

Challenges for the Application of GIS Interoperability in Emergency Management

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Abstract

This paper highlights application challenges for GIS interoperability for emergency management with emphasis on critical infrastructure sectors. In the first part, this paper provides a comparative analysis of emergency management operations in the City of Vancouver; the City of Toronto, the Kitchener Waterloo Region, and the Dufferin County. A variety of qualitative research methods were employed for gathering information from key decision-makers involved with emergency management. The second part of this paper presents a scenario-based case study, which aims to provide a demonstration of the utility of GIS interoperability, for disaster management. This paper also discusses the strengths and weaknesses of leveraging GIS interoperability for disaster management.

1 Introduction

Geographic information system (GIS) interoperability aims to ensure a process that will allow for the use of data, information, and services across organizational boundaries, and to make information available for all of the levels involved in disaster management activities. One of the first studies that aimed to characterize GIS interoperability was by Bishr (1998) who has demonstrated the need for working on data that are scattered over sev-

eral independent databases. This goal has been achieved and the internet has played the key role in connecting systems over a common network protocol. According to Erharuyi and Fairbairn (2003), real-time ability to visualize map locations, determine the scale of emergency, identify and evacuate at-risk populations, and expedite and direct response efforts are key areas in which GIS interoperability is much needed. As a result, a great deal of interest towards disaster management applications using internet GIS is rapidly emerging. Advancements in internet technology, in the form of high speed broadband, have made GIS interoperability more effective and accessible.

This paper will address issues related to GIS interoperability, and will examine the status of GIS interoperability in disaster management, with emphasis on specific Ontario municipalities (i.e., Toronto, Kitchener Waterloo and Dufferin County). The second part of this paper will present an example (i.e., a demonstration case study) that highlights benefits that GIS interoperability could bring to the disaster management community.

1.2 GIS Interoperability

GIS interoperability is unique in that it allows one to ensure easy and compatible spatial data access over the internet (Visser et al. 2002). Farley (1999) indicates that interoperability is important for disaster management applications, because it helps to eliminate system and data heterogeneity. The importance of this has made interoperability a central research and development initiative. According to Goodchild (2003) interoperability aims to eliminate incompatibilities in data formats, software products, and spatial conceptions and data quality standards. The distinction between data transfer and interoperability is very important. Table 1 summarizes the differences between interoperability and transfer.

Table 1. Differences between the process of data transfer and data interoperability (after Glover 1995).

Aspect	Transfer	Interoperability
Scope	Data, no process	Data and Process
Data Unit	Dataset	Object (Dataset or Lower)
Communication	Bind (One Way)	Negotiated (Two Way)
Integration	In Target System	In Server or During Communication

The concept of GIS interoperability, as shown in (Table 1) is a process of using standard protocols to control inter-system access over the Internet. Disasters and their impacts may extend across large areas which, when dealing within a GIS context, invariably involves large volumes of data. Thus, simulating natural disasters may require advanced and high-capacity computing capabilities. Satellite imagery, digital elevation models and vector data available to municipalities and to the provincial authorities may exceed the processing capacity of a desktop computer. This is one of the areas where the strength of network-centric computing and systems interoperability is required. Interoperability can also allow efficient share of data / information in near real time when one is experiencing an emergency.

1.3 Interoperability Specifications

The Open Geospatial Consortium (OGC) is a US-based Industry consortium, with members from government and academia that has a mandate to develop and foster interoperability specifications (OGC 2002a). OGC has initiated interoperability specifications. Three of these specifications represent the backbone for GIS interoperability, which are:

Web Map Service (WMS) specification, which standardizes the process of requests and response between the server and the client for efficient data sharing.

- Web Feature Service (WFS) which controls the process of basic edits over the internet.
- Web Coverage Service (WCS) which standardizes the process of exploring coverage data.

2 Methodology

A comparative analysis of applications, resources and needs was conducted in order to examine the actual need for interoperable GIS applications for disaster management. A focus was placed on the City of Toronto, since it is one of the largest metropolitan centers in Canada. The study compared Toronto with similar selected medium and small-sized cities in Canada. The City of Vancouver was chosen on the basis of its comparable size, similar administrative structure and the similarity of operational activities related to emergency management.

