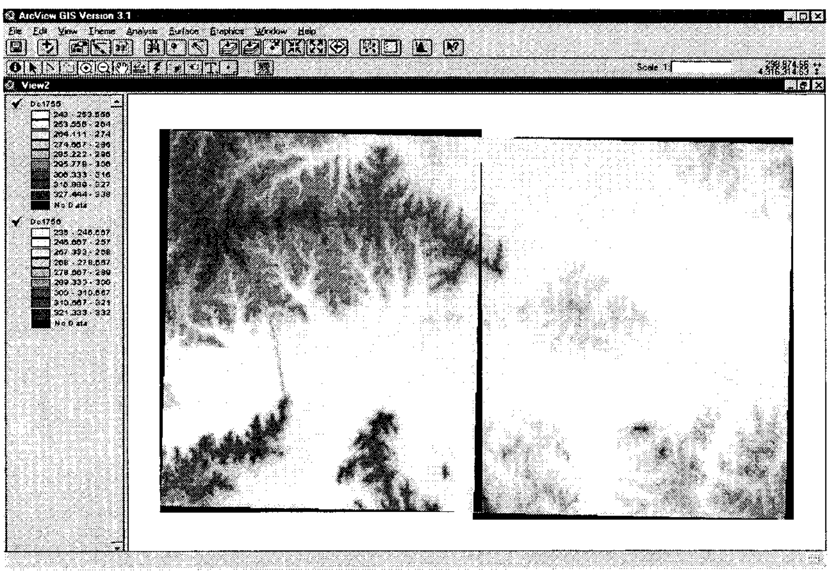


**FIG. 4. 1:24,000 Scale DEM of Douglas County, Kans., DC1755 and DC1756 Quadrangles**

raster form (Fig. 4). The standard DEM consists of a regular array of elevations cast on a designated coordinate projection system. The DEM data are stored as a series of profiles in which the spacing of the elevations along and between each profile is in regular whole number intervals. The normal orientation of data is by columns and rows. Each column contains a series of elevations ordered from south to north, with the order of rows from west to east.

The DEM is formatted as one ASCII header record (A-record), followed by a series of profile records (B-records), each of which includes a short B-record header followed by a series of ASCII integer elevations per each profile. The last physical record of DEM is an accuracy record (C-record). A 7.5′ DEM (30 × 30 m data spacing cast on a UTM projection) provides coverage in 7.5′ × 7.5′ blocks.

*Spatial Data Organization Information*

- Direct spatial reference method/raster or vector object type: raster

*Spatial Reference Information*

- Horizontal coordinate system definition/map projection: UTM
- Zone number: 15
- Datum: North American Datum (NAD) 1927
- False easting: 500,000
- False northing: 0.0
- Geographic/map coordinate units: meters

*Entity and Attribute Information*

- Overview description/entity and attribute overview: The digital elevation model is composed of a six-character integer raster representing a grid form of a topographic map hypsography overlay. Each raster entity contains a six-character integer value between −32,767 and 32,768.

## Orthophotos

Digital orthophoto quads (DOQs) combine the image characteristics of a photograph with the geometric qualities of a map (Fig. 5). The primary DOQ is a 1-m ground resolution, quarter-quadrangle (3.75′ latitude by 3.75′ longitude) image cast on UTM on NAD 1983. The DOQ geographic extent is equivalent to a quarter-quadrangle plus overedge, which ranges from a minimum of 50 m to a maximum of 300 m beyond the extremes of the corner points. The overedge is included to facilitate tonal matching for mosaicking and for the placement of the NAD 1983 and secondary datum corner ticks. The normal orientation of data is by lines (rows) and samples (columns). Each line contains a series of pixels ordered from west to east, with the order of the lines from north to south. The standard, archived DOQ is formatted as 4 ASCII header records, followed by a series of 8-bit binary image data records. The radiometric image brightness values are stored as 256 gray levels ranging from 0 to 255.



