Application Challenges for Geographic Information Science: Implications for Research, Education, and Policy for Emergency Preparedness and Response

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Abstract: *Understanding geographic information is critical if we are to build and maintain livable communities. Since computing has become almost ubiquitous in planning and managing our communities, it is probable that advances in geographic information science will play a founding role in having more-informed decision making available to all. We examine the challenges that occur between humans and their environment under conditions thought to be hazardous to life or habitat. Emergency preparedness and response are reviewed and the results from focus groups at the University Consortium for Geographic Information Science Summer Assembly (1999), which identified and recommended priorities for research, educational, and policy contributions to emergency preparedness and response, are documented.*

The Emergency Preparedness and Response Application Challenge

The emergency preparedness and response application challenge, as defined at the 1999 Summer Assembly of the University Consortium for Geographic Information Science (UCGIS), is mainly concerned with the interaction between humans and their environment under conditions thought to be hazardous to life or habitat. This challenge is not only multifaceted, as its title implies, it covers a wide range of disasters, many with fundamentally different underlying processes (such as earthquakes, hurricanes, and wildfires). Even though the processes that generate the disaster might be fundamentally different, the techniques to assess risk, evaluate preparedness, and assist response appear to have much in common and can share and benefit from advances in geographic information science (GIScience) (e.g., data acquisition and integration; issues of data ownership, access, and liability; and interoperability).

Natural hazards and most human-generated hazards do not recognize political boundaries, yet policy must be generated in order to mitigate effectively against disasters, to manage rescue and response operations, or to organize and deliver relief, and this policy is usually administered within politically defined boundaries. Geographic information and the systems within which they are collected and managed have particular utility in modeling and analysis that transcends political boundaries, while providing the necessary structure for facilitating the implementation of policy within administrative areas.

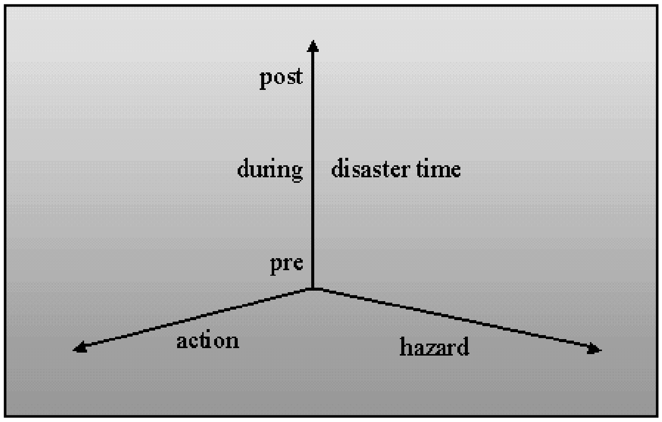
In a similar vein, while hazards do not often differentiate between land uses, the recovery and the cost and impact on society are often greatly affected by this differentiation. In some circumstances, the hazard itself is modified and often magnified by heterogeneous landscapes and land use, such as those found where humans interact with nature. These boundary conditions are difficult to map and virtually impossible to model without the use of concepts, tools, and technologies that are evolving within GIScience. In order to assess and mitigate risk to human life and property and to respond effectively, we must develop predictive and operational models that are embedded within a geographic information system (GIS).

A post-disaster statement might conclude that, if we knew then what we know now, we could prevent or at least reduce the risk, damage, and loss, and shorten the recovery period. Since GIS and related technologies provide an operational forum for realizing this statement, the effort here begins the process of answering the question: What are the challenges for GIScience arising from disaster management?

A Paradigm for the Contribution of Geographic Information Science to Emergency Preparedness and Response

The contribution of GIScience to emergency preparedness and response might best be navigated within a paradigm that, at the very least, might be represented as a three-dimensional grid but more likely is depicted as a graph with three axes as illustrated in Figure 1.0 One axis represents the hazards as we commonly refer to them: 1) natural hazards such as earthquake, volcanic phenomenon, tsunami, landslide, fire, flood, tornado, hurricane, drought, and freeze; and 2) human-induced hazards such as health-related epidemics, social unrest, war, infrastructure failure and collapse, toxic spill, explosion, and fire (accidental or other-

Figure 1. A paradigm for geographic information science contribution to emergency preparedness and response.



wise). A second axis represents time that can characterize actions taken such as pre-event (proactive – risk assessed), during the event (reactive – response), and post-event (reactive – recover). The third axis encodes action taken or response sought by the application of GIScience to assessment, emergency preparedness, and response, such as prevention, discovery, planning, mitigation, management, insurance settlement, and policy.

Geographic Information Science Contributions to Advance the Discussion

GIScience and related technologies have already contributed in many areas encoded within the paradigm. There are numerous examples of ongoing projects to predict hazards, assess the risk to human life and property, assist response during an emergency, discover and recover from damage, manage ongoing hazardous conditions, plan and mitigate for future hazards, and impact policy and decision making. To navigate a small sample of these will not only serve to point out where GIScience is already contributing to emergency preparedness and response, it will also help define the future geographic information challenges for this application area.

Although the following list of hazards is not all-inclusive and some content may appear to overlap with other UCGIS application challenges for GIScience, it is an appropriate list by which to begin the discussion for emergency preparedness and response. In the interests of brevity and breadth of coverage, each hazard is not addressed in detail, but is reviewed for the role that geographic information has played, which includes predicting, responding to, managing, and recovering from these disasters.

As with any hazard to reduce loss of life and damage to property, public safety officials, policy decision makers, and the general public must be aware of the potentially hazardous conditions well in advance. In many past disasters, the general public would have been able to themselves respond in a crisis if they had knowledge of existing conditions. GIScience in its research and education initiatives appears to be able to offer concrete support in this.

Natural Hazards (Natural Disasters That Impact Humans)

In most of the natural hazards examined, a major part of the effort was a focus on mapping. This is not surprising as most solutions involving GIS are data-poor until they become part of an accepted set of procedures. However, the mapping procedures and the way that information is displayed appear to have been impacted by the advancing of technologies within GIScience. Simply encoding where a single variable existed is being replaced by maps depicting combinations of variables and their contribution to and potential for failure in hazardous conditions.

These data and information are being made more available to the general public due to advances in and the acceptance of World Wide Web (Web) technology. It is likely that the advances in Web technology that have greatly impacted emergency preparedness and response mirror the rate and potential impact of advances in GIScience to this application area. Rather than look too far into the future, we will respond to existing conditions as we discuss emergency preparedness and response challenges. In the first section, we examine the nature of the event and role of geographic information for natural and human-induced hazards.

Earthquakes. Earthquakes can destroy human infrastructure and habitat, killing and impacting large populations, especially in urban areas (USDA Forest Service). Although some consider the 1989 Loma Prieta earthquake to be a wake-up call, it reminded others that proactive mitigation efforts pay off, as damage and loss of life were minimal for a large quake in such a populated area.