A questionnaire was carefully designed in order to address three issues, namely: 1) usability of network-centric GIS; 2) GIS interoperability appli-

cations and examples; and 3) issues and challenges related to having inter-operating GIS systems. The questionnaire was sent to each municipality and answers obtained either by email, or through conference call.

The third part of this methodology involved providing an example showcase solution of the optimal application of interoperability for each of the municipalities studied. The developed application utilized datasets for the City of Toronto obtained through the Map Library at York University, with digital elevation data and watershed information obtained from the Toronto Region Conservation Authority. The methodology used in this study is shown in Fig. 1.

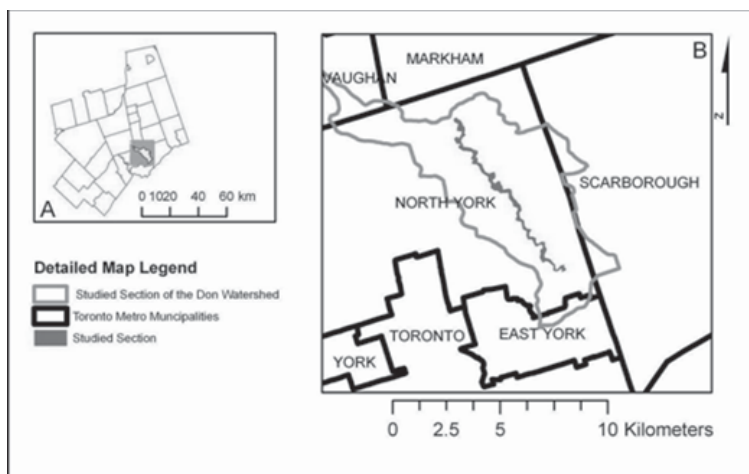


Fig. 1. Process for developing a conceptual model

2.1 Analysis of Interoperability in the City of Toronto

The City of Toronto is located on southeastern Ontario, on a broad sloping plateau cut by numerous river valleys. Toronto, one of the largest cities in Canada, covers 641 sq km, and stretches 43 km from east to west and 21 km from north to south at its longest points (Wright et al. 2000). The City of Toronto has a department that is involved with emergency mapping; this is known as the Department Emergency Mapping Services. It was formed in 1999 as a result of the amalgamation of the municipalities of Toronto, Scarborough, and North York into the Greater Toronto Area (GTA). The Emergency Mapping Services of the City of Toronto is working toward an advanced level of interoperability that integrates data, processing and se-

mantics in both applications and services. Currently the department is using both desktop GIS and web-based GIS technologies for processing and coordinating disaster management activities. The staff of the mapping services department is comprised of over 180 personnel ranging in responsibility from technical to management roles. The Emergency Mapping Department is located in a three story facility. Surprisingly, the funding for this facility is estimated to be less than 1% of the total budget of the City of Toronto.

2.2 Current Status of Interoperability in Toronto

Web-based GIS interoperability is thought to be critically important to the City of Toronto, as evidenced by the fact that the city is moving all GIS mapping services and applications toward web-based technologies. The best examples for incidents in which web-based GIS interoperability was determined to be of great use to the City of Toronto include: data exchange between local governments, exchange of data between government and business users, and exchange of data between government and utility companies. The IT group at the City of Toronto believes that Web-based GIS represents the coming generation of GIS and that it will eventually be used ubiquitously. The Emergency Mapping department of the City of Toronto is coordinating with civil society organizations that are working on the social dimensions of disaster management and emergency response aid in terms of cooperative data sharing, sharing common data exchange standards, and providing cross training of staff.

