16 The Role of Geographic Information Science & Technology in Disaster Management

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Contents

Place-based capabilities have permeated a multitude of mobile applications and have transformed the ways in which technology supports place-based knowledge generation and decision-making. Data-enabled cell phones, smartphones and tablets commonly have location-based services (LBS) embedded throughout various applications, which use real-time geographic data (geo-data) to collect data and/or provide information (even basic cell phones have locational capabilities). While their use spans a wide variety of topics and frequently utilized functions, such as generating directions or finding resources, they are also commonly used in the context of hazards and disasters. For example, one mobile device can now perform a variety of place-based disaster management decision-support functions, from assisting a person's routing for evacuation based on traffic flows to conveying place-specific weather warnings.

Mobile technologies have revolutionized awareness of, and access to, place-based mapping technologies and approaches through relative ease and high level of exposure/usage. By extension, they have dramatically expanded geographic information science & technology (GIS&T) applications to hazards and disasters. This chapter will focus on the potential of using GIS&T, emphasizing geographic information systems (GIS), for spatial (geographic) decision support systems (SDSS), highlighting the ways these technologies can integrate physical and social science approaches to support disaster risk reduction. A disaster management spatial decision support system (DM-SDSS) must be firmly based in research, as well as meet the needs of decision-makers across a diverse set of users who utilize the system. The first

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part of the chapter provides a brief background of GIS&T and the basics of a DM-SDSS. This is followed by examples of current GIS applications in disaster management, a discussion of challenges and opportunities, and suggested directions for future research.

16.1 GIS&T & DM-SDSS Background

GIS&T is a comprehensive interdisciplinary field grounded in geography that incorporates a range of geographic technologies, including geographic information systems (GIS), remote sensing, and even global positioning systems (GPS). As a field of study, GIS&T is comprised of "three interrelated sub-domains" (DiBiase et al., 2006), including geographic information science (knowledge generation based in geography, but multidisciplinary), geospatial technology (management and manipulation of georeferenced data), and applications (uses in wide-ranging discipline/practice areas). Certainly, the integrative capabilities of GIS&T are powerful, bringing together geographic data from a wide variety of environmental, social, and engineering sources for evaluation and analysis. GIS&T enables the systematic exploration of the nexus of geography and the knowledge base of numerous other disciplines so that place can be centrally examined. For disaster management, this translates to robust disaster/hazards place-based research across the social/physical sciences and engineering that is tied to practice with processes for integrating ever-increasing amounts of spatial data in meaningful and efficient ways.

Even though geographic questions have long been of concern to both disaster researchers and practitioners alike, the proliferation of GIS&T has fundamentally increased the capacity of those in the disaster community to incorporate place-based approaches. Geospatial technologies are recognized as key support tools for disaster management (Abdalla & Li, 2010; Goodchild, 2006; Mileti, 1999). The visualization capabilities (map output) alone have almost become expected by policy makers, disaster managers, and even the public, particularly with the advent of mobile technologies and increased access to data through the Internet for easier access. In the most basic way, the mapping of hazard events and the impacts on people has a long and rich history with roots in basic geographic approaches (Hodgson & Cutter, 2001; Monmonier, 1997). For example, daily weather maps were produced first in Europe and then the U.S. in the 1800s and the Sanborn Company compiled systematic maps of urban hazards for fire insurance in major U.S. cities starting in the 1870s. The systematic mapping of hazard zones in relation to human settlement patterns for understanding human response can be linked to Gilbert White in the 1960s and 1970s (White, 1974; Burton, Kates, & White, 1993). The acceleration of the application of GIS to disasters began with the advent of the computer, especially affordable desktop computers and software in the late 1980s and 1990s, and then mobile platforms in the 2000s. Along with increased software and hardware availability and accessibility, spatial/geographic data for hazards, including hazard monitoring and risk information, has increased dramatically through monitoring, assessment and modeling efforts. Simultaneously, the sheer amount of built environment and social data with a location (spatially-enabled) has grown considerably, extending the possibilities for data integration and analysis. Real-time geographic data, now so readily available, can potentially improve the allocation of resources or planning processes.

As GIS&T has evolved, its application in both disaster research and practice as expanded rapidly for supporting risk reduction decision-making; it is fundamental to capturing, understanding, and conveying many dimensions to disaster risk and human adaptation to hazards. Place-based decision support requires broader approaches than GIS alone, drawing on all three GIS&T sub-domains, particularly when considering the complexity of DM-SDSS.

16.1.1 Components of Spatial Decision Support Systems (DM-SDSS)

Although not having a single, strict definition, any DM-SDSS would consist of several essential components, including: (1) data collection, integration, management, (2) analytical solutions, and (3) a user interface that allows the setting of parameters and generation of different solutions. A DM-DSSS is developed to address a specific problem, and must perform sophisticated tasks at the right place and time, involving modeling and analyses that transform spatial data into information for the evaluation of alternatives (Jankowski, 2008). Disaster management requires complex coordination of resources, equipment, skills and human resources from a wide variety of agencies and organizations. As such, a DM-SDSS can foster cooperation and promote disaster loss reduction (Pourvakhshouri & Mansor, 2003; Tomaszewski, Judex, Szarzynski, Radestock, & Wirkus, 2015; Zlatanova, van Oosterom, & Verbree, 2006). Interoperability of emergency services is especially vital during response and relief phases and is frequently supported by DM-SDSS (NAS, 2007). Further, a DM-SDSS also plays a vital role in mitigation and planning (Tate, Burton, Berry, Emrich, & Cutter, 2011). In essence, DM-SDSSs are tools that support individual (disaster managers, policy makers, first responders, or the public) and organizational decision-making in short, medium, and long-term scenarios (Andrienko, Andrienko, & Jankowski, 2003; Jankowski & Nyerges, 2002; Nyerges & Jankowski, 2009).

Technical concerns surrounding the implementation of DM-SDSS include such issues as spatial data acquisition and integration, interoperability, distributed computing, dynamic representation of physical and human processes, spatial analysis and uncertainty, and system design (Cutter, 2003; Radke et al., 2000). A DM-SDSS must allow the efficient and effective interchange of data between modules and modeling techniques. Interoperability ensures that data, algorithms, and models can be shared between various systems that are housed in diverse agencies, departments, or organizations contributing to disaster management.

Data collection comprises a multitude of activities utilizing a variety of primary and secondary sources that have a locational element. Since a DM-SDSS is data dependent, integration and management is no small feat, and requires incorporation of different data types, making the appropriate data available to the correct people at the right time. Data may be compiled directly from the field using mobile devices, GPS, or cell phones and is captured by experts or even through volunteered data from the public. Data can also be generated from people's decisions, perceptions, and behavior via geo-tagged social media, or locations of Internet searches. Remote sensing (satellite imagery, aerial photography, or other detection and monitoring devices, such as unmanned aerial vehicles) are also common inputs (Nayak & Zlatanova, 2008). Many datasets already exist and are maintained by various entities, though they are not always readily available and/or interoperable. Increasingly, data are accessed through web-services whereby a connection to the data is made through the Internet to the location where it is maintained and stored. Ideally, data should be current and timely. Quality control of the data should occur as part of the DM-SDSS, along with data security and management of user access.