Major earthquakes of the recent past, including Adana-Ceyhan in Turkey (1998), Izmit in western Turkey (1999), Taiwan (1999), and Hector Mines in Joshua Tree, CA (1999), demonstrate the wide range of human impact that can result from events of similar magnitudes. Earthquakes can affect any area within a broad zone and may pose great risk to human life and infrastructure, depending on settlement distribution and densities, in addition to building materials, engineering standards, and the like. Unlike hurricanes and, often, volcanoes, the ability to predict when an earthquake will happen still eludes us; however, where they will occur is well mapped by existing fault lines.

Of the many seismic digital mapping projects that have been undertaken, one of the most notable state projects stems from the 1990 California Seismic Hazards Mapping Act, which required the California Department of Conservation, Division of Mines and Geology (DOC/DMG) to map seismic hazard zones and identify *areas of risk* that are subject to potential ground failure. The purpose of these maps is to assist cities and counties in regulating the development in hazardous areas, to indicate locations requiring mitigation, and to assist in making disclosures for the California Natural Hazard Disclosure Act (AB1995). These maps show amplified shaking hazards zones (areas where historic amplified ground shaking has occurred) or local geological and geotechnical conditions indicate a potential for ground shaking to be amplified to a level such that mitigation would be required. They also depict areas of past or potential liquefaction (ground displacements) and past or potential earthquake-induced landslides. Urbanized areas have the highest priority for mapping and, to date, DOC/DMG has mapped most areas in the counties of Alameda, Los Angeles, Orange, San Francisco, Santa Clara and Ventura at a 1:24,000 scale (California Department of Conservation). There are plans to release and distribute these maps to the public on the Web in a variety of data formats (e.g., GIF and PDF) that would be compatible with the most available GIS software.

At the federal level, the U.S. Geological Survey (USGS) has produced the National Seismic Hazard Maps, which were made available on the Web in 1996. These maps cover the conterminous U.S. and depict probabilistic ground motion and spectral response with return times of approximately 500, 1000, and 2500 years. The nation is divided into two regions (central-east and west) for which separate calculations for attenuation relations are used. For the western portion, the maps use a grid spacing of 0.1° (for the east, grid spacing is 0.2°). For grid cells with historic seismic events, seismic hazard is determined based on the number of events greater than the minimum magnitude. For areas with little historic seismicity, "background zones" were created based on discussions at regional workshops (Frankel 1996). Also, at the federal level, predictions by the Federal Emergency Management Agency (FEMA) (using GIS to assist) brought unprecedented efficiency to the process of providing quick relief to victims of natural disaster. After the Northridge earthquake in northern California on January 17, 1994, FEMA reported that 560,000 households would be affected; the agency received approximately 600,000 applications for help.

A notable local or regional organization in the area of seismic hazard mapping is the Association of Bay Area Governments (ABAG). With the help of the USGS and the National Science Foundation, the ABAG has been using GIS technology since 1975 to produce seismic hazard maps for the Bay Area (USGSb, USGSc). The maps, which include designations of fault study zones, ground shaking intensity fault traces, and tsunami inundation zones, are easily combined with other data sources, such as the U.S. Bureau of the Census Topological Integrated Encoding and Referencing (TIGER) street and boundary files, to help local planners in land use decisions and mitigation planning.

Volcanic Phenomenon. Volcanic phenomena can destroy vast areas of productive land and human structures, destroying and killing the population of entire cities (Sheridan). Major eruptions of the recent past include Mount St. Helens (1980), El Chichon (1982), Nevado del Ruiz (1985), Unzen (1991), and Pinatubo (1994). Mount Rainier currently has the potential to threaten the cities of Tacoma and Seattle, and Popocatepetl menaces an area near Puebla and Mexico City, home to more than 10 million people. Hazardous volcanic phenomena range from passive gas emission and slow effusion of lava to volcanic explosions accompanied by the development of a stratospheric plume with associated dense descending currents of incandescent volcanic ash and rocks that race at high speeds along the surface away from the volcano (nuée ardante). Mass movement of surficial materials takes the form of rock falls and avalanches or even the sudden collapse of large sectors of the volcanic edifice. These phenomena and their associated water-saturated debris flows are extremely dangerous geological events and have caused tens of thousands of deaths during the past two decades (Brantley). In many cases, the loss of life could have been reduced if public safety officials and the general population were aware of the potential effect of the phenomena on their local environment.

The management of hazards related to volcanoes in the U.S. is administered by the USGS. The worst instance of volcanoes in the U.S. is the eruption of Mount St. Helens that began in 1980, killing 79 people and disrupting the surrounding areas for several years. Long Valley, California has experienced several crises in the past three decades and is potentially dangerous. The potential rupture of Mount Rainier (and other Cascade Range volcanoes) presents a risk to a very large population and infrastructure. Hazard maps at various scales exist for most of the potentially active volcanoes of the U.S. In contrast, most dangerous volcanoes in developing countries lack adequate hazard assessment and map coverage.

The use of GIS in volcanic hazards studies is very modest. The first papers appeared in the late 1980s and approximately two papers per year have been published during this decade. About half of the topics addressed have been mass movements (landslides and debris flows), and the remainder examined general topics. Sophisticated themes such as distributed computing, visualization, the use of large data sets, and interactive modeling and analysis are lacking.

Volcanoes usually present a known source area of threat, in contrast to earthquakes, which could affect any area within a broad zone. This makes volcanoes particularly appropriate for GIS analysis. In the U.S., the geological histories of most volcanoes are sufficiently understood to forecast the types of phenomena to be anticipated. The relative magnitude and frequency of future events are harder to predict. A complicating factor for volcanoes is that the repose time since the previous event may be very long. The inhabitants surrounding the volcano may have a belief that even if there were eruptions in the past, nothing will happen within their lifetime. At any rate, they are willing to take a chance that they are safe.

The last decade of the 20th century witnessed the development of several forms of computerized models for volcanic eruptions and their associated hazards (Sheridan). Unfortunately, these have not often been linked to interactive GISs. Computation, communication, and information technologies during this period have advanced at a faster rate than the development, testing, and utilization of controlled scientific models. In general, posters, still images, or video scenes of events at other volcanoes have been the main methods used to explain the phenomena to public safety officials and to illustrate potential events at a volcano in crisis to the local inhabitants. Only in a few cases have advanced technologies or computer models been used in the development of volcanic hazard maps.

Tsunami. Tsunamis, like earthquakes, are difficult to predict, but their inundation zone along the coastline can be mapped and an early warning can result. A National Tsunami Hazard Mitigation Program was initiated in July 1994 when the Senate Appropriations Committee directed the National Oceanic and Atmospheric Administration (NOAA) to formulate a plan for reducing the risks of tsunami to coastal residents (TIME, 1999). The program is designed to reduce the impact of tsunamis through hazard assessment, warning guidance, and mitigation. The first step for producing tsunami inundation maps is to assess the tsunami hazard. The Center for Tsunami Inundation Mapping Efforts (TIME) within the Pacific Marine Environmental Laboratory (PMEL) of the NOAA (Bobbitt 1999) was created for the purpose of developing, maintaining, and upgrading maps that identify areas of potential tsunami flooding.