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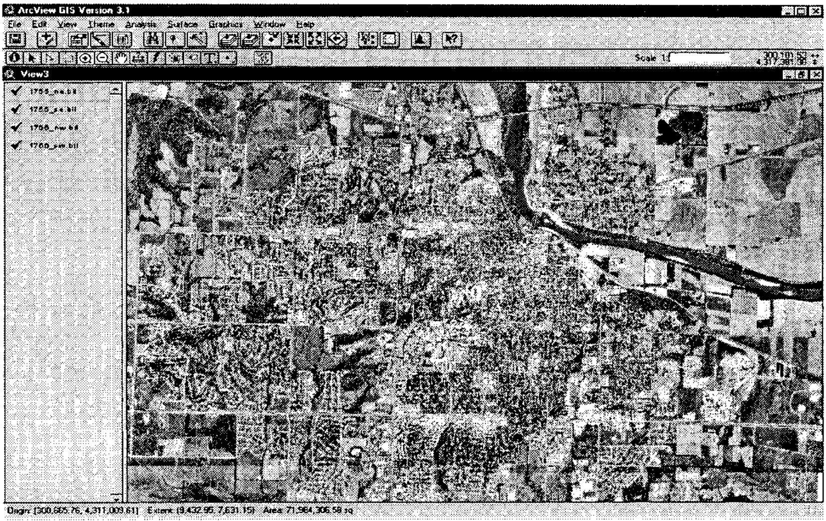


**FIG. 5. 1:24,000 Scale DOQs of Douglas County, Kans., View of Lawrence**

*Spatial Data Organization Information*

- Direct spatial reference method/raster or vector object type: raster

*Spatial Reference Information*

- Horizontal coordinate system definition/map projection: UTM
- Zone: 15
- Datum: NAD 1927 or 1983
- False easting: 500,000
- False northing: 0.0
- Geographic/map coordinate units: meters

*Entity and Attribute Information*

- Overview description/entity and attribute overview: For DOQs from a panchromatic source, each pixel contains an 8-bit gray-scale value between 0 and 255. A value of 0 represents the color black, and a value of 255 represents the color white. All values between 0 and 255 are represented as a shade of gray varying from black to white. For color-infrared and natural color DOQs, a digital number from 0 to 255 also will be assigned to each pixel, but that number will refer to a color look-up table that will contain the red, blue, and green values, each from 0 to 255, for that digital number.

## 1:24,000 Hydrography

The 1:24,000 hydrography of the state of Kansas developed from 1:12,000 USGS DOQs, based on 7.5′ quadrangles and updated with DOQs (Fig. 6). The data set was developed based on the extent and horizontal placement of USGS 7.5′ quadrangles and then revised water bodies and horizontal placement from 1:12,000 USGS DOQs.



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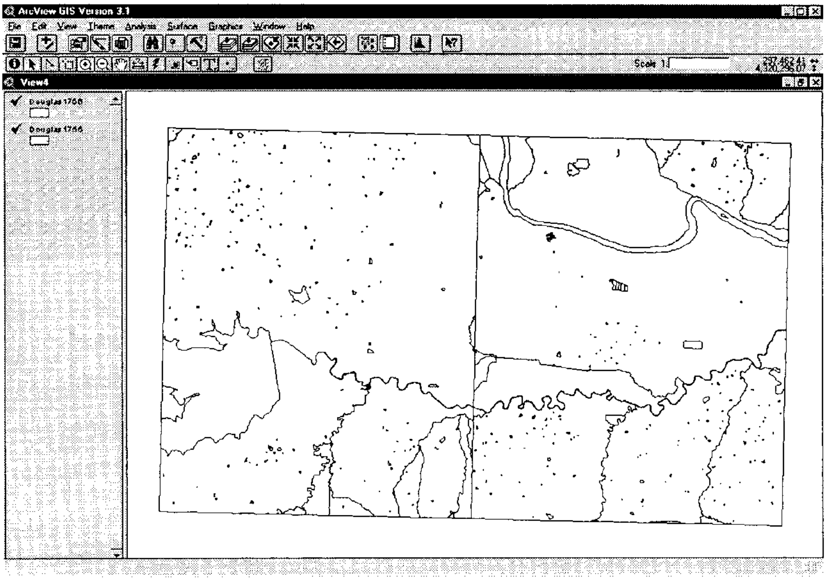