Analytic tools and models process data into useful information that can be utilized for decision-making. Data must be converted to information that is meaningful and useful to those involved in disaster decision-making processes. For example, efficient and reliable hazard forecasting and monitoring leads to early warning and/or mitigation activities. Vulnerability analyses, risk assessments and modeling drive scenario generation (varying inputs based on priorities from stakeholders). Further, a DM-SDSS must be expandable and flexible in order to integrate new sensors, accommodate new users, and integrate new software applications into the future. The level of coordination and sophistication necessary for scenario-building essential for DM-SDSS may seem somewhat unattainable given the wide range of hazard types and the complexity of social, built, and physical environments. However, the increasing availability of geographic technologies and advancements in GIS&T make it more possible than ever to consider an integrated system that supports disaster management to reduce loss (Keenan, 2006).

The development of a DM-SDSS requires that most of the functionality is not technically difficult for the end user. Keenan (1998) points out that the decision-maker should not have to go through long sequences of commands. In other words, the system itself should be user friendly and should meet informational needs accessing appropriate data and running analytical process in the background (not actually seen by the user), representing physical and human processes in an understandable format. In other words, ease of use is a foundational goal for design and development, making the upfront technical development quite challenging. As spatial data, maps, and models become embedded into DM-SDSS, geographic concepts must be addressed and incorporated into the system so that the end-user can set parameters and examine various options to support decision-making, but does not necessarily need proficiency in the spatial data or analysis models. Still, disaster managers, and others involved in response and mitigation to disasters, are usually from disciplines outside of geography or geographic technologies, and thus require some GIS&T education or training, even if just the basics of unique spatial data characteristics and the operation of a DM-SDSS. Training and education are too often neglected in formal processes, reducing the likelihood for adoption.

16.1.2 Geographic Information Systems (GIS) and DM-SDSS

Geographic information systems (GIS), a subset of GIS&T, allows for the mapping and analysis of hazard-related data transforming it into visual information and could be considered a DM-SDSS in and of itself (Keenan, 2006), particularly with the wider availability of Internet-based GIS. GIS is an interface for handling, collecting, sharing, recording, analyzing, updating, organizing and integrating spatial (geographic) data, derived from maps, remote sensing, and/or GPS. Within a GIS, a database is directly connected to the graphically mapped information and so data can be manipulated and mapped, or a user can interact with the map to retrieve data. In addition to simply compiling inventories of hazard risk, the built environment, infrastructure, and vulnerable populations, GIS can relate these to one another and analytically evaluate and explore spatial relationships. For instance, by viewing floodplains along with hospitals and roads, a user could select all hospitals in the floodplain or delineate which roads accessing a hospital might flood. Or, GIS can estimate population characteristics of those at risk, assessing the race/ethnicity, age, or housing characteristics. As another illustration, GIS could be used to evaluate which schools are near fault zones or in floodplains for prioritizing mitigation strategies or for evacuation planning.

A DM-SDSS integrates GIS into a broader framework that also incorporates specialized analytical modeling capabilities, database management systems, graphical display capabilities, tabular reporting capabilities and decision-maker's expert knowledge (see Fig. 16.1). A GIS alone cannot often provide problem-specific model support to a less technical user, frequently requiring the involvement of a GIS expert. Further, a GIS can only partly model, test, and compare among alternatives to evaluate a specific problem (Pourvakhshouri & Mansor, 2003) without extensive processing or often interfacing with other software. A DM-SDSS enables a less technical user to run scenarios, set model parameters, and produce results to inform decision-making since much of the technical functionality are embedded within the DM-SDSS. Although designs vary, a DM-SDSS includes elements beyond a GIS, including analytical tools (to enable data exploration), decision models (to run various scenarios with different parameters), a geographic/spatial

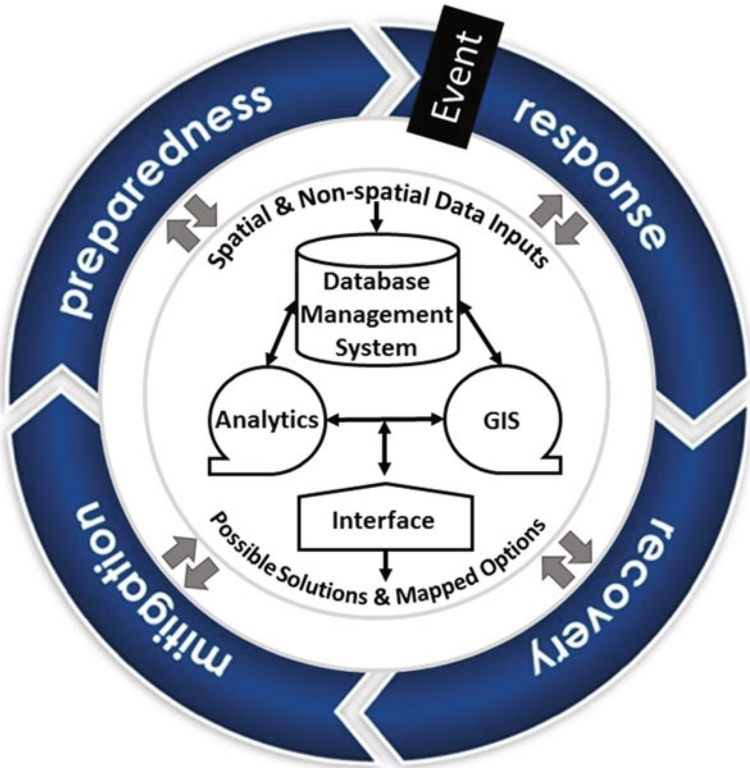

Fig. 16.1 DM-SDSS Conceptual Model

database (whereby data management for the end user is minimized), a user interface, and expert knowledge that informs all aspects of the DM-SDSS (Densham, 1991; Jankowski, 2008; Zerger & Smith, 2003). A DM-SDSS must be flexible and adaptable for dealing with evolving and dynamic scenarios in disaster management (Bui & Sankaran, 2001). Most importantly, its success rests on how well it supports the needs of the decision-maker, not how advanced the technology is (Keenan, 2006).