The PMEL maintains large databases related to the research and exploration of hydrothermal vent processes and applies GIS to integrating multidisciplinary data sets to create both a map gallery and an Internet live map (Tsunami Research Program). The states involved in the PMEL Tsunami Program are Hawaii, California, Oregon, Washington, and Alaska, and they seek to mitigate hazards by focusing development on improved tsunami inundation maps, hazard assessment tools, and advanced technology to increase the speed and accuracy of tsunami forecasts and warnings (Trudeau 1998).

Landslide. Although landslides can destroy human infrastructure and potentially be deadly, with the exception of a few famous incidents, their impact is generally localized and predictable. The USGS has been extremely active in mapping landslide hazards and in developing new methods and models for assessing and analyzing these hazards. In anticipation of the heavy El Niño rains in 1997-98, scientists from the USGS's San Francisco Bay Landslide Team (SFBLT) created landslide hazard maps of the Bay region (USGSc). Following the rains, the San Francisco Bay Area Region Project and their Landslide Hazards Program, both part the USGS, conducted inventories of landslides in the Bay Area, which were then used to develop digital landslide distribution databases, computer landslide models, and landslide hazard maps (USGSb). The SFBLT created digital maps that depict areas of potential slides (slumps and translational slides), earth flows (flows of clayey earth), and debris flows (rapidly moving slides). The map layers include topography in shaded relief, road networks, hydrography, mapped distributions of slides and earth flows, rainfall thresholds for debris flows, and likely debris-flow areas. Most of these data are mapped at the 1:125,000 scale (for local emergency planning) and at the 1:275,000 scale (for regional planning). These maps are part of an overall strategy to assist planners in mitigating and responding to disasters (Pikei 1997).

Additionally, the DOC/DMG has been active in mapping landslide hazards in the state. They produce six types of maps that depict landslide hazards. Among them are the Landslide Hazard Identification Maps, which are mapped at the 1:24,000 scale and show landslide features, landslide susceptibility, and debris-flow susceptibility. They were produced from 1986 to 1995 under the now-repealed Landslide Hazard Mapping Act. Another type are the Watershed Maps, which are also mapped at the 1:24,000 scale and include landslide features to assist in timber harvest planning and water quality protection. They were produced in concert with the California Department of Forestry. Four categories of active and dormant landslides are depicted, including debris flows, debris slides, translation slides, earthflows, and torrent tracks. These maps cover parts of Mendocino, Humboldt, and Del Norte Counties.

Fire. In the landscape, fire is frequently a naturally occurring phenomenon and in the long run is often considered more beneficial than hazardous. However, Philadelphia's most famous citizen, Benjamin Franklin, understood the hazards of fire when it intrudes upon human habitat and wrote on the need to regulate urban growth in order to decrease fire and environmental hazards. Although wildfire is often considered a natural hazard, the extent of the hazard can be mitigated with sound land use practices and management. Today, the practice of fire suppression in both rural and urban environments mostly does not follow sound vegetation management plans and has created potential catastrophic conditions for fires. A fire hazard exists to a greater or lesser extent across the North American continent, but is greatest in California. The Mediterranean climate, the rugged topography, a shifting urban-wildland interface, and the recent practice of fire suppression all collaborate to create catastrophic conditions. In the hills east of the San Francisco Bay alone, 5298 structures have been lost in dozens of fires since 1920 with the majority of fires occurring in the last decade (Radke 1995).

GIScience plays a critical role in mapping and documenting fire, then subsequently predicting its course, analyzing alternative fire-fighting strategies, and directing tactics and strategies in the field. The California Department of Forestry (CDF) began an intensive program of mapping fire in response to legislation in the early 1980s. This legislation required the CDF to map different classifications of fire hazards with State Responsibility Areas, or areas of state fire prevention responsibility (i.e., outside of large, incorporated cities). As a result of the catastrophic Oakland Hills fire, the Bates Bill (AB337) was passed in the California legislature in 1992. This bill required the CDF to work with local fire authorities to map Very High Fire Hazard Severity Zones within Local Responsibility Areas, generally referring to areas subject to wildfire hazard that are within incorporated city boundaries. These maps are intended for the purposes of enforcing roofing and vegetative clearance requirements, in addition to serving as the basis for disclosure statements in real estate transactions under AB1195 (CERESa). For both types of maps, fire hazard is determined on the basis of fuel loading, fire weather, and slope, among other criteria. Vectorized fire hazard zones were overlaid on USGS topographic maps at 1:24,000, 1:62,500, and 1:100,000 scales (Irby, 1997, CERESb, and CERESc).

Nationwide, the U.S. Forest Service has implemented the Wildland Fire Assessment System, based out of the Forest Service's Rocky Mountain Research Station. Unlike the mapping efforts of the CDF, this system is designed more for short-term fire danger warning than for long-term hazard assessment. The system continually generates maps of fire weather and fire danger components of the National Fire Danger Rating System, based on daily observations from 1500 weather stations throughout the U.S. Because each station is merely a sampling point, values between stations are estimated with an inverse distance squared technique using 10-km grids. The Fire Danger Rating Maps that result are based on current and antecedent weather, fuel types, and the state of live and dead fuel moisture. Fuel models to be used are generally decided upon by local managers. Weather forecasts are based on data from the National Weather Service. Live fuel moisture is generated from greenness maps, derived on a weekly basis from Normalized Difference Vegetative Index data from satellite imagery. Dead fuel moisture is available on digital maps showing 10-hour, 100-hour, and 1000-hour fuels. Additionally, drought maps and lower atmosphere stability index maps are used (USDA Forest Service).

At the local or neighborhood scale, mapping and modeling topography and fuel load based on vegetation and structures are gaining in popularity due to advances in geographic information technology. The 1991 Oakland Hills fire resulted in a local study integrating fire models and data inputs within a GIS to map the potential *firestorm* risk (Radke 1995). Although much of these input data were encoded by hand, many additional GIS encoded databases have since become available with Web delivery. This simple advance has not only led to additional modeling, it has stimulated the development and use of new fire models embedded within GIS. FARESITE, a stand-alone fire growth simulation model, is a good example of such a model. It runs within several GIS software (ArcInfo, ArcView, or GRASS) and is used to simulate wildland fire growth and behavior under complex conditions of terrain, fuels, and weather.

Floods. Flood zones can be mapped and floods predicted with some degree of accuracy. The widest-scale and most systematic mapping of flood hazards comes from FEMA. FEMA produces flood insurance rate maps (FIRMs) for the purposes of determining if properties lie within the "floodway" of a river system or the 100-year flood plain (FEMA, Map Service Center). These maps form the basis of FEMA's policy under the 1969 National Flood Insurance Act (and later amendments). These policies call for the restriction of development in the floodway and require the purchase of flood insurance and/or flood proofing for structures within the 100-year flood zone. FEMA has worked in recent years to make these maps digitally available.

