Use of Spatial Data and Geographic Technologies in Response to the September 11th Terrorist Attack on the World Trade Center

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Introduction

The emergency management community is keenly aware of the potential for mapping technologies (geographic information systems (GIS), remote sensing, and global positioning systems (GPS)) in support of emergency response operations (Mileti, 1999, Cutter, 2001). Despite this awareness, systematic knowledge about, and experience with, the use of geo-technologies in this capacity is somewhat limited because of the relatively recent development of this application area. Documenting how geographic (mapping) technologies were used in the aftermath of disasters is an important process so that they can become more refined tools for effectively supporting emergency management decision making.

The September 11th terrorist attack on the World Trade Center provided an opportunity to evaluate the use of geographic technologies in response to a catastrophic event. In the days and months after September 11th, maps and imagery of the sites and surrounding areas appeared in newspapers and on television, depicting the extent of the damage and conveying the level of emergency response operations. The emergence of the maps and related stories in the media clearly indicated that response efforts were employing a wide variety of geographic technologies in a decision-support capacity. The glimpse of map products led to a set of questions:

1. What geo-technologies were utilized?
2. Were they effectively able to be used?
3. How were they supporting response efforts?

In an attempt to better understand these questions, a research team conducted field work in New York City shortly after September 11th in order to identify broad issues associated with implementing geographic technologies in support of emergency response. This information can inform communities beyond New York City that may wish to integrate GIS and related geo-technologies into emergency response plans in order to improve emergency preparedness and response.

Geo-technologies in Support of Emergency Management

Geographic technologies contribute to all phases of the emergency management cycle (Figure 1), especially hazard and vulnerability assessments (Hodgson and Cutter, 2001; Cutter et. al, 2000; Federal Emergency Management Agency, 1997; Carrara and Guzzetti, 1996; Hodgson and Palm, 1992). Increasingly, GIS, remote sensing, and GPS are being used for hazard mitigation as well as response (Showalter, 2001). Many people find maps (a common output from a GIS) accessible for understanding information because of their visual nature (Monmonier, 1997). Consequently, a GIS can be the perfect medium for establishing dialog among stakeholders involved with mitigation, or to guide first responders in rescue operations. Geographic technologies are not just about visualization, however. The most powerful aspect of GIS is the capability to analyze and display risk in conjunction with human systems. For example, a planner could identify areas unsuitable for development based on hazard risk. Or, first responders might be able to quickly identify where vulnerable populations live, such as homebound elderly, for more effective evacuation practices.

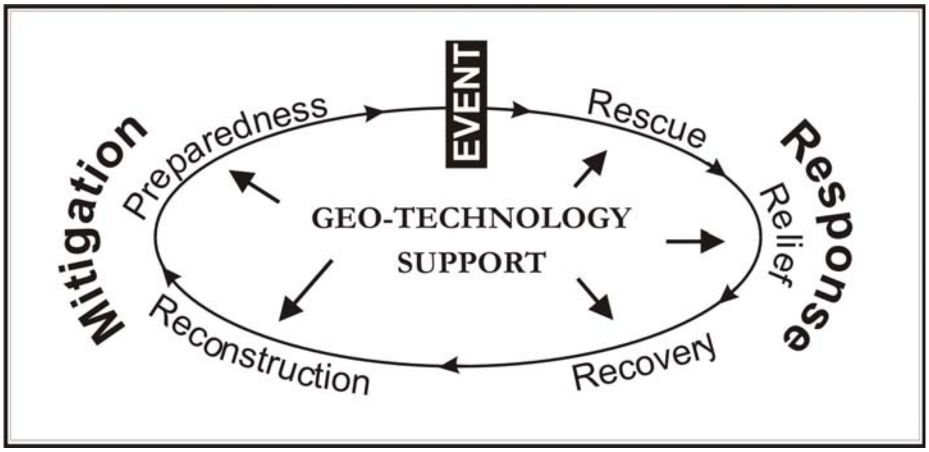

Figure 1. Geo-technologies and the emergency management cycle.