**FIG. 6. 1:24,000 Scale Hydrography of Douglas County, Kans., DC1755 and DC1756 Quadrangles**

*Spatial Data Organization Information*

- Direct spatial reference method/raster or vector object type: vector

*Spatial Reference Information*

- Horizontal coordinate system definition/map projection: UTM
- Zone: 15
- Datum: NAD 1927
- False easting: 0 m
- False northing: 0 m
- Geographic/map coordinate units: meters

*Entity and Attribute Information*

- Overview description/entity and attribute overview: The DLG3 attribute codes are used to describe the physical and cultural characteristics of DLG node, line, and area elements. Attribute codes are used to reduce redundant information, provide enough reference information to support integration with larger databases, and describe the relationships between cartographic elements. Each DLG element has one or more attribute codes composed of a three-digit major code and a four-digit minor code.

## THE MODEL

The whole tool will include three main databases: a disaster/emergency database, a facilities database, and a resources database. These three databases

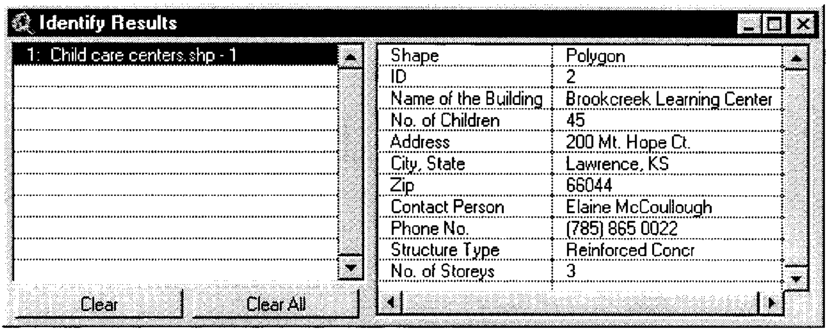


**FIG. 7. Typical Facilities Database Entry for Child-Care Centers Theme**

will be used in different stages of emergency management. The disaster/ emergency database will aid the emergency managers by providing a damage overlay, allowing them to visualize the extent of the emergency. In this case, it will be a visual or graphic data display of the flood zone, depending on the increase in the water levels of the rivers. This database will be developed using DEMs of Douglas County. The DEMs allow users to have the grids on the map and to specify the zones with the same elevation on the map. This feature will be used to determine the flooded zones' neighboring water features, depending on the increase of water levels in those bodies of water. The research focus is on the process of building this database with the best possible accuracy while using the existing features of the software and the digital maps.

The facilities database will play an important role in identification and evaluation of the key public facilities that are likely to be damaged. This database will be created according to the needs of the emergency management agency. For its development, a list of facilities that are considered to be critical, or of high interest, in case of a disaster was provided by DCEMA. This list includes

- Schools
- Medical facilities
- Day care facilities
- Industrial facilities
- Hotels/motels
- Recreational areas
- Mobile home parks
- Government buildings

Each facility is assigned a spot in the database and is located on the orthophotos. The database will contain important information about each facility and will be accessible directly from the base map. Fig. 7 shows a typical facility database entry. Efforts are currently under way to collect the necessary data for each facility and create the database for use in the system. In this effort, it is very crucial to collect the current information about the high interest facilities and keep them updated.

The resource database will support the development of the response plan. It will include the construction and engineering resources that can support disaster response operations. Development of this database has not yet begun.