As part of a Map Modernization Program, Digital Q3 flood data were developed by scanning FIRM hardcopies and vectorizing flood zones as a thematic overlay, including the 100- and 500-year floodplains (i.e., 1% and 2% annual probability of flooding). Q3 data do not contain all the information from the FIRMs and are not as accurate. Rather, Q3 data are intended to support regional-scale uses, such as planning activities, insurance marketing, and mortgage portfolio reviews. For more precise parcel-based queries, or for engineering analysis, the more detailed digital (DFIRMs) or paper FIRMs are more appropriate. DFIRMS include all of the information required to create a hard copy FIRM in digital form. This includes base map information, graphics, text, shading, and other geographic data necessary to meet the standards and specifications set for FIRMs. These data provide the basis for the digital line graph of flood risks, known as DFIRM-DLG (FEMA, Map Service Center).

Another very different application of flood mapping technology was used to assist emergency managers in the evacuation of flood-prone areas in North Carolina prior to Hurricane Fran in 1996. Before this hurricane, the North Carolina Center for Geographic Information and Analysis had used the Sea, Lake and Overland Surges from Hurricane (SLOSH) model to prepare several Hurricane Storm Surge Inundation Area maps for coastal areas of the state, showing the historic extent of storm surge inundation. The model was used to produce maps showing flood extent under conditions of slow- and fast-velocity hurricanes. These flood extents were then overlaid on 1:24,000 USGS topographic quads. Based on the SLOSH model, Hurricane Evacuation Restudy Maps were prepared that were used to guide the evacuation of residents from low-lying and coastal areas. These maps were also used by other agencies, such as the Division of Forest Resources, which prepared overlays of these maps with forest cover layers to predict the amount of forest damage (Dymon 1999).

The Office of Emergency Services of California (OES) has produced digital flood maps depicting areas at risk from dam failure. These maps are intended to be used by local and state officials in devising emergency procedures under the Emergency Services Act (Section 8589.5 of California Government Code) and in making natural hazards disclosure statements under the California Natural Hazard Disclosure Act (AB1195) (CERESa). The inundation maps produced by the OES represent the best estimate of where water would flow if a dam failed suddenly and completely under full-capacity conditions, recognizing that later downstream land use changes may affect the extent and intensity of inundation. These digital maps were produced by scanning paper blue line copies of the original maps, are organized by county, and are available from the OES Web Site as PDF files.

Tornadoes. Tornadoes are one of nature's most violent storms. In an average year, 800 tornadoes are reported across the U.S., resulting in 80 deaths and more than 1500 injuries, which is the most severe of any country in the world (Edgetech America, 1999) These violently rotating columns of air extend from a thunderstorm to the ground and are capable of tremendous destruction with wind speeds of 250 mph or more (NOAA). Damage paths can be in excess of 1 mile wide and 50 miles long. Tornado strength is measured on the F-scale, ranging from F0 through F5, with F5 being the most powerful storms.

Although GIS is employed to map and summarize the events of tornadoes, in a growing number of communities it is used in real time on the front line. On the evening of May 3, 1999, the National Weather Service issued a tornado warning for southeastern Sedgwick County, Kansas (DeYoe 1999). Although not officially part of the emergency response personnel, the Sedgwick County GIS Department produced more than 300 maps for the Emergency Operations Center to get initial locations of damage reports and identify the actual properties. A probable path, a damage map, and estimated values based on the damage reports received up to that time were provided.

Hurricanes. Hurricanes can destroy human infrastructure and habitat, killing and impacting large populations across vast territory (NHC). We only have to refer to a few (Agnes (1972), Hugo (1989), Andrew (1992), and now Floyd (1999)) to illustrate the damage and loss to society.

After the devastation of Hurricane Andrew, FEMA upgraded its pre- and post-disaster planning and response capabilities. The GIS-based system, called the Consequences Assessment Tool Set (CATS) and developed by Science Applications International Corporation, enables FEMA to predict the effect of impending disasters such as hurricanes and to quickly mobilize a well-coordinated and directed response (Corbley 1999, and Kehlet 1998). This allows FEMA to pinpoint critical evacuation areas as well as make accurate damage predictions for phenomena such as storm surge and wind damage that facilitates a quick recovery (Trudeau 1998).

As disaster strikes, CATS, using combined government, business, and demographic databases, produces reports and graphics that provide emergency managers and the national media with timely information. Known damage is reported along with mapped estimates of the extent of damage and affected population. Suitable mobilization sites are identified along with nearby airstrips, empty warehouse space, and information regarding federal and local sources for disaster relief. When hurricane Eduardo (1996) was threatening to endanger the U.S. coastline, FEMA identified areas of potential water contamination and quickly moved freshwater supplies to those sites ahead of the storm.

In the aftermath of Hurricane Mitch, the USGS's Center for Integration of Natural Disaster Information (CINDI) created a digital atlas containing more than 60 different types of geospatial information (DOI). These new maps showed the locations of landslides and floods, damage to roads, bridges, and other infrastructure, precipitation information, and the impacton agricultural lands. The information used to create these maps came from remote sensors as well as existing ancillary databases such as geological maps, aerial photos, and dozens of other digital and paper sources. The maps, which are available at the CINDI Web Site (http://cindi.usgs.gov/), serve as a critical resource for allocating resources in short-term relief efforts, for understanding the disaster's long-term impact on ecosystems, and for planning the region's economic recovery and reconstruction.

Human-Induced Hazards That Impact Humans and Environs

Unlike many natural hazards, most human-induced hazards could be prevented, reducing or even eliminating loss of life and damage to property. With a better understanding of the underlying forces that induce disasters, we can work toward mitigation and the possible elimination of some of these hazards.

Health-Related Epidemics. Epidemiologists use maps to log location, encode association, and study the spread of disease (Clarke et al. 1996). Add to the map, the ability to undertake spatial analysis through advances in geographic information tools and the result is a technology that is well suited to tracking disease. Studies that quantify lead hazards (Tempalski 1994), model exposure to electromagnetic fields (Wartenberg 1992), and monitor air- and water-borne diseases all benefit from the development of technologies in GIScience.

GIS was used to identify and locate environmental risk factors associated with Lyme disease in Baltimore County, Maryland (Glass et al. 1995). Watershed, land use, soil type, geology, and forest distribution data were collected at the residences of patients with Lyme disease and combined with data collected at randomly selected addresses to fuel a model detecting the most probable locations where Lyme disease might occur. With GIS, it is much easier to combine epidemiology data and ecological data to model and predict disease spread and transmission. This data integration is essential if we hope to mitigate in this hazardous area through better health policy planning,

At a national level, GIS has been used to help design a surveillance system for the monitoring and control of malaria in Israel (Wood et al. 1994). The GIS-based surveillance system located breeding sites of *Anopheles* mosquitoes, cases of imported malaria, and population centers in an effort to better respond to the outbreaks.

On a global scale, the National Aeronautics and Space Administration (NASA) established the Global Monitoring and Disease Prediction Program at the Ames Research Center to identify environmental factors that affect the patterns of disease risk and transmission (Ahearn and De Rooy 1996). The program developed predictive models of vector population dynamics and disease transmission risk using remotely sensed data and GIS technologies and applied them to malaria surveillance and control (Beck et al. 1994)

Social Unrest – War. Although one could argue that war is a good candidate for a health-related epidemic via germ warfare, the use of geographic information technologies by the military has been more proactive than simply monitoring and surveillance.