Geo-technologies allow users to create maps and to combine various spatial (geographic) data resources, making them ideal tools to aid in hazard analysis and disaster management (Radke et al., 2000). This has come to mean the development of a wide variety of hazard-based GIS applications, including, but not limited to, hazard detection (Ambrosia et al., 1998; McKean et al., 1991; Kerle and Oppenheimer, 2002), identifying vulnerabilities (Cutter et al., 2001), determining critical needs in the aftermath of disasters (U.S. Geological Survey, 1999), developing evacuation routes (Cova and Church, 1997), damage assessment mapping (Hodgson and Cutter, 2001), and risk perception and communication (Hodgson and Palm, 1992). In essence, GIS supports the decision-making process throughout the emergency management cycle by providing people with a tool for assessing and analyzing the geographic nature of any one or all of its components. In New York City, geo-technologies were implemented for precisely this reason.

Methodology

To facilitate our understanding of the immediate post-event application of geographic technologies, this evaluation concentrated on the first 21 days after September 11th, primarily the rescue and early relief phases, representing "real-time" application. Data were gathered through an interviewing process, as well as by tracking the use of maps in the *New York Times*. While the interviews were the primary source for understanding the broad use of geo-technologies, communication to the general public in the media using maps is also a crucial contribution in support of the emergency management cycle.

Fieldwork conducted on October 8–10, 2001, in New York City provided an impression of mapping activities and was used to identify key people involved in the geo-technological response efforts. Interviews were not conducted at this point since response efforts were still underway and people's attention focused on the events at hand. The site visit did provide an invaluable opportunity to witness the GIS system in place at the Emergency Operations Center (EOC), giving a context of the mapping process for the interviews that followed.

Telephone interviews were conducted throughout November after the site visit, starting with those connections first established in New York City. These people, in turn, identified others to contact. Through this snowball sampling approach, 21 formal and informal interviews were completed. Although this is not the total number of people involved with mapping, these respondents did represent all of the main mapping groups (various levels of government and private sector). Since the focus of the study was on geo-technology implementation in real-time settings, not an end-user assessment, end users were not interviewed, only those involved with providing geo-technology support.

A structured questionnaire regarding the implementation of geographic technologies by agencies and organizations guided the interviews (see Table 1). First, contact and organization information was collected, followed by 11 questions that garnered information about the types of geo-technologies used, how they were used, and who was involved in mapping activities. Recognizing that geographic technologies are data-driven, several of the questions addressed this specifically. Generally, the questions were open-ended; the interview was not conducted in the form of a survey.

Common themes emerged from the interviews; similar issues were often identified by the respondents, although with a slightly different perspectives. The following discussion draws on these, as well as supporting literature on hazards, GIS, and remote sensing. The review includes all facets of geographic technologies, including data, personnel, software integration, hardware infrastructure, and organizational arrangements in the rescue and relief and preparedness stages of the emergency management cycle.

Mapping Efforts in New York City

Maps were created to support local and federal response efforts in the days and months following September 11th. Multiple types of geo-technologies were utilized, including GIS, remote sensing technologies (such as LIDAR (light detection and ranging), thermal radar, and orthophotography), and air monitoring/modeling, as well as GPS-based technologies. In addition, numerous maps depicted various aspects of the aftermath to the public in the *New York Times* and other media outlets.

Table 1. Eleven broad questions used to guide interviews.

Which types of geo-technologies were used? For those that were used, rate the effectiveness on a scale of 1–5 (5 being excellent).
When were these used (what point in the emergency management cycle)?
What types of geographic data were used?
What data were not available?
Did you experience any difficulty obtaining data?
Of the data that were used, were there problems?
Were expectations met by agencies providing data?
What were some of the pitfalls in the technologies used?
What were some of the successes, and which use has the most potential in the future for emergency management?
From your perspective, what was the most important lesson learned?
Do you have any additional comments?