A need for GIS interoperability was demonstrated by the City of Toronto on a variety of occasions. The most recent examples involved the modeling of West Nile Virus, and Severe Acute Respiratory Syndrome (SARS). GIS applications are very useful in modeling epidemic disease outbreaks, since GIS provides the location information and diffusion patterns in visual databases. As well, it provides the desired level of coordination between health authorities, municipal authorities, and community decision-makers. The City of Toronto has also used GIS in planning for two massive festivals, namely: (1) on World Youth Day in 2001, and (2) the rolling stones concert in 2003. These two events were attended by hundreds of thousands of people. In case of emergency it would not be an easy task to find suitable dispatch routes, or the nearest hospital or service provider. GIS interoperability can certainly help with each of these aspects. In addition to those examples, the City of Toronto has used GIS interoperability for a variety of evacuation plans including Nuclear Planning Exercises.

2.3 Comparison with Vancouver

The City of Vancouver is located in southwestern British Columbia, Canada and is part of the Greater Vancouver Regional District (GVRD), otherwise called the Lower Mainland. The emergency management department is the City of Vancouver's agency that deals with emergency mapping. GIS applications for emergency management at the City of Vancouver are over 15 years old. This makes GIS applications for disaster management at the City of Vancouver very mature. Both desktop and internet GIS in addition to mobile GIS are used on a regular basis for processing and coordinating disaster management activities in the field.

The emergency management department at the City of Vancouver is administered by about 20 technical GIS staff members. It operates the Emergency Operation Centre (EOC), which is a command control center wherein all disaster management stakeholders (City of Vancouver, Province BC, PSEPC, and RCMP) meet during emergency situations. EOC is a sophisticated emergency center which provides complete emergency management services, including GIS modeling and Visualization. The City of Vancouver relies mainly on desktop GIS for data processing, but also on mobile GIS, which is used for field data collection.

The City of Vancouver has expressed a keen interest in GIS interoperability for disaster management coordination. The aim of the GIS Technology development plan for the City of Vancouver is to create a GIS database that is as complete as possible and one that can be updated daily or even more frequently if necessary. Additionally, the important role of web-GIS in the day-to-day activities of the emergency management department has further justified the need for interoperable GIS. This justification stems from a multi-stakeholder, multi-institution and multi-tier decision-making process. Using the same levels of integration evident in the City of Toronto; the City of Vancouver is integrating its data sources with various governmental levels as well as with business (e.g., The City of Vancouver also shares the City of Toronto's vision that web-based GIS applications will dominate in the future).

There is a high level of coordination between the City of Vancouver and its NGOs that are represented in the city Emergency Operations Centre (EOC). This coordination, allow these organizations to have direct involvement in decision-making processes, as well as to facilitate their data and information access with the Emergency Operations Center.

The City of Vancouver has extended its GIS applications to address the social implications of disasters. The City of Vancouver coordinates GIS data delivery in an interoperating manner locally between Engineering, Police and Fire departments, as well as with other governmental agencies.

Field data collection using mobile GIS devices is the most advanced application in Vancouver.

In terms of challenges, the City of Vancouver EOC has provided the city's GIS expertise to various decision-making levels involved in disaster and emergency management. This might be justified by the fact that Vancouver is considered to be more vulnerable than Toronto, due to Vancouver's location in a seismically active zone and the city's proximity to the ocean. The City of Vancouver has identified intergovernmental data sharing as an issue for achieving collaborative disaster management coordination. This is largely due to the difficulty of extracting important information from the system.

2.4 Comparison with Waterloo Region

The City of Kitchener, in southwestern Ontario, had a population of about 204,000 in 2004 (Dept. of Geography, University of Western Ontario 2000). Kitchener is the location of the Waterloo Regional Municipality and is adjacent to the smaller City of Waterloo. The IT department in this region is responsible for GIS applications, including emergency management applications. Both desktop and internet GIS are used, with emphasis on desktop GIS.

Waterloo Region has utilized GIS interoperability for emergency management for the first time in the preparation of the Ontario Emergency Management Act. In the process of complying with this act, Environment Canada has launched the atmospheric hazards website (www.hazards.ca), which provides interoperable GIS service for all municipalities. Table 1 is showing comparative analysis of data handling capabilities in the studied municipalities. As it is obvious from this table, larger municipalities, have better resources.