The National Imagery and Mapping Agency (NIMA, 1999b), a major combat support agency of the Department of Defense and a member of the intelligence community, was established in 1996 to provide accurate imagery, imagery intelligence, and geospatial information in support of the nation. For example, during the 1995 Bosnia peace accord, the Defense Mapping Agency (now NIMA) employed technology called Powerscene, developed by the Cambridge Research Associates, to recalculate the territorial balance between rival factions as the borders were modified and adjusted based on landscape and political conditions. This interactive process was undertaken at Wright-Patterson Air Force base in Dayton, Ohio where orthorectified imagery and digital terrain elevation data were integrated to produce a Terrain Visualization Maneuvering Support system (NIMA 1999a). This system enabled the commanders and peace negotiators of the North Atlantic Treaty Organization to tour the 650-mile cease-fire border and any disputed territory without endangering lives on the ground.

GIS is also used as a tracking tool for troops in training and combat, and as a planning and negotiation tool for peacemakers. A prototype terrain visualization system was installed at the National Military Command Center in the Pentagon in 1994 to help support national command level missions such as locating downed aircraft (Scott O'Grady's F-16) and troop withdrawals (from Somalia) (NIMA 1999b). To serve such technology better, NASA's Shuttle Radar Topography Mission (SRTM) collected vital very high-resolution elevation data during February 2000. The mission, a partnership between NASA and NIMA, will use the data to generate digital elevation models and three-dimensional pictures of the Earth's surface. In addition to scientists using the data to study flooding, erosion, land-slide hazards, earthquakes, ecological zones, weather forecasts, and climate change, the military will use it to plan and rehearse missions, improve weapon accuracy, and for modeling and simulation purposes.

Geographic information technology is also being used for environmental monitoring and clean up at several Navy installations as part of the Navy's comprehensive long-term environmental action program, and at the Rocky Flats Nuclear Weapons Complex (Bromley 1995).

Toxic Spills , Explosions, and Fires (Accidental or Otherwise). Man-made crises are extreme events that can be accidental, such as toxic spills, or premeditated, such as bombings by terrorists. No matter what the origin, many of these human-induced disasters could be lessened or even prevented by integrating geographic information technologies. For example, in a case of release of toxins, population data, residential locations, and wind speed and direction could populate a model to map the extent of the disaster and suggest evacuation strategies.

All crises require an immediate and well-coordinated response where data handling and system interoperability are critical. In addition to the political and technical challenges of fusing data from mixed sources, proprietary data formats often impede interoperability. Commonalities such as coordinate systems and the representation of locations, boundaries, and aerial features must transcend a broad community of users and tool vendors. Metadata are crucial for identifying and managing the quality of data, while access protocols and retrieval parameters will determine the speed of extracting data from a digital archive or library. During a crisis, such as the Oklahoma City bombing, data-access speed is paramount for rescue workers, and advances in robust indexing mechanisms, such as geographic footprints (Goodchild, 1996), will prove invaluable. Although many successful initiatives are already underway at both the local and the national level, they could greatly benefit from advances in GIScience.

The city of Winston-Salem, North Carolina built an Integrated Network Fire Operations (I.N.F.O.) system that is designed to reduce the time it takes for firefighters to respond to emergency (911) calls and to provide information about the address of an incident to aid fire fighters in making better-informed decisions and plan the fire-fighting effort while en route (Chakraborty and Armstrong 1996). I.N.F.O. automatically uses the address of an incident to search for any prefire and HazMat planning information that might be available (e.g., building floor plans, hazardous waste information, and occupants).

FEMA developed HAZUS, a natural hazard loss estimation methodology software program that is useful for earthquake-related mitigation, emergency preparedness, response and recovery planning, and disaster response operations (FEMA, HAZUS). HAZUS is implemented within personal computer-based GIS software.

Linkages to UCGIS Research Challenges

The search of hazards to determine UCGIS application challenges for emergency preparedness and response not only demonstrated how geographic information is being integrated into solutions, it also illustrated the important role that the Web now plays in communication and disseminating information to the public for mitigation, management, and recovery from a disaster. Although much of the information on the Web might be represented as a document, the results, often displayed in graphic form, are clearly the result of applying geographic information technologies to the problem. In some instances, it is clear that geographic information technology has advanced the information from simply data display to output from an advanced modeling effort.

UCGIS research priorities are all applicable to emergency preparedness and response. While recommendations for specific research contributions are discussed in the last section, it is valuable to report on activity and needs for specific UCGIS research priorities here. To illustrate emergency preparedness and response needs within these UCGIS research challenges, some scenario building is undertaken.

Spatial Data Acquisition and Integration

Data acquisition and integration may be the single largest contribution area needed for emergency preparedness and response. Although models can be developed for handling disasters, making them operational on a day-to-day basis means huge investments in data acquisition and integration.

There are essentially three parties that have spatial information needs in an emergency management arena. These include

Table 1. Spatial information needs.

Interested Parties	**Disaster Cycle**		
	before	during	after
public sector personnel			
private citizens			
researchers			

public sector authorities such as emergency managers and government agencies, private citizens, and researchers. Also, as discussed above, the disaster cycle can be divided into the temporal stages of before, during, and after a disaster. Using these two dimensions, we can define a matrix where each cell represents a given party's spatial information requirements at each stage in the disaster cycle.

This matrix can be used to examine the information needs of various parties at various stages in the disaster cycle. For example, if we focus on the cells in the diagonal, the cell in the upper left-hand corner of the matrix would represent the public sector's spatial information needs before a disaster. This would include risk mapping, emergency simulation, and any other activities that involve spatial information in emergency planning or analysis. The cell in the center of the matrix represents the spatial information needs of private citizens during a disaster. This would include evacuation orders and routing, information about the spatial extent of the hazard, and any other information relevant for citizens. Finally, the cell in the lower right-hand corner would represent the spatial information needs of researchers after a disaster. This might include data on the processes that led to the disaster, the routes taken by evacuees, or any other relevant spatial information. It should be noted that there is a significant amount of overlap in the information needs of these parties during the various cycles of a disaster. However, the matrix supports the notion that the information needs of these parties are not identical.

A significant challenge in emergency management is delivering the appropriate information to the proper party at the appropriate place and time and in a useful form. "Useful form" in this context refers to the scale, accuracy, and detail of the delivered information. The UCGIS research agenda for spatial data acquisition and integration should focus on research associated with questions and problems related to acquiring and integrating spatial information to meet the various needs of the parties listed in Table 1 for the given time periods.

As an example, assume that an engine company from county A has been instructed to respond to an emergency call in county B. The challenge is to provide the company with the nature of the incident and the needs of the parties in distress, the location of the incident, and, ideally, the best route to the site. This information must be delivered and in an appropriate form, where errors in the information may have serious consequences. The fact that the information must also be delivered in a timely manner puts unique demands on any system designed to deliver this information. It implies that there is a time window within which the information must be delivered to have value.