16.2 Examples of GIS Applications to Disaster Management

While GIS is only one subcomponent that contributes to GIS &T and DM-SDSS, focusing on this technology provides insights into complex place-based solutions for the study of disasters/hazards. Examples range from relatively simple local scale hazard mapping to fully interactive GIS interface. Many GIS applications span preparedness, response, recovery and mitigation, although some are specific to one or two of the phases. For instance, hazard mapping is necessary for supporting decision-making in all disaster management phases while evacuation planning is much more specific to preparedness and response. GIS has wide-ranging potential in disaster management, including, but not limited to, damage assessment, risk prediction and situational analyses, vulnerability and resilience assessments, or prioritization of mitigation alternatives.

Disaster/hazards GIS-based research generates place-based knowledge production that can/should inform the development of any DM-SDSS tool. However, the translation of research results into practice and decision-making varies. So, while GIS is now pervasive in disaster management, research is not necessarily infused as consistently. This is especially true in a rapidly evolving technological arena where advances in practice often outpace research. As such, the following section highlights exciting GIS applications in practice along with GIS-based disaster/hazards research.

16.2.1 Monitoring and Detection

Hazard event monitoring and detection requires extensive data collection efforts and lays the groundwork for risk assessments as well as early warning systems. A thorough discussion of the use of geographic technologies for monitoring and detection, detailing extensive efforts in all areas, is beyond the scope of this chapter. Still, this important area must be mentioned because of the foundation these data collection processes provide for any type of DM-SDSS, which are inherently data-driven and require high quality data.

Many examples exist of organizations that collect and disseminate hazards event data. The National Aeronautics and Space Administration (NASA, 2016a) shares global remote sensing images of historical and recent hazard events for the public and scientific community to better understand worldwide hazards. The U.S. Geological Survey's Earthquake Global Seismic Network (USGS, 2016a) is one of several monitoring and detection systems for earthquakes and collects, maintains, and disseminates data globally. The USGS (2016b) also maintains the stream gauge network for the U.S., providing real-time and historical data on streamflow conditions. The National Oceanic & Atmospheric Administration's (NOAA) Satellite and Information Service (2016a) integrates a variety of satellite and data products for tsunamis, wildfires, drought, and all weather and climate hazards. Parallel organizations in many other countries also maintain a stream-gauge network for flood monitoring and detection (for example, the European Centre for Medium Range Weather Forecasting or the European Severe Weather Database), though many parts of the globe do not have hazard-related organizations collecting high quality data.

In all of these instances, data collection is important, but the post-processing to ascertain risk is the vital next step. Monitoring and detection is particularly powerful when married with a mechanism for dissemination of warnings. For example, the Bangladesh Flood Forecasting and Warning Centre (BWDB, 2016) captures data from a variety of sources (such as satellite imagery, meteorological data, water levels) to create real-time maps and information products, along with flood forecast models. These products, including current warnings, daily inundation reports/maps, and river level forecasts, are released to many outlets from government authorities to the media. As another illustration, NOAA collects and disseminates severe storm and weather data through the National Weather Service (NOAA, 2016b). In support of the *Weather-Ready Nation* initiative focused on the U.S., current watches and warnings for all weather-related events are posted with corresponding maps. These data are one element of a broader early warning system, as well as the basis for fostering awareness, assessing risk, and enhancing communication efforts. While the monitoring and detection of hazard data has expanded and evolved, capabilities for monitoring social, economic, and political trends is not nearly as robust.

16.2.2 Risk Assessment

Risk assessments encompass a wide variety of activities, from evaluating groundwater pollution from historical hazardous waste dumps to deriving air pollution levels across an area, and involve calculating the potential for negative outcomes on human, built, and/or physical systems for any natural and/or technological event (s). Data from monitoring and detection are evaluated in attempt to understand the potential for harm. The systematic mapping of hazard zones in order to assess who is at risk has a long history for a variety of hazards, including floods, earthquakes, and tropical and severe storms. Risk mapping underpins basic decision-support by transforming data into information that is then made available to end-users (decision-makers).

Floodplain and earthquake mapping applications, in particular, demonstrate the potential for a DM-SDSS. In the U.S., the Federal Emergency Management Agency's (FEMA) Flood Hazard Mapping Program began in 1968 as part of the National Flood Insurance Program in order to make a determination about properties located in high risk flood areas (FEMA, 2016a). Although a complex scientific (highly technical modeling of floodplains) and political (conveying to communities for incorporation into systematic planning) endeavor, the intent of these efforts is to support mitigation decision-making for flood loss reduction. In fact, numerous inundation mapping efforts are underway in U.S. states and countries throughout the world to calculate flood risk, utilizing Digital Elevation Models (DEM) and Airborne Light Detection and Ranging (LIDAR) remote sensing, combined with metrological, coastal and hydrologic data. As another example, the USGS has long provided systematic earthquake risk mapping for the U.S. and the world (USGS, 2016c). At the state level, California's Seismic Hazards Mapping Program was mandated in 1990 to reduce threats from earthquake-related events, which must also be conveyed during real estate purchases (CGS, 2016). These few examples illustrate how geographic technologies contribute to evaluating hazard risk as a foundational component to a DM-SDSS.

16.2.3 Vulnerability & Resilience Assessments

Although without a single definition for either and not interchangeable or inversely related, vulnerability and resilience both explicitly emphasize the interaction of human systems with hazards in the creation of risk (Fordham, Lovekamp, Thomas, & Phillips, 2013). Vulnerability has evolved from stressing the hazard event and physical realm as the primary source of destruction to recognizing the significance of human systems (Fordham et al., 2013; Tobin & Montz, 1997). Resilience has recently emerged in research and practice as a term that embodies withstanding and adapting to disturbances of all types (Folke, 2006; Resilience Alliance, 2016). While distinct in many respects, conducting a place-based assessment that incorporates social considerations with hazard risk is fundamental to both.

Vulnerability and resilience continue to require attention with few explicit guidelines for how to conduct a comprehensive, multi-hazard assessment at the local level (Cutter, Mitchell, & Scott, 2000; Cutter et al., 2008). Cutter's Vulnerability of Place Model (1996) perseveres as a place-based, GIS assessment framework, which takes an all-hazards approach integrating social variables into a summary appraisal. However, solutions for incorporating multiple hazards with different recurrence intervals, varying geographic scales, and multiple approaches for conducting hazard risk models into a single, multi-hazard risk layer remains immensely challenging. While progress on quantitatively evaluating social vulnerability has occurred (Cutter & Fitch, 2008), mechanisms for meaningfully combining and interpreting social and built data with composite multi-hazard output remain unresolved. In fact, many aspects of social vulnerability are not easily incorporated onto a map (Morrow, 1999), but still GIS also offers many opportunities that should be further investigated and developed.