Table 3. Data handling capabilities among studied municipalities

Data	Toronto	Vancouver	Waterloo	Dufferin
Production	Yes	Yes	Limited	No
Sharing	Limited	Limited	No	No
Conversion	Yes	Yes	Yes	Yes
Commercialization	Yes	Yes	Limited	No

2.5 Comparison with Dufferin County

Dufferin County is located in south-central Ontario, Canada. Orangeville, the County seat, is located approximately 75 km north-west of Toronto. It consists of three towns: Mono, Orangeville and Shelburne; and five rural townships: Amaranth, East Garafraxa, East Luther Grand Valley, Melancthon, and Mulmur. Although the region is small, it has had an Emergency Management Coordinator since 1989.

Dufferin County is a typical small region with limited resources. Emergency management activities in this region can be directly related and compared to large regions. Dufferin County does not have a specialized GIS officer to deal with emergency mapping issues. All GIS work related to emergency management and other activities is managed by a public works drafts person. Table 2 shows a comparative operational analysis for the municipalities assessed in the study.

Table. 4 Comparison of available resources for the studied municipalities

Resources	Toronto	Vancouver	Waterloo	Dufferin
Emergency Mapping	Yes	Yes	Yes	No
GIS General Operations	Yes	Yes	Limited	No
Emergency Operations Center	Yes	Yes	No	No
Specialized GIS Personnel	Yes	Yes	Yes/IT Dept.	No
Need for External resources	No	No	Limited	Yes

3 Demonstration Case Study

This section demonstrates the optimal solution that GIS interoperability might provide for enhancing emergency management operations. The designed demonstration scenario stems from the various problems with data and systems heterogeneity found when analyzing the utility of GIS interoperability for emergency management in four local governments. It is important to mention that the main objective of this section is to demonstrate how GIS interoperability can provide a solution for disaster management. Hypothetically an emergency response can be simulated in order to show how GIS interoperability functions in such a situation and what this could provide to emergency management decision-makers. In the present case, when the various flood scenarios under different flood levels have been

simulated and the damages can be assessed, the results obtained can be published and visualized in a 3D web environment using GeoServNet.

A hypothetical flood scenario in the Don Valley was used to demonstrate the solution that GIS interoperability can provide for emergency management. The Don River is a system that flows through the Greater Toronto Area (GTA). The origin of the Don River is in the Oak Ridges Moraine where the headwaters are fed by numerous aquifers. The river then flows for 38 km to Lake Ontario, providing drainage for 360 square km of land. The section used for this study is part of the Don Valley watershed system in the province of Ontario, as shown in Figure 2. DMTI Topographic digital maps in the form of shapefiles and DEM were obtained from the York University Map library (DMTI 2004). Topographic sheets of the area were used as a reference for conducting this study. Data describing flow statistics were simulated.

4 Emergency Management Actors and Roles

Based on the Ontario Emergency Management Doctrine (EMO 2004), different ministries are responsible for dealing with different natural hazards. This section provides a generic overview of what the exact benefits are that each ministry can gain by utilizing GIS interoperability. Due to information privacy and security issues, it was not possible to simulate this model as part of a real exercise. However, the adopted techniques have closely mimicked the simulation exercise environment.

The TRCA is responsible for flood simulation, floodplain mapping and water surface measurement. All hydraulics and hydrology data are under the custody of the TRCA. In such an event the TRCA will provide flood models and data through interoperable access to all decision-makers involved. Products like the flood plain map shown in Figure 2 can be simulated and made available to all actors involved. Real and semi-real time situational awareness models can be generated and accessed on demand based on stakeholder needs. Access to tabular and text information is also possible.

City of Toronto emergency services is responsible for providing services in a variety of situations, ranging from simple road maintenance closures to extreme disaster situations. The city produces and hosts its own data, and aims to make data standardized and interoperable with other parties. The City of Toronto can provide data about land use categories affected as a result of the flood and about what kind of infrastructure sectors can be impacted by the flood, as shown in Figure 4. The city can also pro-

vide real-time field information by utilizing interoperable mobile devices for data collection and transmission.