The overall research challenge in spatial data acquisition and integration for emergency management can be viewed as one of delivering accurate, appropriate information to all parties involved at the proper stages of the disaster in a timely manner. There are a number of research questions that can be generated from this overarching research challenge. Namely:

- What information should be provided to what parties at what times during an emergency?
- What sources of data are available for meeting these information needs and what data need to be collected during an actual emergency?
- What problems arise in integrating sources of spatial information with various levels of accuracy and detail to meet the unique needs of each party at various points in the disaster cycle?
- What amount of uncertainty can various parties tolerate when receiving information provided to them at various stages in the disaster cycle?

Distributed Computing

Modern computer simulations of complex natural phenomena, such as rapid forest fire growth or the development of a volcanic plume, require supercomputer facilities with distributed simultaneous computing on many processors. Linked to GIS, these models for pre-disaster planning, crisis management, and post-disaster recovery could become extremely valuable mitigation and response tools.

Although this level of analysis is not possible today, during a crisis, such a system could be highly interactive allowing real-time communication between parties and aiding in the execution of models that could be viewed remotely. This would allow scientists and civil protection agencies to apply results immediately to the current extremely dangerous conditions. Here, the data must be output in various levels of format complexity allowing images and animation of various scenarios to be viewed by scientists, decision makers, and the general public (with the approval of the appropriate public safety and government officials).

It is important that any new data systems be developed on a platform that is widely compatible with those of existing data users. It is also important that these systems be designed to run on thin clients, as in an emergency it is likely that portable, wireless computers will be the communication tool in the field.

Extensions to Geographic Representations

A key area to pursue is the dynamic representation of physical and human processes in emergency preparedness and response.

GISs have not traditionally been designed to represent dynamic phenomena, but this is critical in assessing and responding to emergencies. Very little research has been conducted in this area, despite the obvious consequences of making critical decisions with inaccurate or incomplete information.

There is a need to improve our representation of risk and human vulnerability. The computational representation of human vulnerability has lagged behind the theoretical advancements in this area. As such, GIS is not representing the depth and richness of the theoretical frameworks, and empirical research on human vulnerability to environmental hazards remains incomplete. Risk and human vulnerability are much more dynamic than the representations that are now being used in GIS. There is a need to be able to rapidly model and summarize alternative scenarios, especially when the future is uncertain (e.g., tornado, hurricane, or fire).

Before proceeding to extending representations, it is important to make sure that the representations available are up to date. In many cases, the data on which emergency managers rely are simply out of date. As an example, during the recent tornado season in Oklahoma, many schools were not included in the 1997 TIGER database. We need to progress to hazard, risk, and vulnerability classification systems that include multiple hazards. An example of this approach is the Community Vulnerability Assessment Tool for New Hanover County in North Carolina, developed by the NOAA Coastal Services Center. However, most research in this area has focused on single-hazard scenarios. In other words, classifying based on just one hazard. Finally, there is a need to develop representations of past disasters and events both static and dynamic: What factors led to a particular disaster? Where did the event occur? What development has taken place since the last disaster? How many hazardous events have occurred at a particular location?

Cognition of Geographic Information

The scientific domain of the cognition of geographic information includes humans, computers, and the earth. Research in this area centers on questions related to human conceptualizations of geographic spaces, computer representations of geographic space, and human perceptions of computer representations of geographic space. During a crisis, the emergency worker has the added pressure of time, and the representation and depiction of complex spatiotemporal information can easily be overwhelming. Uncertainty increases when decision making is data-starved, the process of extracting support information is flawed, or communicating information accurately and effectively is impeded. Mistakes can serve to magnify the crisis or even propagate false hope or false fear leading to greater disasters resulting from evacuation. A balance between sufficient information and inducing panic and overreaction is critical.

The trend toward digital information foreshadows potential data saturation where emergency workers would be overwhelmed by vast influxes of digital data from a variety of sources such as HazMat, police, transportation, weather, demographics, social welfare, etc. Automated or robotic processes will be necessary to cull and mine these data into a manageable and worthwhile emergency assist tool. Algorithms will replace humans at the firing line where geographic information is synthesized for modeling and decision-making purposes. Getting this accurate is critical in healing rather than exacerbating disasters. Emergency preparedness is heavily influenced by social decision-making processes that depend in part on how information is understood and communicated between participants in groups. Improvements in representations, operations, and modeling of spatial data are needed and are very real. The UCGIS directives on research in the cognition of geographic information address many issues relevant in emergency preparedness and response.

Interoperability of Geographic Information

The technical problem of interoperability arises from the need to share data, algorithms, and models (DAMs). What DAMs need to be shared in emergency management arenas? Institutions must know about DAMs that exist elsewhere before the need to share data arises. International attempts are in progress in the area of sharing geographic information for emergency management purposes. The Global Disaster Information Network (GDIN) is a prominent example.

GDIN is an interagency program that was undertaken at the initiative of Vice President Al Gore to assist fire and emergency management personnel. It has two proposed components: 1) a national disaster information network; and 2) a global system. It will operate on the Internet and, possibly, Guardnet (National Guard Network) during disasters to broadcast and integrate disaster management information from all sources and provide it rapidly and readily. Training and communication in the areas of emergency preparedness and mitigation will also be promoted. GDIN is expected to produce many benefits including saving lives and minimizing costs, enhancing the coordination and sharing of compatible capabilities, facilitating the leveraging of existing resources, and assisting in validating and verifying information. To date, completed projects include the State of Florida Hurricane Simulation Exercise and the State of Alaska "Information Process Flow Report." In addition, a regional, theme-based disaster information network is being developed to promote collaborative activities between the U.S. and Canada. The Red River Basin Disaster Information Network was established in response to the 1997 flood-affected portions of North Dakota, Minnesota, and Manitoba.

Experience has shown that a top-down approach to data sharing in disaster management is not entirely effective. The problem of interoperability in emergency preparedness and response must be approached by first assessing the needs of the use: What geographic information needs to be shared? What information needs to be acquired? What information exists in other agencies, institutions, and companies? Data sharing and interoperability of geographic information must occur under tremendous time constraints in emergency preparedness and response. There are incompatibilities between physically based forecast models and the data stored in geographic databases. This is the data integration, or coupling, problem in all its forms.

Scale

The Digital Elevation Model (DEM) resolution is not adequate for many applications in risk mitigation. Until the February 2000 SRTM space shuttle mission, better DEM data were available for Mars and Venus than for the Earth and it may be many years before sea-floor and sub-ice surfaces are acquired at similar resolution. Even now, the SRTM data will move more rapidly into the military domain than into civilian use. Present applications use simplified flow models that display results in two-dimensional form as data files or images. Such small data sets are easy to use on personal computers or workstations, and computational nodes for models are widely spaced. For example, standard DEM data sets have 30-meter spacing of nodes, and working files are on the order of megabytes. Although these data make very large files for ordinary computers, the detail is insufficient for the realistic prediction of many natural phenomena for which small differences in topography or other parameters could have a large effect on the spatial pattern of the result. A more suitable grid spacing could be meter-scale and the data sets could be as large as one or two gigabytes. The development of such large data sets on a supercomputer could provide a valuable source that could be distributed for use at various remote GIS sites.