As one initiative, in an effort to integrate social data with hazard risk modeling, FEMA's Hazus-MH (Hazards U.S. Multihazards) estimates potential losses from earthquakes, floods, and hurricane winds (independently) and approximates loss to the built environment, populations and critical infrastructure from these models (FEMA, 2016b). The program includes U.S. national datasets and models for the hazard events along with socio-economic and building stock data. However, it is not truly multi-hazard in the sense that the models cannot be run in a single session. In other words, a user must examine floods independently from earthquakes

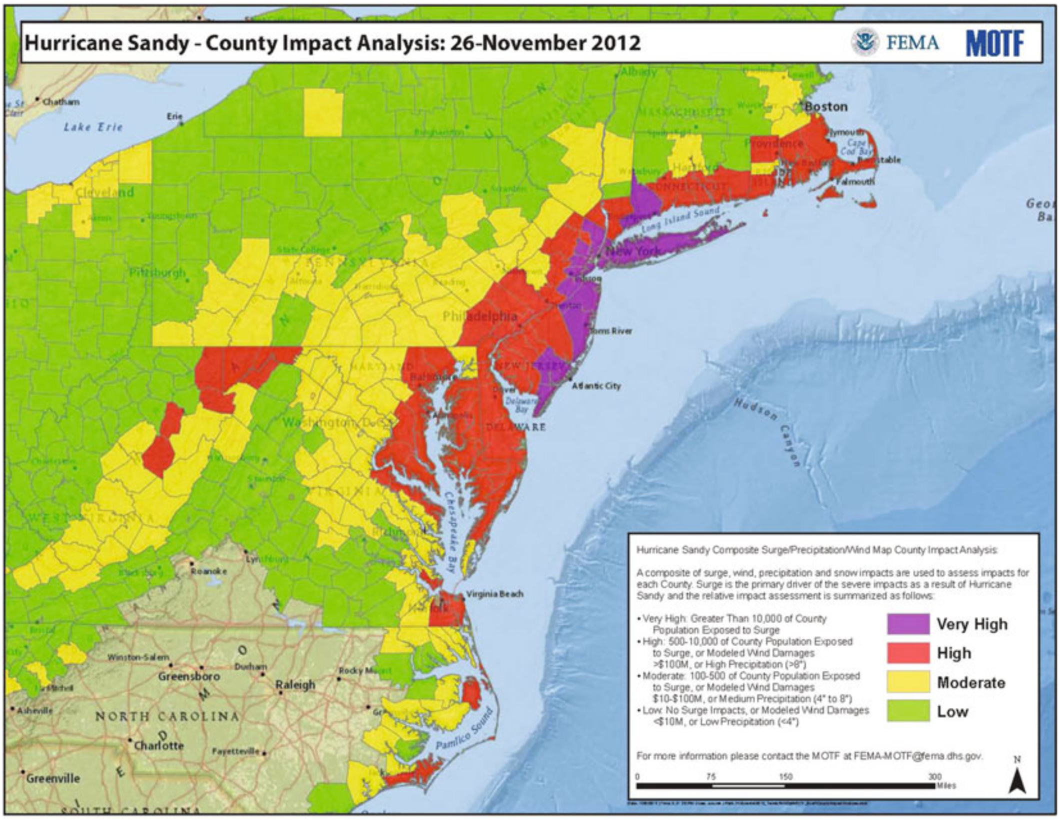

Fig. 16.2 Hurricane Sandy Impact Analysis. Courtesy of: Jesse Rozelle, Sean McNabb, Herbert "Gene" Longenecker, Nicol Robles-Kyle, and Austen Cutrell/FEMA. With permission

without the ability to generate composite risk from both or to quantify the impacts on people, buildings, or infrastructure together. Further, with the emphasis on loss estimation, the role of social vulnerability is rather minimal. The FEMA GIS platform seeks to increase situational awareness (see Fig. 16.2 as an example). The efforts represent an attempt incorporate multiple facets of vulnerability in a platform that allows refining data, setting parameters, and generating scenarios explicitly for decision-support.

16.2.4 Evacuation Planning

Evacuation planning highlights the use of a DM-SDSS for a specific purpose within disaster management with a long history of refinement (Cova, 2014). So, while this is a hazard-specific application, SDSS elements are clearly demonstrated. These systems link transportation models with GIS and decision systems in a manner that offers a more improved output than any of the systems could produce individually, a key contribution of a SDSS.

A few examples for evacuation from potential radiological disasters illustrate the integration of datasets, modeling, and decision-making approaches. Lindell et al. (1985) created a system that calculated the radius of the area for the evacuation, the delay time between warning and start of evacuation, and the speed of evacuation. In addition, changing meteorological conditions, alternative transport routes, modes for evacuation, and the identification of critical facilities (such as schools, hospitals and vulnerable population) were also incorporated. De Silva et al. (1993) developed an interface for simulating and modeling evacuation routes. In this instance, simulation models were included directly into the SDSS to predict traffic flow for several scenarios (vehicle break down or road closure). De Silva (2001) expanded the use of a DM-SDSS to a true interactive planning tool to examine simple scenarios and to assess the evacuation process and progress. The system had four main components, including a traffic simulation module, a GIS module, an integration module, and a user interface. Importantly, the system incorporated expert users' input directly into the model. Although this was directed at a specific stakeholder group, it illustrates the full functionality that is anticipated from DM-SDSS by allowing the incorporation of user priories and parameter-setting capabilities. Other evacuation scenario models are applied to wildfires (e.g. Cova, Theobald, Norman, & Siebeneck, 2013), hurricanes (e.g. Lindell & Prater, 2007; Wilmot & Mei, 2004), or floods (e.g. Simonovic & Ahmad, 2005). All are problem specific (evacuation planning) and exclusive to a single hazard type.

16.2.5 Technological Hazards

The potential for incorporating technological hazards into a comprehensive DM-SDSS is immense, both because of SDSS development in this realm and due to the fact that natural and technological hazards are frequently closely intertwined. Natural hazards commonly trigger technological events, such as gas leaks after earthquakes or dispersion of hazardous materials during flooding, among numerous other examples. Other hazards emerge directly from the interaction of natural and human systems and so can be difficult to classify infectious disease outbreaks or climate change, for instance.

Technological hazards are commonly modeled in support of emergency management for assessing and minimizing the impacts on health. Chemical accidents, for example, require an emergency response and the Computer-Aided Management of Emergency Operations (CAMEO) was developed by the U.S. Environmental Protection Agency (USEPA) and NOAA to assist emergency managers and first-responders (USEPA, 2016). The software incorporates necessary information about chemicals, a dispersion model, along with response recommendations, using mapped output to convey results.