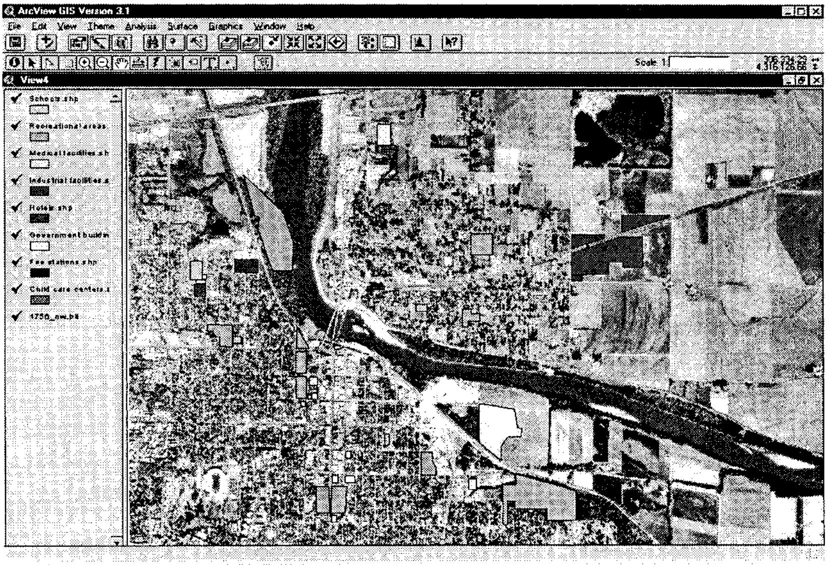


**FIG. 8. Facilities Database**

It will be the most difficult of the three to develop because the information it contains is constantly changing. Although it would be nice to know where everything useful in disaster planning and response is located, it is not realistic. In most cases, the best that can be hoped for is tracking government assets only. These assets are more stable, and tighter reporting procedures can be developed.

Although much of this work could be done in a number of ways, the use of a GIS frame provides key benefits. As shown in Fig. 8, the facilities database can be overlaid on the DOQs. This allows the emergency manager to see the relationships between various facilities. The next step is to overlay the disaster database over this combination. The disaster database for flooding is created by manipulating the DEMs to show specific water elevations. These elevations can represent specific heights above normal water level or specific flood levels as defined by FEMA. This manipulation can be seen in Fig. 9.

By combining the data from both the facilities and the disasters databases, it is possible to develop relationships between the two. The emergency management officials are able to identify those facilities that are most threatened. This can be clearly seen in Fig. 10.

Once the threatened facilities have been identified, the emergency manager can begin the mitigation and/or planning processes. In nearly all cases, actual mitigation work is beyond the capability of the emergency manager. However, it becomes the responsibility of the emergency manager to identify potential problems to the authorities who are capable of action. Mitigation efforts could include relocation of the facility, reinforcement of the facility, or construction of protective structures.

If mitigation is not a feasible option, then response planning is required. The planning effort should include the facility owners, emergency managers, and representatives of other public services. The goal of all planning sessions is to develop procedures leading to efficient response to threatening situations.



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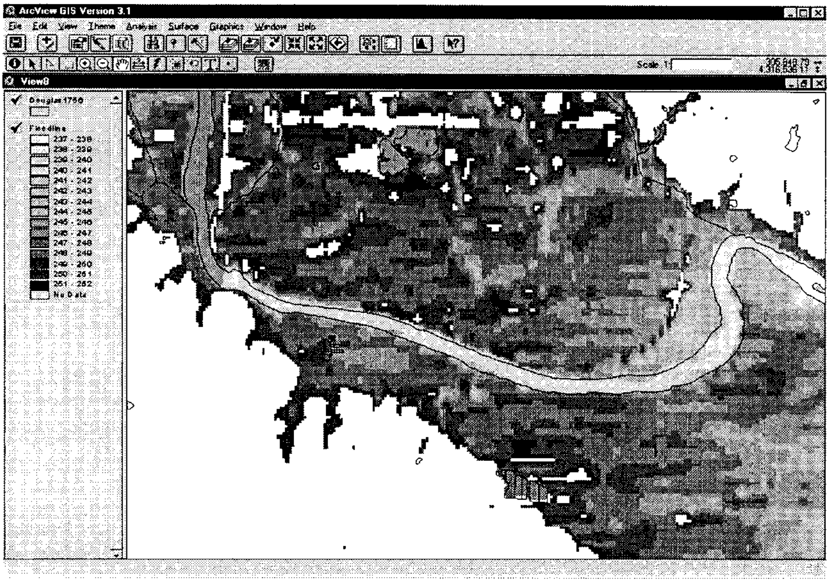