The Toronto Police Service is responsible for maintaining law and order in the city. In emergency situations the city police department can utilize GIS interoperability in a very efficient way. This includes accessing flood data provided by the city's emergency mapping department and that provided by the Toronto Region Conservation Authority (TRCA), pinpointing areas that are most vulnerable to traffic problems. Based on this information they can deploy officers to organize traffic in that region. Another example of how GIS interoperability can be utilized is that police can transmit real-time field data of traffic problems, or any related security problems, on the fly for all stakeholders involved in a particular emergency management scenario.

In emergency situations the city fire department can play role similar to that of the city police, however, in addition the fire department can assist with evacuation operations for particular locations in the city. Also the fire department can access data and information provided by the city and the TRCA to identify the most vulnerable areas and to concentrate its efforts there.

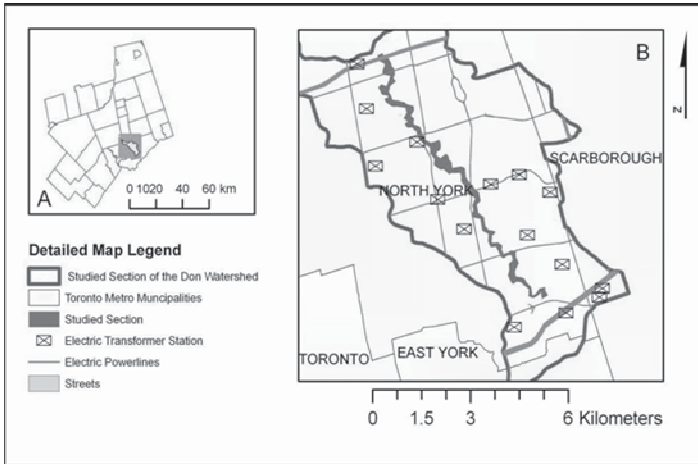


Figure -1. Infrastructure proximity; (A) Location of a focus section of the Don Valley within the GTA, Toronto, Canada; and (B) Detail of infrastructure proximity to flood extent

Toronto EMS can utilize GIS data and information for predicting areas at high risk of experiencing an emergency and for planning how they can dispatch their services to these areas. Another important utility of GIS in-

teroperability for EMS is that, in emergency situations, it is not easy to prioritize your response to calls from different parts of the city. Knowing where a call is coming from relative to the emergency is invaluable to prioritizing response.

A key role for the EMO is to monitor emergency situations, and to not get involved unless it is required. Towards this end, GIS interoperability could provide EMO with improved situational awareness models by assembling data from all different departments and to make these available for basic analysis and visualization as shown in Figure 3. The legend on the clip was captured from the web-based program. It is interactive and can be shown by either activating the legend feature or by pointing to the particular item in the map.

5 Strengths and Weaknesses

GIS interoperability can provide enormous benefits to the disaster and emergency management community. It is clear from the analysis of the questionnaire that the level and capability of GIS interoperability for emergency management is not very well established or utilized at the municipal level, in particular in the small municipalities studied. Network-centric computing is necessary for processing large volumes of data and is achieved through the sharing of the computing power of other systems within the network.

A limitation of a non-interoperable environment is that users from different decision-making levels are not able to access the same information at the same time. In such a case it is not a simple task to secure simultaneous data access and processing. This makes the elimination of system and data heterogeneity potentially very useful for disaster management applications. Such applications make GIS interoperability a highly demanding mechanism for disaster management coordination.

Strengths

GIS interoperability is very useful in disaster and emergency management. Disaster and emergency management stakeholders can benefit from GIS interoperability by gaining access to standard, fast, accessible, shared GIS for achieving efficient decision-making processes. This section will highlight some key implementation benefits that the emergency management community can gain by leveraging GIS interoperability.

Establishing advanced interoperable applications and services is a key future aim of GIS and technology development plans at the City of To-

ronto. A second aim is that of providing the required geomatics services to support City of Toronto emergency management detection, prevention, planning, response, and recovery challenges.