GIS-based SDSS is also used for support in managing oil spill incidents (Ivanov & Zatyagolva, 2008). The Environmental Response Management Application (ERMA) offers an online mapping tool aimed at providing a resource for oil and chemical spill preparedness, planning, and response (NOAA, 2016c). A multi-criteria SDSS can detect coastal area sensitivity in support of decision-makers providing alternatives for spill control and clean-up (Pourvakhshouri & Mansor, 2003; Vafai, Hadipour, & Hadipour, 2013). The *BP Deepwater Horizon Oil Spill* was one of the largest disasters of any type in the 2000s, needing complex physical, technological, and socio-economic analysis for short- and long-term management. Leifer et al. (2012) describe the use of remote sensing specifically for this extensive event and NOAA scientists modeled oil spill trajectories (Fig. 16.3), making these maps available to inform response efforts (NOAA, 2016d). Similar to the evacuation planning SDSS, those in the realm of technological hazards are well developed, but specific to a particular problem.

16.2.6 Information Sharing for Decision-Support and Risk Communication

The Internet disseminates hazards data, static maps, and interactive disaster mapping. Currently, online mapping incorporates little analytical capabilities or possibilities for adjusting parameters, either by an individual end-user or to capture input from stakeholders for prioritizing local, regional, and/or national approaches. Further, the number of Internet sites related to mapping are so numerous, disparate, and disconnected, they likely do not adequately reach the necessary audiences and can be confusing. Still, it is not hard to imagine

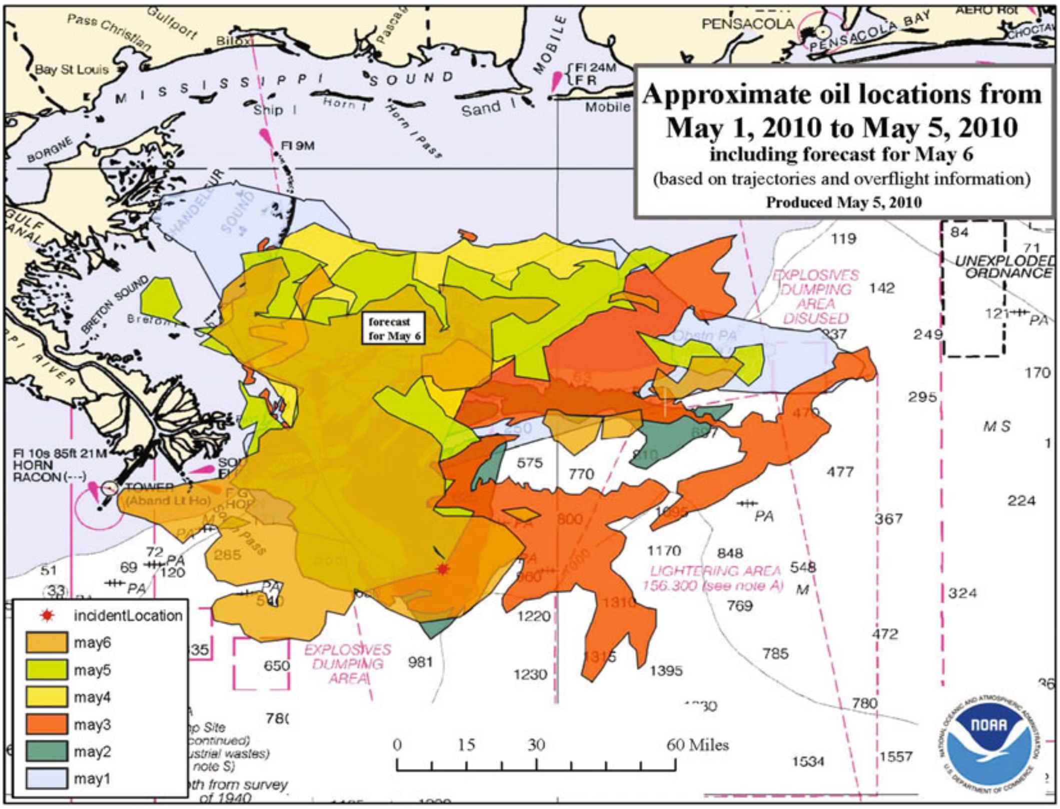

Fig. 16.3 The approximate oil locations from May 1, 2010 to May 5, 2010 based on trajectories and overflight information, including forecast for May 6. Produced by NOAA's Office of Response and Restoration (OR&R). With permission

the expansion of the capabilities embedded in existing web-based systems to include some of this functionality. Several regional, national, and international efforts serve as information sharing tools for both spatial and non-spatial hazards and disaster management resources.

Many data distribution endeavors supply spatial (geographic) hazards-related data through a data portal or clearinghouse, often including static maps. Increasingly, these data are made available through a web service (live data feed), which means the data are maintained by a particular agency/organization and other groups can access the data with an online connection, pulling them directly into a GIS or web-based interface (even non-mapping programs). These data support hazard, vulnerability and resilience assessments, though usually requiring technical GIS expertise. As one example, the USGS maintains and supplies a multitude of hazards event databases, including earthquakes, volcanic eruptions, landslides, floods, tsunami, and geomagnetic storms spatial data, along with educational materials (USGS, 2016d). The Global Disaster Alert and Coordination System (GDACS, 2016), although focusing on major sudden-onset disasters and not mitigation, acts as a repository for event-based data and acts as a cooperation framework between the United Nations, the European Commission and disaster managers worldwide to improve alerts, information exchange and coordination in the first phase after major sudden-onset disasters. The World Health Organization has published an online atlas with data sources in support of public health preparedness across the eastern portion of Europe

(WHO, 2016). The Center for Research on the Epidemiology of Disasters maintains an international database on natural and technological disasters by country and region, including deaths, injuries, damages, and impacted people that is an important data repository for understanding hazard impacts at the global scale (CRED, 2016). Though the data are seemingly extensive, navigating and compiling them from a vast number of sources is overwhelming and can be extremely time intensive.

In addition to the web data portals and static mapping, many mapping efforts have interactive interfaces whereby a user would not need to have extensive GIS skills to consider the data and/or the risk maps, though often capability is limited to visualization. Online availability increases access to the most current information and is useful for viewing complex hazard datasets and risk. Data are incorporated from a variety of sources to drive the system, which displays information selected by the user. Perhaps one of the most elaborate examples, the Pacific Disaster Center (PDC) provides disaster management information integration and sharing throughout the Asia Pacific Region and has developed an integrated mapping decision-support system for disaster management and humanitarian assistance (PDC, 2016). *DisasterAWARE* supplies access to many disaster-related databases, including emergency services, public facilities, utilities, transportation communications, political boundaries, demographics, hazard, image data, elevation, hydrograph, climate, weather, landforms and land use. Importantly, the user chooses what and how to display the data (PDC, 2016). *SERVIR*, another example that utilizes online data products, provides integrated geospatial data and tools to support environmental decision-making in Africa, the Himalayas, and the Mekong region (NASA, 2016b). California's interactive *MyHazards* (CalOES, 2016) mapping tool aims to enhance hazard risk awareness by the public. These Internet-based projects illustrate the possibilities for integrating new and emerging information technologies, observation systems, and communications for disaster management.