Current risk simulation codes work on small areas with large grids and are slow. Future codes should operate on fine grids of data sets that include the entire area of risk surrounding, for example, a volcano. For optimal use, the data will be a high-density grid of topographic points (x, y, z data) at a horizontal spacing of 10 to 30 meters and a vertical increment of 1 to 10 meters. The areas encompassed by a single network may be as large as 50-km x 50-km grids. Such a large computational grid is too large for a single processor computer and, hence, supercomputers are necessary for the computation and visualization. Even finer resolution data will be required for cities to model the movement of fire, chemical, or biochemical plumes through complex urban canyons. Currently, such data are being acquired by laser and lidar devices.

Spatial Analysis in a GIS Environment

Computer simulations linked to GISs could permit analysis of loss of life and disruption of infrastructure that is not possible with the current set of available tools. Sophisticated visualization systems allow public safety officials, scientists, and the general population to understand the effect of the various phenomena in their areas of interest and to design appropriate mitigation plans. A three-dimensional visualization system could provide an animated illustration of the areas threatened by volcanic phenomena at several scales.

Perspective views of the phenomena could be interactively manipulated to include a spectrum of possibilities ranging from individual rivers, streets, and buildings to entire disaster scenes. Overlays of images on topographic grids would create a realistic 3-D appearance of the phenomena that will move in real time with data moving in and out of the system dynamically. The GIS interface could allow query and manipulation at various levels and between multiple viewers at different sites. The use of CAVE (CAVE Automatic Virtual Environment) (Pape et al. 1996) or even holograph technology could create realistic simulations necessary for training and prevention missions, as well as for coordinated, distributed simulations for the management of multiple actors in disaster response.

It is important that scientists involved in the GIS analysis have the capacity to interact in several different ways. Multiple windows on their computer desktops could allow interaction via the Internet. Such an interaction would enable explicit equations or mathematical expressions to be sent at the time of crisis. This could permit scientists to continuously update parameters and expressions that represent, for example, the current scientific state of the lava flow. These changes could then filter through all other areas of the system infrastructure, providing scientists with the ability to see the effects immediately. Another window could display a representation of the volcano or area around it, in the form of a picture, graphic, or other visual representation. A third window could control general functionality of the other windows. For example, automatic refreshing of all information and what files are viewed. At any time, a scientist could change this set-up. It would also allow the scientist to have multiple graphic windows and no equation interface if desired. This type of interface should focus on communicating the nature of the disaster, including the magnitude, extent, and uncertainty of the event. A very important element is to ascertain the risk of making a wrong decision.

The Future of Spatial Information Infrastructure

Emergency managers rely on a system for managing emergencies called an “incident control system.” This system specifies exactly the function that a party (e.g., police, fire, highway patrol, or mayor) is responsible for during an emergency and precisely how communication, authority, and many other critical facets of the emergency management process are to take place. The system is nationwide at local and state levels. Is there an equivalent institutional protocol, procedure, or approach for agencies to determine exactly who will collect and share geographic information before, during, and after an emergency? The UCGIS could be central in developing and disseminating model data-sharing procedures that address the institutional and technical issues associated with geographic information data sharing in emergency preparedness and response; an “incident control system for geographic information,” if you will. This might exist in the form of information sources, flows, and ultimately application. There is also a need to develop foundation data models for sharing geographic information that is multidimensional, multi-scale, and multi-source in nature.

Uncertainty in Geographic Data and GIS-based Analyses

As methods and models of GIS analysis become more sophisticated, the quality of data increases in importance. Many data sets undergo temporal adjustments that add an uncertainty to the analysis. For example, using data just 1 or 2 days old in volcano forecasting at the time of the crisis would lead to a faulty conclusion. The same is true of other disasters where geopolitical or natural conditions change from moment to moment. It is important to be able to analyze and incorporate such temporal uncertainty in the analysis and forecast that we make.

We must be able to quantify the uncertainty in the data (and the analysis) and express this in a satisfactory mode. A major problem exists in how uncertainty is reported in GIS. For example, what significance do we place on the lines on various maps and diagrams? How do we address this issue? A case in point would be designing a hazard map for flooding on an alluvial fan where there is no defined channel and the flood has different probabilities of spreading in various directions. Another major problem is the propagation of uncertainty through the data set as we combine several sets of data of different levels of confidence and even potentially different types. Research on this topic should help to resolve this problem.

GIS and Society

GIS is the "new new thing" in society and new things often arrive with added baggage. Questions arise about rates of adoption and participation across society. Is there equity of access? Is there equity in the distribution of the costs and benefits? Access to GIS can simultaneously marginalize and empower different groups in society. The adoption of geographic technologies to emergency preparedness and response can fall prey to this equity-of-access issue where some groups are kept safe at the expense of those that cannot afford the technology. Risk assessment and subsequent mitigation actions can impact a community and have a wide range of consequences. Incomplete data can lead to unwarranted fears, restrictive and costly regulation, and even serve to affect property values. These can all lead to increases in disaster insurance, bias in the allocation of emergency resources, and the attachment of stigma to a neighborhood. There is a strong need for public participation, both in developing GIS for emergency preparedness and for gaining access to it during a disaster. This sense of participation and ownership has implications for empowerment within community and grassroots groups who are often relied upon during emergency response.

Defining potential barriers between GIS technology and different segments of society will aid in delivering critical information during a crisis. Often, information considered private becomes invaluable in managing a disaster but also raises legal and ethical questions about intrusion into private lives. What role, responsibilities, ethics, and motivations in disseminating geographic information for warning, preparedness, and response do the media play? How are new technologies such as pagers, hand-held devices, and other electronic innovations affecting equity, vulnerability, and the perception of risk? How are issues such as socio-economics, insurance, race, and other issues related to the application of geographic information in emergency preparedness and response? Much research is needed addressing GIS and society.

Linkages to UCGIS Education Priorities

The search of hazards to determine UCGIS application challenges for emergency preparedness and response illustrated the important role that the Web now plays in communication and disseminating information to the public. It appears that an informed population is more prone to accept and even embrace mitigation, respond and participate in the management of a hazard or emergency, and be better equipped to assist and appreciate recovery from a disaster. Much of the information on the Web is commonly represented as a document; however, images, maps, and graphics illustrating the results of some analysis are slowly finding their way onto emergency preparedness and response-related Web sites.

UCGIS education priorities are applicable to emergency preparedness and response. The most important educational needs or components that surface when one looks at individual hazards, either natural or human-induced, focus on issues of certification of specialists to undertake response and settlement, public education and awareness of response during a disaster, the development of a model curriculum to train GIScience experts for emergency preparedness and response, and the development of simulators to train rescue workers and settlement specialists. It is clear that only a few people who work within this area will require in-depth education in GIScience, while most others will benefit by training on installed GIS-related technology. However, training needs to be presented within the context of the profession with appropriate amounts of spatial literacy and integrated with other technologies common to the profession.

To best illustrate emergency preparedness and response needs within these UCGIS education priorities, some discussion is undertaken here.

Emerging Technologies for Delivering GIScience Education

Technology is playing a central role in education at the college and university levels. In some instances it serves to lower the cost of education, while in others it enhances and even makes possible some opportunities never before imagined. Distance learning taught by domain experts, Web-based programs, and simulators to create better and cheaper technology are all served by these emerging technologies.