GIS Response

There were three primary mapping endeavors in New York City directly supporting emergency response efforts. The Urban Search and Rescue teams supported by the National Incidence Management Team (including Federal Emergency Management Agency (FEMA) personnel) provided micro-scale mapping focused largely on the World Trade Center site itself and maps with a focus on national issues. The Phoenix Group out of the New York City Fire Department used GIS and remote sensing, again focusing primarily on the 16-acre site, for search and rescue efforts. At the EOC on Pier 92, the Director of Citywide GIS oversaw mapping activities, particularly those supporting local response efforts. The maps produced here were generally at a more macro, city-wide scale, although they also included many site-specific maps. Many people and groups supported mapping at the EOC, including GIS specialists from agencies throughout New York City's local government, vendors (notably Environmental Systems R), volunteer mappers, and local universities (for example, the Department of Geography at Hunter College).

Using broad ways in which geo-technologies are used for hazard applications as a guide, Table 2 provides some examples of the types of maps created during the response phase in New York City. The general categories on the left are not necessarily discrete categories, nor are the New York City examples on the right a comprehensive listing of all geo-technology uses.

Normally, the technology application categories are relevant for most types of hazards, including natural and human-induced. However, the nature of the terrorist attacks limited the use of these technologies for mapping the event itself and for conveying evacuation routes. In the face of a different hazard, a hurricane or flood for example, these uses would certainly be more extensive.

Table 2. Uses of geo-technology in New York City after September 11th.

General Geo-technology Hazard Applications	NYC Map Examples
Event mapping *Prediction and warning* *Monitoring event*	Showing routes of airplanes
Response coordination/resource allocation	Displaying deployment of rescue workers Showing search and rescue grid of the World Trade Center site
Damage assessment	Mapping damaged buildings to establish extent of impacted area; to convey which buildings were re-habitable
Environmental monitoring	Monitoring of air quality, asbestos, and particulate matter
Risk assessment	Assessing debris piles and temperature hot spots on World Trade Center site Examining location of underground storage tanks
Risk communication *Public* *Emergency workers*	Illustrating extent of smoke plumes Showing debris and fire hazards on World Trade Center site
Relief & resource locations	Depicting where people could go for support services
Identification of vulnerable populations	Showing evacuated areas
Coordination and monitoring of cleanup	Planning clean-up efforts and portraying progress
Lifeline status	Illustrating utility service provision and status of electric, water, and telephone
Evacuation efforts/status of transportation routes	Portraying the changed subway network enabling people to plan alternate routes to work

The EOC processed over 1,500 map requests in the few months after September 11th. In essence, geo-technologies were used to re-map the changed geography of Manhattan. This included the creation of lower Manhattan base maps with affected buildings, as well as search and rescue grids, utility outages, and the altered nature of the transportation system. These maps were used not only to document the impacts of the hazard and identify affected people and places, but also to aid in resource allocation for rescue worker deployment and getting affected people to the proper services.

Remote Sensing Efforts

The New York Office for Technology (OFT) coordinated the remote sensing activities and the production of derived products. Numerous remote sensing data collection efforts were planned and successfully implemented by public/commercial groups. Importantly, several remote sensing data collection activities took place much earlier than September 11th. These data found a new use because of the event.

Remotely sensed data were used at the World Trade Center site for several hazard-related purposes. The public most commonly saw the graphic images of the building destruction. Images were collected from low-altitude aircraft (both fixed-wing and helicopters) and through commercial satellites. Imagery from commercial satellites has relatively low spatial resolution (i.e., about 1 meter x 1 meter) and therefore offered somewhat limited use. Several companies and agencies collected vertical aerial mapping photography over the disaster site (Figure 2). These images became the most current “map” of Ground Zero as previously mapped features had been obliterated. Because of rescue operations, and later cleanup efforts, the “map” changed daily.

Historic remotely sensed imagery can be used to document the myriad set of landscape features around a hazard event. For example, Earthdata, an imaging company, had collected aerial photography of the World Trade Center area in July of 2000. Analysis of the archival and new imagery became useful for damage assessment as they documented construction materials as they were transported away from the site.

Airborne LIDAR data over the World Trade Center were used to map the surface elevations each day and to analyze the day-by-day changes of the debris pile. Ground control points for the LIDAR-derived surface models were collected by National Oceanic and Atmospheric Administration staff. In part, these data were used to estimate the volume of debris. It was also anticipated that the spatial changes in volume would reveal unexpected shifts in the pile and thus identify risks to the response personnel on the ground.