16.2.7 Community-Based Efforts and Volunteered Geographic Information

Through the extensive availability of mobile technology, place-based applications, and the evolution of social media, individuals and local communities can now participate in disaster management in innovative ways that challenge top-down approaches traditionally taken by formal disaster management organizations. Public participation GIS (PPGIS), which engages all stakeholders and emphasizes the role of local community members, is not new (Elwood & Leitner, 1998; Talen, 1999), nor is citizen data collection (citizen science) (Elwood, Goodchild, & Sui, 2012). Community-based disaster management, frequently incorporating mapping, also has a long history with numerous applications globally for promoting disaster risk reduction (Maskrey, 2011; Pearce, 2003; PreventionWeb, 2016). When used in a participatory or community-based fashion, data development and interpretation involve an exchange of information and integrates information about hazards, capabilities, assets, vulnerability, and resilience from the public (Khan, Enriquez, & MacClune, 2015; Pearce, 2003). Multiple segments of society should have access to disaster decision-making information along with experts. Further, the community-derived information has value alongside expert data sources. Still, in many ways the more "scientific," expert-driven approaches still dominate.

Rapidly evolving technologies now provide a platform to engage in community-based disaster management, with information sharing commonly occurring outside of formal disaster management structures. Increasing access to place-based applications through mobile platforms allows for the creation of Volunteered Geographic Information (VGI), data with a location generated outside of traditional structures by the public and uploaded to a mapping interface via a data connection. The emergence of this form of rapid data collection has challenged the top-down control of data creation and dissemination, and allows for increased

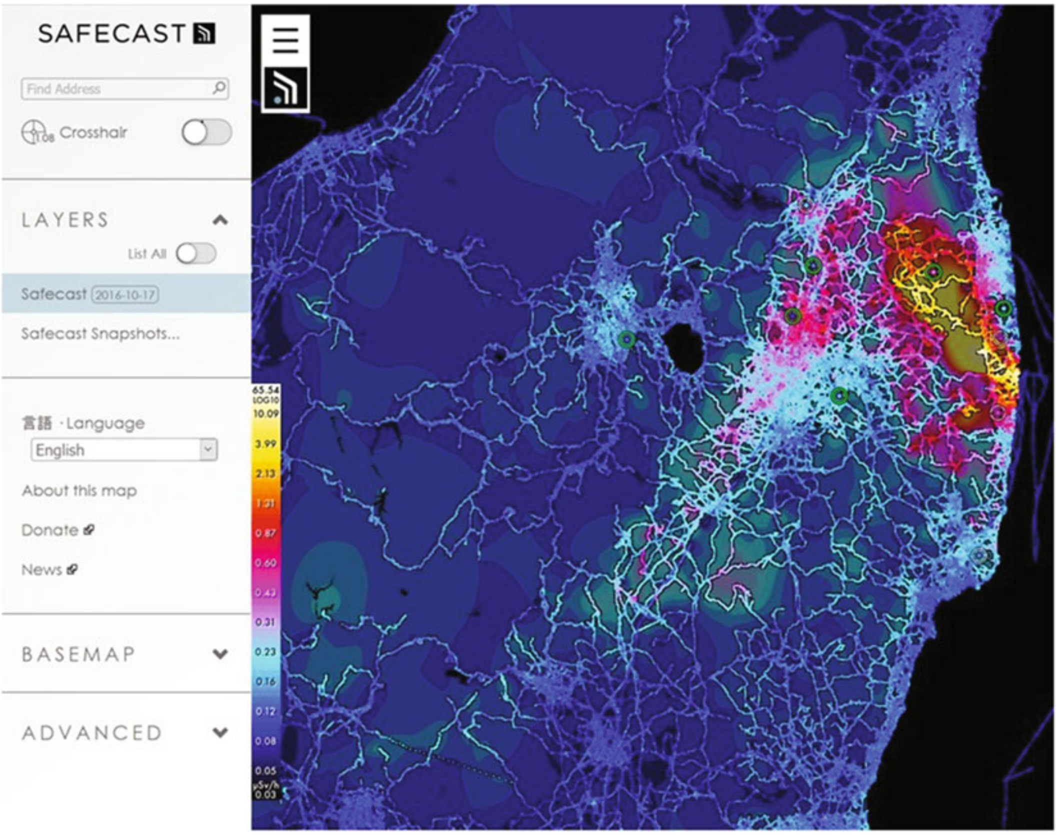

Fig. 16.4 Crowd-sourced radiation data collected after the Fukushima Daiichi Nuclear Disaster. Safecast distributed inexpensive Geiger counters to volunteers starting one week after the event. These data were then uploaded and mapped on an interactive site. Safecast Interactive map availabe at: http://www.safecast.org/tilemap/ With permission

community-based sharing of information and empowerment of citizen engagement (Haworth, 2016). In addition, social media, such as *Facebook* or *Twitter*, have also promoted the organic exchange of data and information and have augmented possibilities, though with challenges, for the integration of social media with geographic technologies (Sui & Goodchild, 2011).

VGI is now employed for nearly every recent disaster, and crisis mapping has become commonplace in less than a decade. The 2010 Haiti Earthquake launched a transformational shift in crowd-sourced information and VGI (Zook, Graham, Shelton, & Gorman, 2010). As another example, within a week after the Fukushima Daiichi Nuclear Disaster, Safecast distributed inexpensive Geiger counters to volunteers. These data were uploaded to an interactive mapping site, producing a crowd-sourced high resolution depiction of radiation levels (Fig. 16.4) at a moment when risk communication from formal sources was not terribly forthcoming. Various groups (e.g., Harvard Humanitarian Initiative, The Humanitarian OpenStreetMap Team, CrisisMappers) contribute to these endeavors, as do numerous platforms (e.g., Google Crisis Resources, Ushahidi), many of which are free and/or open source (Leidig & Teeuw, 2015a). Even near real-time maps exist of conflict areas (for instance, the Syria Crisis, Liveuamap, 2016).

16.3 Trends and Future Directions

Taken together, the rapid expansion of mobile technologies, the ever-increasing volume of generated spatial data, and the numerous topic-specific examples of support-systems suggest immense possibilities for DM-SDSS, supporting a wide range of user constituents. While the potential is exciting, this all points to challenges and future needs. The technological and data needs are immense and the required physical and social models vast. This section focuses on trends and considerations for the development of DM-SDSS, suggesting future directions for research.

