Transactions in GIS, 2003, 7(4): 439–445

Review Article

GI Science, Disasters, and Emergency Management

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Abstract
Societal responses to disasters begin with the initial post-event rescue and relief operations, followed by recovery, reconstruction, and then transcend into mitigation actions including the development of pre-impact preparedness measures, collectively known as the emergency response cycle. This paper highlights some of the applications of GI Science to the emergency response cycle, citing examples from natural hazards and from the World Trade Center disaster on 11th September 2001. More importantly, the paper describes some of the constraints on the utilization of GI Science by the practitioner community: understandable user interfaces; data quantity, quality, and integration; real-time data and information. Finally, the paper suggests some important GI Science research areas based on the needs of the disasters and emergency management research and practitioner communities.

1 Introduction

Globally, it is estimated that more than 535,000 people were killed by natural disasters during the past decade with more than $684 billion in losses from direct damages to infrastructure and crops (International Federation of Red Cross and Red Crescent Societies 2002). In the US every state in the union (except Alaska) has experienced at least $1 billion weather disaster in the past two decades (National Climatic Data Center 2003). The longer-term economic impact of these disasters, both domestically and internationally continues to affect economies at all scales (local to global).

Disasters normally are singular large scale, high impact events. They are different than hazards and risks (Cutter 2001). Hazards (defined as the potential threats to people and the things they value) arise from the intersection of human systems, natural processes, and technological systems. Examples include earthquakes, tornadoes, blizzards, floods, drought, industrial plant failures, terrorism, and air pollution. Hazard zones can

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be spatially delineated (such as the floodplain) and have a risk (the probability of a hazard or event occurring) estimator attached to it, such as the one percent chance flood (often called the 100 year flood). Disasters, on the other hand are an outcome of the risk and the hazard, and are difficult to spatially delineate beforehand, let alone assign a probability and magnitude estimator. Historically, sociologists and engineers studied disasters, primarily focusing on failures in the infrastructure and built environment and societal responses to the extreme event. Geographers, planners, and natural scientists studied hazards and risks, examining the underlying social and physical processes that produced the hazards and which precipitated the disaster event.

2 Emergency Management

There is a prescribed system of how societies respond to disasters, which often is referred to as the emergency response cycle (Figure 1). This cycle includes actions immediately following an event such as rescue and relief, to longer-term stages in the recovery process. As communities recover and rebuild in the aftermath of the disaster, the cycle moves into the mitigation phases where reconstruction is undertaken in ways that aim to reduce vulnerability and improve preparedness for the next unexpected event. GI Science has been used throughout all phases of the emergency response cycle, although in some phases more than others. For this paper, the term GI Science is used in its broadest sense to include the suite of geographical information methods, models, processing and visualization techniques such as GPS, GIS, remote sensing, and spatial analysis. This paper highlights some of these applications and offers some suggestions for improving the utilization of GI Science in disasters research and emergency management.

Through technological advancements, GI Science tools and techniques have improved our identification of hazard events, especially in real or near-real time. Examples include the use of NEXRAD (Doppler Radar) to identify the hook echo in a thunderstorm super cell containing a violent tornado, to the range of satellite sensors (Aster, MODIS, TOMS) that monitored the 1997 fires in Southeast Asia or the western forest fires in 1998 (Jensen 2000, King and Herring 2000). Monitoring global drought conditions (Kogan 1995) or examining the spatial extent of drought severity in the U.S. on a weekly basis (LeComte 2003) are additional examples that show how GI Science can help policy makers in anticipating drought conditions and developing mitigation alternatives before the drought becomes a disaster. Perhaps the most recognizable use of GI Science in threat detection is the use of remote sensing to monitor the development and

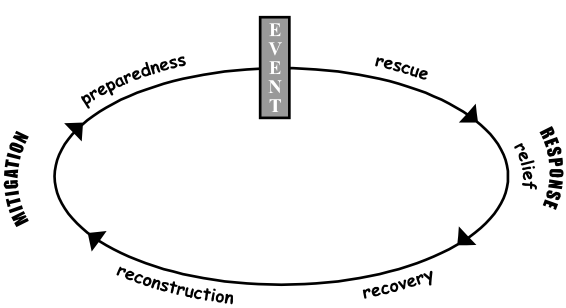

Figure 1 Schematic representation of the emergency response cycle

progression of hurricanes in the Atlantic and Caribbean basins and typhoons in the Pacific Rim.

Once the event occurs (Figure 1), the initial response involves rescue (hours to days) and relief operations (days to weeks). GIS-based incident command systems and consequence analysis tools help emergency managers in the immediate response phase. In heavily damaged areas, such as hurricane-affected coasts or cities damaged by earthquakes, it is often difficult to assess precise locations as most buildings and landmarks have been destroyed. The use of GPS (for coordinates), coupled with GIS and remote sensing data have been employed to assist in compiling quick damage estimates (Ramsey et al. 2001).