Thermal imagery was also collected on the same overflights of the World Trade Center site as the LIDAR data. Essentially these data became a map of the absolute temperature of the surface each day (at the moment of imagery

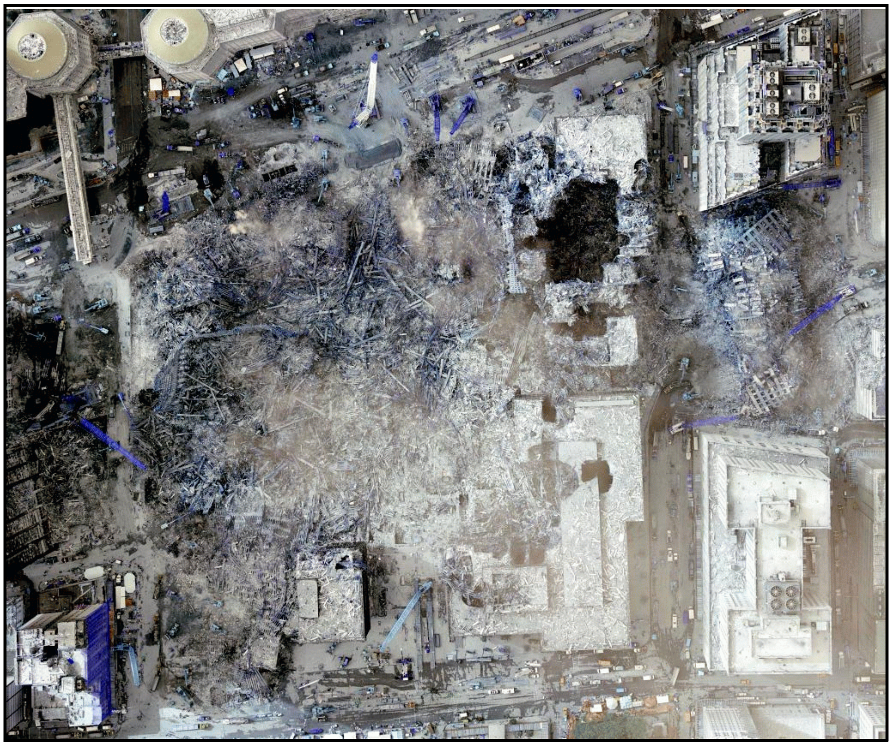

Figure 2. World Trade Center site after September 11th. (photography collected by the National Oceanic and Atmospheric Administration)

collection). Expected uses of thermal data included documenting the location/spread of continuous and new fires within the debris pile. Again, identifying risks to response personnel was the intended use, but was not ultimately particularly useful because of processing issues.

Maps for Communicating to the Public

In terms of communicating to the public, a content analysis of maps in the *New York Times* is revealing because the newspaper was a major source of information about the September 11th disaster. Maps were common additions to the stories, and in several instances, the focus of the story itself described how geographic technologies were aiding response efforts. The newspaper was one of the primary ways of reaching the public with information about the event. In a practical sense, the maps gave local residents the means for finding relief resources, returning home, or getting back to a daily routine.

During the first month after September 11th, approximately 84 maps or mapping stories about the World Trade Center attack appeared in the *New York Times* (Figure 3). Coverage peaked in the first week after the event and diminished as the newspaper's focus shifted to Afghanistan beginning on September 19. The initial map coverage reflected the broad uses for emergency response such as damage assessments, alternative transportation routes, service provision status, risks in the environment, and relief resources. During the first week all 35 maps appeared in Section A of the *New York Times*. Thirty-eight were printed in Section B in the following three weeks, with five in Section C. The quality and number of these maps only highlights how mapping may be used for communicating to the public in a future event.

Response GIS Realities

The post-event response experiences in New York City support the premise that geo-technologies can and do support response efforts. While they contain a wealth of valuable information, real-time or near-real-time geo-technology efforts are resource intensive and require significant advance planning to perform most effectively. Pre-impact planning serves multiple purposes, putting infrastructure in place for response as well as identifying and implementing mitigation measures to minimize hazard impacts.