16.3.1 Data Considerations

Data issues are mentioned by nearly everyone who writes on GIS, GIS&T, or DM-SDSSs, and is one of the greatest challenges facing the development of effective DM-SDSSs (NAS, 2007; NRC, 1999). Since these technologies are fundamentally data-driven, the lack of documentation about the information, data standardization, up-to-date information, or access to existing data all limit usefulness. High quality, relevant, timely, accessible, and integrated data are foundational to a DM-SDSS.

The nuanced data behind the maps and the models used to define risk data have variable quality with uncertainty embedded throughout the display. Describing and conveying uncertainty in an interactive mapping environment is just as, if not more, difficult than paper versions, a challenge that is not yet solved. Geographic data have many unique characteristics, such as scale, resolution, and projection. For instance, the scale at which data are collected directly impacts the level of detail included, which in turn affects the types of questions that may be answered or the analytical approach required. Evaluating whether a property is in a floodplain illustrates this point. Ideally, one would want very detailed tax maps along with engineering maps of the floodplain to make a determination. Using a statewide roadmap with streams and rivers (smaller scale maps) would not be an adequate option. Scale is but one geographic data consideration. Some others include how often and how recently the data were collected and by whom, the type of sensor for remotely sensed data, the original source, format, and procedures for collecting and processing. Not surprisingly, the quality of data and the geographic characteristics directly influence uncertainty and error embedded in results and visualization.

Studies surveying emergency managers revealed that real-time decision support require *temporal* detail in combination with the mapped information (Aubrecht, Fuchs, & Neuhold, 2013; Zerger & Smith, 2003), which adds a level of complexity if data are even collected, or collected in a way that is applicable. For example, data on many vulnerable and special needs population, such as tourists, homeless people, or undocumented workers are still not even collected or maintained in a consistent fashion (Cutter, 2003; Morrow, 1999); thus, these groups remain entirely under-represented in disaster GIS. Understanding day-time and night-time populations (for example, work or school versus residence), as well as movement between various activities persist as data gaps, nor is socio-economic composition captured for temporal shifts around a community. Importantly, disaster management requires both geographical and non-geographical data, all of which must be incorporated into any DM-SDSS, but are not always of the same high quality.

Even after decades of planning, debates, and consideration for disaster management data needs, there still is not a centralized data clearinghouse, portal, or repository for hazards or social science data that are already collected. Further, common data standards do not exist for collection, storage, or dissemination (NAS, 2007), which would facilitate efficient integration without significant manipulation. So, while vast quantities of data do exist, they are in disparate locations with variable access and quality. Even when high quality datasets do exist, they may be held by a private company (e.g. critical infrastructure related to utilities) or not available due to security (e.g. dams) or privacy (e.g. health records) concerns; all of these are stored in disparate systems and organizations. Data sharing agreements are often necessary when data are not publicly available, though often not in place prior to an event. Cloud computing now offers immense possibilities in terms of sharing data and processing. However, reliance on the Internet poses a potential pitfall since it may not always be available (Johnston, Banerjee, Cothren, & Parkerson, 2014). So, while taking advantage of web-based solutions offers tremendous possibility, ensuring viable alternatives requires careful consideration and research.

At the same time, global positioning systems, remote sensing imagery, and geographic information systems are all accessible in ways not even possible five or ten years ago, generating ever-increasing amounts of geographic data. Other emerging technologies, including unmanned aerial vehicles (UAVs), 3D mapping applications (Breunig & Zlatanova, 2011), and video (Mills, Curtis, Kennedy, Kennedy, & Edwards, 2010) are all already generating immense quantities of data that will increase into the future. Individually and in combination, these increase data processing, storage, and management needs.

Although coming with exciting possibilities, the emergence of VGI data poses some unique data quality and dissemination challenges as compared to data collected through formal processes because of the lack of data collection/dissemination protocols and controls. The very strength of VGI through distributed and rapid collection also gives rise to substantial uncertainty in both the spatial and non-spatial data (Camponovo & Freundschuh, 2014). Issues of data quality, management, liability and security all need significant attention (Elwood et al., 2012; Haworth & Bruce, 2015; Sui & Goodchild, 2013). The decentralization of power poses unique need and opportunities for evaluation of VGI data quality and credibility (Flanagin & Metzger, 2008; Sui & Goodchild, 2013). VGI, as new paradigm for the generation and exchange of geographic information, has far-reaching implications, possibilities, and challenges for both practice and research (Elwood et al., 2012; Goodchild & Glennon, 2010; Sui & Goodchild, 2013).

The emergence of vast amounts of spatial data and interactive mapping have not necessarily facilitated access and use. The key for DM-SDSS is making information available to decision-makers in a meaningful and efficient manner. In fact, the massive quantities of spatial data now generated require big data analytics (BDA) to convert data into useable information (NIST, 2015), and much research is needed in this realm. Currently, there is a mismatch between what end users/decision-makers need from these data and the data science that produces meaningful results (NSTAC, 2016?). Research is necessary to ascertain whether and how this vast amount of data enhances disaster mitigation, preparedness, response, and recovery. Further, as spatial data is disseminated in various forms, effective map and risk communication principles must be explored.

While the Internet provides significant opportunity for dissemination, most online mapping efforts fall short of an integrated, robust DM-SDSS in several ways. Many predominantly focus only on the display and visualization of hazards data. Perhaps not surprisingly given the agency/organizational-oriented nature of data collection, online mapping interfaces tend to focus on a single hazard or set of related hazards, limiting the potential for all-hazard approaches and creating disjointed platforms that inhibit cohesive decision-making. Further, they are often oriented towards finding a specific location and then displaying the risk for a particular hazard without the inclusion of other social, physical, or built environmental data. The ability to change parameters and examine various scenarios is rarely an option. As an extension, they do not commonly include user priorities and perspectives, instead usually delivering information in one direction, often with limited analytic capabilities.

16.3.2 Social & Organizational Needs

Because a DM-SDSS is used by people within a particular context, social and organizational success is not simply based on technical concerns. In other words, a DM-SDSS may be developed and run efficiently, but may never be utilized to the fullest capacity without taking social and organizational issues into account. As important as the technology, the realization of risk reduction guided by DM-SDSS is dependent on coordination between and within organizations, user needs, data/technology access, and ethical considerations, incorporating and applying the technologies in ways that change behavior.

A system must meet the needs of an organization, as well as the end user/disaster manager. A DM-SDSS' compatibility with existing workflows augments decision-making, rather than requiring users to learn a different process. At the individual level, the design of the system should incorporate user need assessments, which reveal how technology can support the decision-making process. An end user can represent a range of stakeholders, from the expert to the lay person; design requires careful identification and consideration of who this is. At the organizational level, interoperability requires the cooperation of organizations for the transfer of data and models. Agreements must be in place prior to events, and a plan for the flow of information and models should exist. The International Charter, "Space and Major Disasters," is an example of this type of data sharing agreement and gives organizations in countries affected by major disasters access to necessary remote sensing data if they are an authorized user.