During the reconstruction phase (months to years), communities are rebuilt after a disaster, and often their spatial data and information management systems are reconfigured or at a minimum, updated. GI Science is used to guide and monitor land use, delineate transportation routes for potential evacuations, and re-delineate hazard zones based on new knowledge or changes in the natural or human use systems (Greene 2002). Finally, in the pre-impact planning or preparedness phase, GIS-based vulnerability assessments are now emerging, applications that integrate both social and biophysical indicators of vulnerability at specific places (Cutter et al. 2000, Wu et al. 2002). Other uses of GI Science in the pre-impact preparedness phase include the development of E-911 systems to facilitate emergency response and public notification of impending dangers such as a chemical spill or wildfire.

3 Disaster Response

The terrorist events of 11th September 2001 demonstrated in unmistakable ways the value and utility of GI Science in emergency management. As has been noted elsewhere (e.g. Cahan and Ball 2002, Thomas et al. 2002, Bruzewicz 2003), the use of GIS was extensive during the initial rescue and relief operations. Applications ranged from the positioning of logistical support and resources (such as the Urban Search and Rescue (USAR) teams) to public maps of the damage by the mass media (print and electronic). Remote sensing and GIS were used to develop preliminary damage assessments – at gross scales and by individual building and/or infrastructure. One of the noteworthy uses of GI Science was communication to the public on the availability of services (electricity, subway, telephone), which were visualized in the form of daily maps published in the *New York Times* and in other outlets. Whether or not it was realized by emergency responders, spatial decision support systems were used routinely in the rescue and relief operations in the World Trade Center disaster. These ranged from micro-level risk assessments (shifts in the debris pile and temperature hot spots at the site) to the spatial status of lifelines (electric, water, telephone, transportation networks), all of which changed almost daily.

4 GI Science Issues

Previous researchers have outlined some of the applications and challenges of GI Science in disasters and emergency management (Alexander 1991; Carrara and Guzzetti 1996; Radke et al. 2000; Goodchild 2003a, b; Kwan 2003). From the viewpoint of the GI scientist these can be classified as follows:

- Spatial data acquisition and integration
- Distributed computing
- Dynamic representation of physical and human processes
- Cognition of geographic information
- Interoperability
- Scale, spatial analysis, and uncertainty
- Decision support systems

From the perspective of the local responder or emergency management practitioner, the questions are quite different. What data need to be collected and where or who has it? Is there a ready-made model or software program that I can plug my data into that will provide the answers to my questions and where do I get it? Can my computer talk to yours? What features need to be analyzed and at what locations? Not surprisingly, there is a large disconnect between the language used and needs of the research and the applications communities.

The vast majority of first responders (such as police, fire, emergency medical personnel) is not that familiar with GIS, nor are they likely to use these systems in the immediate response or rescue phase. The development of advanced spatial decision support systems for disaster management is an important application element for GI Science, but how does this really help the local firefighter in his or her search and rescue operation in the minutes to hours after an event occurs? The decision support system must be transparent with output that is easy to understand to the non-technical manager, and more importantly, not filtered through vast bureaucratic layers of "technical support" personnel. In the case of the World Trade Center collapse, New York City lost its Emergency Operations Center (and its GIS capabilities) due to the collapse of the building (Galloway 2003). Fortunately, it took a little more than a day to rebuild the system. At present, practitioner preferences are oriented towards paper maps, not digital ones; and human intelligence information, not information derived from remote sensing systems. For first responders, the major constraint to utilizing GI Science technology is an understandable user interface and willingness to adopt new technologies.

A second key issue is the development of baseline data to support GI Science applications in emergency management. Data quantity, quality, and integration continue to plague the community. For example, the Federal Emergency Management Agency (FEMA) has developed its GIS-based disaster modeling and loss estimation model, HAZUS (FEMA 1997), which currently includes earthquake hazards (hurricane wind and flood modules are under development). Touted as an "off the shelf" application, the default inventory of buildings and structures, geology, and economic values included in the model is derived from very general national overviews and inventories and has not been populated with local level data. Local emergency managers can glean a general picture of potential losses from scenario events, but cannot detail expected losses for specific places (communities or counties) without updating and providing data on local building inventories, geology, and critical infrastructure. This is a very data intensive exercise, one that is often beyond the economic and human resource capacities of emergency management agencies. There is a growing recognition of the need for a national spatial data infrastructure such as the National Map (USGS) or the federal government's GeoSpatial One Stop. More importantly, local communities are using 11th September 2001 funds to develop foundation data such as high-resolution orthophotos and multipurpose cadastral maps.