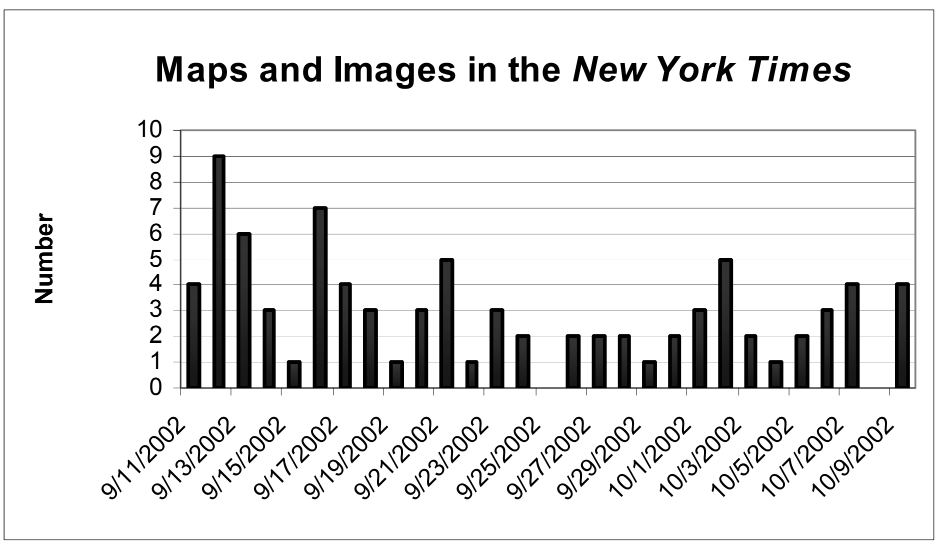

Figure 3. Trends in newspaper mapping coverage.

Organizational Plans for Geo-technologies

Geographic technologies do not just take root overnight within an organization. Creating an effective mapping system requires substantial planning, effort, time, and most importantly, money. It often has modest beginnings within an organization, evolving and becoming increasingly integrated into the decision-making process over time (Chrisman, 1997). The challenge at the moment is that preparedness for terrorism or bioterrorism is at the forefront of the American consciousness and there is an impending need to have better mapping capabilities supporting the entire emergency management cycle, but particularly response. Facing this challenge requires immediate attention to implementing geo-technologies and integrating them into the emergency management decision-making process.

Planning the flow of information through the organizational structure and explicitly defining how geo-technologies fit into this plan is vital to their successful use in a post-event situation. In the face of any disaster, having a coordinated GIS in place beforehand is clearly the ideal situation.

Although a single city-wide GIS did not exist before September 11th, many New York City agencies within the local government already had established formal and informal relationships and coordinated efforts were underway. These efforts and arrangements became the basis for building a response GIS in the post-event period, which was coordinated by the Director of Citywide GIS. In addition, federal, state, and local mapping efforts also required coordination. Several of those interviewed noted that jurisdictions ideally would not want to depend on informal relationships, having to develop information flow processes, or creating data on the fly. This translates to the need for technology plans (including organization and personnel) within the response plan, as well as designing a mechanism for integrating data sets. In this way, the duplication of effort and resources among agencies will be minimized and the most effective tools made available within the necessary time frame.

Post-September 11th meetings to identify lessons learned were held between some participants associated with remotely sensed data collections. Most parties agreed that having one agency—the New York Office for Technology (OFT)—coordinating the remote sensing collection streamlined the mission planning process for both federal and private partners. The OFT became the focal point (or "go-between") for user data requests and for coordinating collections. Unlike the contractual problems observed in historic natural hazard events, the relationship between the State of New York and federal and private partners was quickly established, enabling almost immediate collection of photography, LIDAR, and thermal imagery of the New York site. Finally, it should be noted that the remote sensing collections required numerous participants for each overflight, ground control, and subsequent analysis. Collections of remotely sensed imagery after a natural hazard or technological hazard event are often problematic because of the physical environment as well as the political, contractual, and legal hurdles.