Even as community-based approaches and VGI disrupt traditional communication flows and access to data fosters unrestricted communication, the digital divide between subgroups of people and parts of the world not all having access to these technologies exacerbates inequities (Leidig & Teeuw, 2015b). In some ways, the most vulnerable become even more peripheral to information exchanges since they are least likely to have access to technology that can facilitate access to vital information. In fact, this is also true of many rural areas or low-income urban communities in high income countries, as not all places have high-speed Internet access, nor can all people afford it. In turn, they do not have the same access to risk information as people or organizations that are "connected." Although there are exciting and interesting examples of GIS use in lower and middle income countries, particularly with the availability of geospatial open source software (Teeuw, Leidig, Saunders, & Morris, 2013), computing infrastructure and data beyond Internet access are not as readily available.

A DM-SDSS should ensure equitable data access balanced with privacy and security considerations. These systems should contribute to documenting disaster loss reduction balanced with minimizing infringement on individual or community rights. Further, some data are secure (proprietary or legally restricted, such as dams in the U.S.). In an era of digital geographic data, the very data that are utilized to support improved hazard mitigation and preparedness may, in fact, reveal too much detail about communities and/or individuals. For instance, knowing where undocumented workers or people with disabilities live is necessary for vulnerability reduction. However, these data could be employed in a vastly different way by groups, such as law enforcement, with an alternate motivation. Further, the ways in which places are reconceptualized by GIS must be examined (Curry, 1997), since the way a community may want to be portrayed can differ from expert depictions.

16.3.3 Sustainability and Dissemination

Even though numerous DM-SDSS examples exist, their adoption and dissemination is currently not well understood. Why does a particular DM-SDSS persist, while others are rarely used and/or disappear entirely after a short time? What might be considered a success in terms of adoption, VGI is now nearly ubiquitous during major events response, but it has not been widely applied in other disaster management phases. The rapid dissemination of VGI likely reflects a relative advantage over more traditional GIS for the public in response scenarios, so understanding how this may, or may not, translate to recovery, mitigation, or preparedness is relevant. Further, many DM-SDSS initiatives have come and gone, possibly suggesting limited financial, technical and human resource support; or, just as probable of an explanation, the tool was not widely adopted and so support became inappropriate. In reality, many DM-SDSSs remain siloed mapping tools for a particular hazard or management issue with fairly specific purposes with little integration between applications. In fact, on a portal for interactive tools NOAA (2016e), no less than 59 options, most with mapping capabilities, are listed related to various aspects of coastal and disaster decision-making, which could be overwhelming for many users who might benefit from their use. Further, tools are frequently developed without user needs assessments, thereby not identifying the requirements for decision-support at the onset of development. Once available, limited support for analysis and evaluation may constrain use (Uran & Janssen, 2003). Significantly, little is known about the actual use of DM-SDSS and whether, and how, any of these tools influence decision-making or organizational/individual behavior.

Research is needed on the cognition of geographic information for disaster management and risk communication. In other words, knowing how people process and understand spatial data aids in the creation of appropriate and effective maps and other corresponding output from the DM-SDSS. The ways in which people understand and interpret maps varies. Thus, not only does the data impact the output, but people's perceptions and map reading skills should also be considered. For example, red is generally interpreted as 'danger' and so using a yellow to depict wildfire-prone areas would not be as effective. Cartographic (map-making) principles should always be incorporated into the design and implementation of any DM-SDSS interface and visualization capabilities (for example, MacEachren, 2004 or Robinson, Morrison, Muehrcke, Kimerling, & Guptill, 1995). Related to this, developing theory-based mechanisms for conveying uncertainty that exists in all physical and social models, as well as in the data itself, is necessary. However, in the face of information that is not one-hundred percent correct, disaster managers still must make costly decisions about evacuation or prioritizing mitigation measures. Individuals and communities are faced with the same dilemma.

In the end, if elaborate decision-support tools do not change individual and organizational behavior and ultimately reduce risk, investment in them is ill-placed. Little research currently exists on how maps (or a DM-SDSS) influence risk perception or decision-making. Ultimately, changing behavior is cornerstone for reducing loss, not the generation of vast amounts of unusable data or decision-support tools that are not adopted, used or applied. Research is necessary that directly explores how (and whether) research embedded within DM-SDSSs translates to risk reduction.

16.4 Conclusion

The proliferation of GIS&T throughout disaster/hazard research and practice enables and facilitates placed-based approaches for disaster risk reduction. GIS&T guides all elements of a DM-SDSS, which incorporates database management systems, specialized analytical modeling capabilities, graphical display capabilities, and reporting capabilities with the ability to consider scenarios by an end user. GIS, one type of geo-technology in GIS&T, has wide-ranging potential in disaster management, including, but not limited to, damage assessment, risk prediction and situational analyses, vulnerability and resilience assessments, or prioritization of mitigation alternatives. Rapidly evolving technologies now provide a platform to engage in community-based disaster management, and geo-enabled mobile technologies have rapidly expanded the potential for widespread geographic problem-solving and decision-making. With proper design considerations, DM-SDSS should reduce information overload and assist all types of stakeholders in the assessment of risk reduction activities.

As DM-SDSS utilization increases, critical evaluation of the technology should be undertaken. Little is known about the way DM-SDSS tools are adopted and disseminated. By extension, limited research explores how GIS and maps directly affect decision-making or how people process and utilize geographic information, including uncertainty, for risk reduction actions. Research is still needed that explores tensions between access, security and privacy, continually promoting equitable and inclusive solutions. For example, the digital divide and consistent access to the Internet still present significant barriers to the utilization of spatial data and mapping, the basis of a DM-SDSS. The rapid emergence of VGI, and associated social media, has transformed the potential for broad citizen participation in GIS&T, offering expansive opportunities for needed research in data credibility, social decision-making, and user motivation. With the availability of ever-increasing amounts of data from numerous inputs, including remote sensing, GPS, VGI and new sensors, the mismatch between vast data availability and the ability to process into meaningful results warrants significant attention. Not only is there a need for centralized data repositories & clearinghouses (social and physical sciences and engineering), research in big data analytics (BDA) specific to spatial data is necessary to convert data into useable information.

DM-SDSS has not reached its fullest potential and significant gaps in research exist across numerous DM-SDSS dimensions. Although immense promise exists, the proliferation of GIS&T applications throughout disaster/hazards research and practice does not always translate to decision-support or behavior change. The proliferation of technology for the sake of technology is not particularly useful; it is cutting-edge approaches that support disaster decision-making that will ultimately reduce loss, which requires commitment to interdisciplinary research that transcends boundaries between the physical and social science, as well as engineering.

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