**FIG. 9. Disaster Database for Flooding Obtained by Manipulating DEMs**

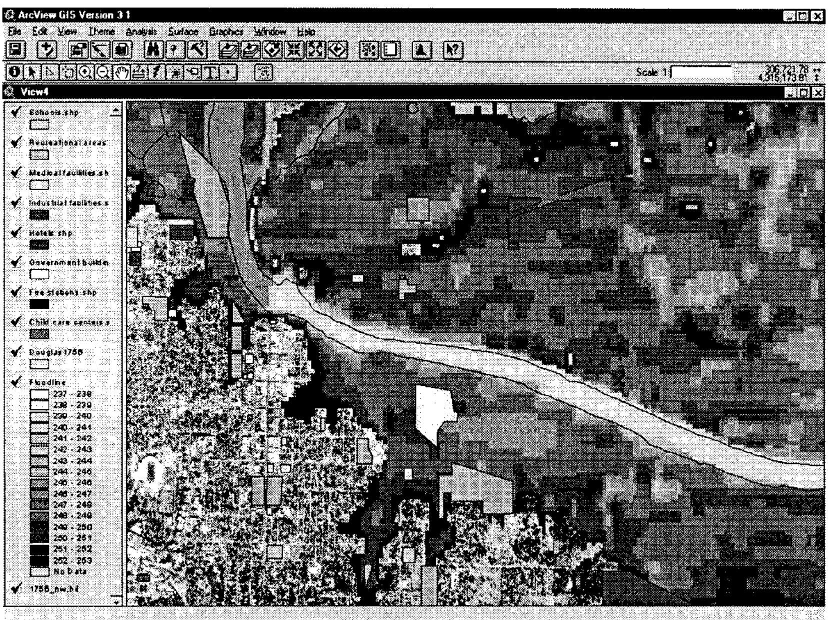


**FIG. 10. Flood Database on Top of DOQs and Facilities Database**





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These procedures would include evacuation plans, notification processes, and temporary mitigation measures.

## CONCLUSIONS

The use of a system such as the one described above clearly gives the emergency manager the ability to visualize potential problems. Another advantage of the visual image is that nontechnical observers will be able to understand the information provided without extensive training. Steps can then be taken in every phase of the emergency management cycle to improve response and decrease risk to life and property.

The major drawback to a system such as this is implementation. Each site has to be identified, added to the appropriate database, and located on the map. This takes time and manpower. Even when the product is finished, someone will have to maintain it. Depending on the size of the area covered and the population density, it could become a full-time job. In the long term, each county would have to have a cost-benefit analysis to determine the viability of maintaining the system. Support from the state and federal levels will be crucial to the final success of systems such as this.

In preparing this model, a third database was originally planned. This database would contain information concerning the location and types of resources available to support disaster response operations. After consulting with Paula Phillips, the director of DCEMA, the resources database was scrapped as not viable. Collecting and maintaining the data used would be a more than full-time job, even if the database were restricted to government agencies and equipment. Even if it were possible to create the third database, DCEMA did not have the capability to maintain it.

The focus of this effort was on flood management and all the work revolved around this one type of disaster. However, the model can easily be translated to other forms of disaster. The facilities database remains the same while the hazard database is adjusted to reflect different disaster types. With DCEMA, the next step will be adding hazardous material spills and large blasts, particularly of the types related to chemical plant or grain elevator accidents. For coastal counties adding hurricane maps is possible, and counties on fault lines can plot the extent of various magnitudes of earthquakes. Although these disaster databases are more complex than the flooding one, they are still viable.

## ACKNOWLEDGMENTS

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