In conjunction with the vast array of geographic technologies deployed in New York City and the unprecedented local coordination of efforts, there were still some challenges in managing geo-technologies. While people's first priority was, no doubt, to aid in the search and rescue, relief, and recovery efforts, there was evidence of some competition among vendors and contractors to demonstrate their capabilities. This may have resulted in uncoordinated efforts or the duplication of GIS and/or remotely sensed data collection. More importantly, different endeavors may have complicated risk communication by conveying dissimilar messages. Outside the vendor arena, even some of the efforts among levels of government may not have been as efficient as possible. Having detailed plans in place for geo-technologies and for the flow of spatial information limits the potential for this.

Alternative Plans

Among the most significant lifeline disruptions in New York City was the destruction of the city's EOC, the nerve center for coordinating response and recovery. As the EOC was recreated, the GIS system also had to be reconstructed, including the spatial information. Mapping efforts cannot depend on internet availability, accessible mapping experts, or even one location for data, software, and hardware. Experiences in New York City clearly point to the need for alternative and flexible plans for geo-technology capabilities. As with all response efforts during an event of this magnitude, mobilization and coordination were challenging in the initial few days, especially because the original EOC had been destroyed. In this case, mapping efforts initially depended on local efforts in a make-shift environment. Support staff was not immediately available since air travel was prohibited and additional experts from anywhere outside of New York City were unable to gain access swiftly. Resources of all types were stretched, and this was no less true of mapping. Computers, people, software, and data were hastily mobilized and the use of geographic technologies expanded in the days after September 11th.

Data Accessibility and Quality

Having a spatial data infrastructure in place before any event is vital to ensure successful mapping during rescue, relief, and recovery (National Research Council, 1999). A uniform spatial data infrastructure is an absolute necessity in emergency response, especially when the applications occur in real time or near real time. With data in place that integrate into a single platform and have the appropriate spatial and temporal resolution, the foundation is set for utilizing geographic technologies to their fullest during response efforts.

New York City had many elements of a city-wide spatial data infrastructure in place before September 11th. Most importantly, base layers, such as parcel information and street centerlines, had already been created and were commonly used. The structure, however, was distributed throughout many agencies, with different agencies housing data in sometimes disparate systems. So while many New York City agencies were utilizing GIS extensively, it was not an entirely integrated GIS system containing all of the necessary data elements (both spatial and attribute). For example, some of the sub-terrain features, such as subway lines or underground storage tanks, were not housed in a GIS, but instead were in CAD (computed aided design) system, some other database system, or even existed only as paper maps. Although incomplete at the time of the World Trade Center attack, the city was in the process of creating uniform (and unique) building identification codes that integrated those used by various agencies. Consequently, while not seamlessly integrated, once re-established, the EOC did have the spatial data to produce many of the requested maps. In addition, data were added from the field and some data sets updated daily.

The quality of available GIS data varies extensively across departments, jurisdictions, and communities in the United States. In addition, many desirable data sets simply do not exist. For example, if we are interested in vulnerable populations, there is little information on homeless people, undocumented workers, or even the day-versus-night populations of urban centers and/or buildings. These data gaps must be filled for effective response using GIS. Another important point is that data collection is not a finite process. Instead, it is ongoing either because of new data needs or the maintenance and updating of data already collected.

Another challenge is the creation of integrated data sets across multiple jurisdictions. Although the databases were maintained by various agencies in the case of New York City, at least they were not faced with trying to integrate spatial data from multiple jurisdictions. In most other metropolitan areas faced with this different scenario, spatial data requirements would require data sharing between communities. Unfortunately, few places across the United States maintain regional GIS databases.

Data sharing agreements must be in place before any event to ease the transition to real-time, response-based GIS. During emergency response, privately held data, such as utilities, as well as classified data will likely be needed. A mechanism for obtaining this type of data should already be negotiated. This may translate to having data stored in a secure environment or obtaining it from a secure site. One point is clear after the destruction of the EOC in building 7 of the World Trade Center—these data should be stored in multiple locations in addition to at the main center. The reality of forming integrated, accessible data sets can be quite difficult for political or economic reasons, but these events only highlight the potential value.