Finally, there is a critical need for real-time data and information, a temporal requirement that often cannot be met in the field. For example, the pre-and post processing time for remote sensing images may negate their use in immediate response activities. There was certainly ample evidence from the 11th September 2001 events that time dependence, scale, and even organizational issues (including interoperability, connectivity, and agency cooperation) thwarted the use of remote sensing imagery (Bruzewicz 2003).

5 GI Science Research Needs

There are many GI Science research areas that would enhance the disasters and emergency management research and practitioner communities. In the interest of brevity, only a few of these will be discussed here. First, the community needs better temporal and spatial estimates of tourists, homeless people, and undocumented workers. Seasonal tourists occupy many hazardous regions (Atlantic and Gulf coasts during hurricane season) and getting more definitive seasonal and diurnal estimates of this population would enhance evacuation planning in these regions. Similarly, improved estimates of homeless people or undocumented workers in urban areas would assist preparedness efforts for responding to building collapses (either by human-induced threats such as bombs, or natural events such as earthquakes), or establishing sheltering and mass care needs in the preparedness phases of the emergency response cycle. The daily and diurnal occupancy of high-rise buildings is another important data need especially for planning evacuations (due to fires, bomb threats, and so on) (Kwan 2003).

Second, and this point echoes one made by Radke et al. (2000), we need better integration of physical processes and social models to enhance the prediction of hazard impacts. In this way we can examine the exposure to such risks and hazards with a population at risk over time and across space utilizing spatial analytic tools (Cutter et al. 2001). A practical example of these dynamic models is the coupling of hurricane forecast tracks (and likely landfall positions) with near real-time demographic data in order to narrow the length of the coastal area that should be evacuated and thus reduce the clearance times necessary to safely evacuate the area. At present, these physical models have so much uncertainty in them, let alone the paucity of data on population daytime distributions, that emergency managers are forced to take a precautionary approach to evacuation – ordering a greater area earlier than what might be necessary, just to err on the side of safety.

Third, the community needs better representations of risk and vulnerability, visual images that capture the spatial and temporal shifts in the risks and local vulnerability, but also the uncertainty inherent in the information being presented. For example, how good are the data that are used to make the evacuation decisions? The users of this information, more often than not, lack any formal geographical training and have varying abilities to understand complex spatial information. Maps and other visualizations of data (either hard copy or digital) must be simple and easy to interpret by an educated public. Unfortunately, this is not often the case.

Finally, the infrastructure for GI Science technology and data during emergencies is often non-existent or pieced together in an ad hoc fashion using a combination of local, county, state, federal and private providers and assets. The technical issues of data sharing, interoperability, power sources, and human resources often are insurmountable and pose major constraints on the use of GI Science for rapid response. Similarly, behavioral and social issues such as inadequate training, aversion to technology, and the "culture" of the response community itself limits the adoption of GI Science techniques in disaster and emergency management.

6 Conclusions

We have witnessed how essential GI Science was during the Coalition War in Iraq where spatial decision support systems were used to identify command and control structures and movements of opposing forces, positioning of assets, and the identification of targets. In other words, spatial information-based responses were just as vital as spatial information-based destruction. The precision targeting was derived from very detailed spatial information, and when such targets were destroyed, the "before" and "after" images were proudly displayed for the anxious public to view on the nightly news.

While it may seem as though there is an optimistic future for the utilization of GI Science for disaster and emergency management, there is reason for some pessimism, especially if the commercial and research GI Science communities do not fully understand the limitations and constraints of the practitioner community, and the lack of fundamental data in some of the most hazardous places. The most significant research questions will be derived from the everyday experiences of the practitioners, "Why is this community more vulnerable than the one next door? How many people are on the beach on 4th July that I might have to potentially evacuate?" While these questions originate from very practical concerns, some of the most critically important theoretical issues are embedded within them, issues that the GI Science community can help address. Closer collaborations with this user community (a bottom up approach versus the top down approach most often taken by non-applied scholars) will help inform GI Science researchers on the nature and scope of spatial information problems faced by the emergency management community. GI Science can, and should make a difference in emergency preparedness, response, recovery, and mitigation activities. It should become ubiquitous within the practitioner community, but it currently is not for many of the reasons outlined above. As researchers it is important to maintain the scientific challenges inherent in our geographical information science, but it is also the responsibility of the GI Science community to make the science and its application accessible, usable, and relevant to the emergency management practitioners.

Acknowledgements

This is the written version of an invited paper presented at the GIScience 2002 conference held in Boulder, Colorado in September 2002. The author would like to thank David Cowen, Bryan Boruff, Melanie Gall and John Wilson for their helpful comments on an earlier draft of this paper.

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