Emerging technologies make it possible to educate more people and are even more effective for training. It is now relatively common to find Web-based training courses where one can enroll and conveniently become well versed in GIS. However, unlike the rigors of the college classroom, quality, accreditation, and assurance are not clearly defined and regulated. Assessing liability and assuring accountability in a disaster may call for the regulation of emerging technologies as they are applied to education.

Supporting Infrastructure

As training and modeling in GIS become more the status quo for personnel in emergency preparedness and response, demands on technology classrooms and Internet portals will rapidly increase. Who will bear the cost of such infrastructure in the short run and will this persist and set a trend? Emergency preparedness and response support are recognized during a disaster when many groups step forward to lend a helping hand, but what is being done over the long haul to help mitigate and be prepared if a disaster strikes?

Access and Equity

The GIScience community must ensure access to the technologies and data to disadvantaged groups and impaired individuals so that they may also be effective in emergency preparedness and response in their communities. The first goal of this education priority is to ensure access and to determine what is the necessary "spatial literacy" to effectively use GIS. However, in an emergency, access and equity issues quickly shift from how effective is the trained emergency worker to under what circumstances should rescue workers have access to private information? Under what circumstances may a community breach ownership rights in order to acquire and access data? In the heat of a disaster, is it impossible even to address some of these issues let alone come up with solutions?

Alternative Designs for Curriculum Content and Evaluation

Although the basic GIScience concepts might be the same, as domains are crossed, specific concepts vary. Likewise, in emergency preparedness and response, the level of geographic information necessary for emergency workers to carry out their jobs varies. At one end of the spectrum a worker may need to be able to read a map, while at the other end a sophisticated understanding of spatial statistics might be in order. Delivering education under such extreme needs calls for a scaleable curriculum to increase the likelihood that GIS will be deployed properly and effectively in the emergency preparedness and response area.

Adopting these technologies and employing them in the field to save lives and property does not come easy. The emergency worker must have faith in the technology as well as confidence in the data. Building this confidence starts with a sound education where the student participates in data collection so that ownership and a stake in the data buy into its use in emergency preparedness and response.

Professional GIS Education Programs

The majority of emergency preparedness and response workers need training on how to use the technology to extract information about infrastructure, follow guidelines in assessing risk, navigate and follow procedures during a crisis, and assess damage after a disaster. It is likely that the majority of workers in this area will not have been widely exposed to geospatial technologies and professional training will play a key role in filling this gap.

Research-based Graduate GIS Education

To advance the state of any science, researchers must be educated so that they may lead on the frontiers of research and then train and collaborate with those emerging researchers to push those frontiers forward. Unlike professional GIS education programs where a student is trained to use the state-of-the-art systems, research-based graduate GIS education designs and creates new technology that will eventually define the path that new technology will take. Emergency preparedness and response researchers will benefit from this high-level focused approach and be able to build better sensors, predictors, models, and data management environments.

Learning with GIS

Learning with GIS in emergency preparedness and response employs a curriculum that emphasizes specific topics and uses geographic information to study them. Since most disasters can be mapped, GIS can provide a very effective navigation tool for dissecting problems and learning the steps necessary to deliver an effective response.

Proactive approaches to disasters lead to practice sessions where geographic information fueled simulators play out a variety of disaster scenarios. These simulators will play a critical role in educating the emergency preparedness and response community and its response strategies during an emergency.

Accreditation and Certification

Although accreditation and certification may carry with it problems associated with licensing, liability for emergency preparedness and response workers is a serious issue and accreditation and certification are most often embraced. Just as emergency response workers must be certified on their knowledge of search and rescue techniques and technologies, certification on the proper use of geographic information data is a necessary component if quality control and assurance are to be taken seriously.

Policy Implications

Both natural and human-generated hazards usually transcend political boundaries that are effective for defining regions used to successfully mitigate against disaster, manage rescue and response operations, or to organize and deliver relief. Since policy is most often generated and administered within politically defined boundaries, we must develop new policies that emulate hazards rather than human administrative structures.

Policy and regulation are commonly applied on the landscape as a function of form. For example, brush must be cleared to create a specific size protective buffer zone around homes in an urban-wildland intermix region. Although the specific buffer zone, represented here as a form, can easily be complied to and administered, it is naive and unrealistic to assume that the impact of this buffer zone will be uniform over space. Advances in GIScience will bring about a shift where policy and regulation can become a function of the underlying process rather than relying on an easily administered but limited form-based policy. The greater our confidence in data and models, the more likely that policy will be process-based rather than form-based.

Three primary policy arenas are: science policy, information policy (ownership, privacy, access, liability), and public policy. Within these arenas several questions arise with respect to emergency preparedness and response:

- If you have confidence in data and models, can policy then be *process-based* rather than *regulation-based*?
- Should there be different disaster access policies depending on pre-, during, or post-disaster? Is there a general policy to cover all possibilities? Can a policy be designed that is generalized across disasters?
- What information policies result in the most effective use of geographic information in emergency response situations? (For example, comparative studies are necessary where one examines the experience of city A with city B.) Is there a need to distinguish between pre-, during, and post-situations? Is there a need to compare unpredictable versus more predictable events (those that are time-dependent)?

Conclusions

Research and education in emergency preparedness and response are crucial as we search for conditions thought to be hazardous to life and habitat, undertake mitigation efforts, respond during emergencies to reduce loss of life and property, and settle and restore a damaged environment. In some instances, we found that early warning systems need to be built, while in other instances, elements that are more fundamental such as land use and life style need to be changed. In almost all instances, large databases that contain information on humans, their activities, and their habitat are necessary. We need to insure that these data are accessible to assess risk, prepare to engage disaster, and aid in effective response and settlement. Although they must be engineered to effectively assist emergency workers, we must also insure the privacy of the individual so that exploitation cannot occur.

We set out to discover whether advances in UCGIS research and education priorities might contribute to needs within the application emergency preparedness and response. By identifying and recommending priorities for research, educational and policy contributions to emergency preparedness and response, and cross-referencing them with the UCGIS priorities, we identify a focus for GIScience for this application challenge. We discovered that interaction between humans and their environment under conditions thought to be hazardous to life and habitat can be facilitated through advances in GIScience. Through emergency preparedness and response, we will be able to realize shifts where policy can be more directly linked to underlying process rather than simply the form that appears during and as a result of a disaster.

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Glossary

Emergency: a deviation from planned or expected behavior or course of events that endangers or adversely affects people, property, or the environment.

Disaster: the scope an emergency defines a disaster. An emergency becomes a disaster when it exceeds the capability of the local resources to manage it. Disasters often result in great damage, loss, or destruction.

Risk: the potential or likelihood of an emergency to occur. For example, the risk of damage to a structure from an earthquake is high if it is built upon, or adjacent to, an active earthquake fault. The risk of damage to a structure is low if no earthquake faults exist.

Hazard: generally a reference to physical characteristics that may cause an emergency (for example, earthquake faults, active volcanoes, flood zones, and highly flammable brush fields).