Given the unique threat that terrorism presents, many agencies took data off-line in the aftermath of September 11th. While not directly part of the New York City local response, the broader implications for data sharing are immense. Policies of publicly available data are being re-evaluated out of concern that this same information can fall into the wrong hands, prompting public debate on data access and its corollary, privacy issues. While there are philosophical issues surrounding this debate, in a practical sense it has very real implications for the GIS and emergency management communities. Making data on hazardous threats more difficult to obtain could hinder preparedness or mitigation, and could create even greater vulnerabilities.

Need for Technical Expertise

Even though New York City experiences heightened the awareness of how mapping products can support emergency response, implementing the suite of geo-technologies is no small task. The challenge of integrating geo-spatial data, platforms, and software into the response efforts is technically daunting for most emergency managers, even at a pre-impact stage. Real-time or near-real-time applications in the aftermath of a disaster are even more complicated. Considering all the potential technologies available, such as the variety actually used in New York City, advanced knowledge is required up front (pre-positioned) to know where the assets are, to know what types of activities they can support during response efforts, and to understand how to process the information with the software. The mechanisms for obtaining and processing data from various sensors and sources should be in place before any event and links to technical support established, including universities; private firms; and federal, state, and local government agencies.

Geo-technologies as Decision-support Tools

The goal of implementing geo-technologies is to improve emergency workers' abilities to do their jobs by giving them useful tools. If these technologies fail on this account, then they have not effectively supported response efforts. There is a distinct need to ensure that products, including models and maps, meet the needs of end users and that appropriate tools make it into the hands of the right users. Many of the maps and visualizations created in New York City were used in support of risk communication. This is a key element of the emergency management cycle, creating useful tools for improved decision making in the face of a disaster. The informational needs are not the same for all groups, however, nor are GIS and map-reading skills. Emergency responders' information requirements differ from those of managers, or even the public.

In the case of New York City, many maps were requested, which suggests response teams and managers were using these products. This research was unable to establish details on how maps were actually used by end users, since they were not interviewed. Several respondents stated that maps were widely used, while others expressed a lack of use, even indicating that the maps went directly in the trash. A number also suggested that vendors were using this as an opportunity to showcase their software capabilities, rather than truly supporting the needs of response efforts. For example, remotely sensed imagery was used to monitor the debris pile, but apparently was not a major source of information for the emergency response or cleanup personnel at the site itself. An analysis of map requests (unavailable for this research) with follow-up interviews in New York City would provide some insight into user needs in that situation. In creating GIS implementation plans for support of emergency response, user need assessments are essential so that appropriate and usable maps will be created.

Conclusion

This study provided an overview of how geo-technologies were used in the aftermath of the September 11th disaster in New York City, as well as supplying some practical considerations for other communities when incorporating GIS into emergency management plans. We are still far from understanding the full potential for these technologies during response efforts, however. There is clearly a need for a true post-audit of the experiences in New York City to assess the full range of successes and shortcomings associated with mapping technologies. This would include an assessment of how people actually used the maps, as well as identifying the ways in which they were incorporated into the decision-making process.

The level of recognition of what and how geo-technologies can contribute to response and decision-making efforts most certainly increased in the wake of September 11th. The original EOC in New York City had one computer terminal devoted to mapping. The makeshift EOC on Pier 92 had an entire section with over 20 computers, a server, and a whole staff dedicated to creating maps. Because of this demonstration in this national disaster of how maps can aid in the rescue, relief, and recovery efforts, the role of mapping in any future New York City EOC and potentially other locations, will certainly be reassessed. The number of maps included in the *New York Times* over this period also points to an increased role of mapping. In fact, the public and emergency responders and managers may now expect high-quality informative maps in any future events after having had a glimpse of mapping products. The full range of ways that mapping can support emergency management is only beginning to be realized, and the extensive use of mapping in New York City further emphasizes the need to explore the effective integration of these geo-technologies into the emergency management cycle for all hazards.

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