The City of Vancouver is working on improving and extending the current level of interoperability in order to improve the efficacy of their Disaster Management coordination. It is also working to improve network-centric GIS computing through a three year evaluation and upgrading plan. Furthermore, the city is considering to extend their visualization and analysis applications to include 3D GIS. The City of Vancouver is also looking for university contribution in the area of data management and sharing.

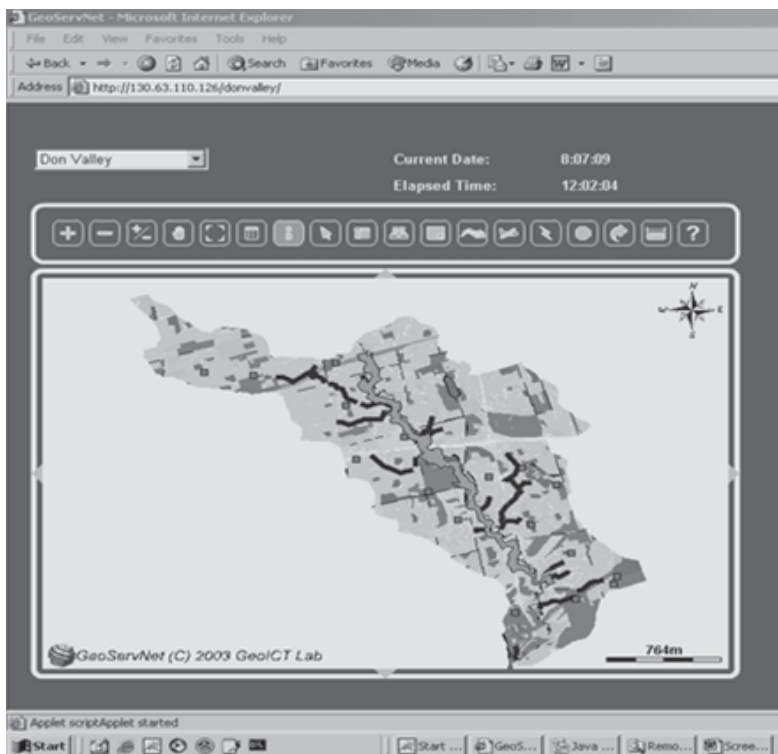


Figure -2. GeoServNet web-interface; (a) GeoServNet controls; and (b) Don Valley flood scenario visualization and analysis

Emergency service must aim to be timely and accurate, whereby geospatial information and geoprocessing services are easily accessible and

capable of being shared across jurisdictions and multiple security levels. Also, the city plans go further to advance GIS interoperability and capabilities through the hosting of a web map service (WMS/WFS) site. The City of Toronto GIS Emergency Mapping Department is also aiming to get assistance from universities for GIS development for Disaster Management applications with regards to standards and specifications development. The City of Toronto is intending to use web-based GIS for disaster management and emergency response projects for operational plans and in the event of an emergency, this constitutes a Geomatics-centric Incidence Response. The specific benefits resulting from GIS interoperability are summarized in the following several sections.

GIS interoperability allows for open access to multiple data sources. This benefit helps decision-makers to access multiple servers, thereby obtaining data and services that do not necessarily occur in the same location or even within the same organizational boundary for that matter. Through GIS interoperability, the emergency management community can move towards one or several closely related standard data formats that can be used in data transfer and information sharing.

Standards-based GIS interoperability helps to provide a simple and accessible means of integration to decision-makers. This is crucial since emergency management operations stand to benefit considerably from a process that allows for timely gathering, modeling and analysis of information. If the system is not simple and accessible it will not be easily implemented during disaster management and emergency response. GIS interoperability, through its standardized protocols has allowed GIS users to utilize a simple and standard service.

Within the context of interoperability, transparency refers to the process of accessing and sharing data between systems without the use of complicated, cumbersome protocols. This differs from the concept of 'common format' in that a common format is not necessarily easy to use. Through a transparent system, emergency management stakeholders can readily access GIS data and systems that are external to their system domain.

GIS interoperability can be expanded or contracted by adding or eliminating nodes. This flexibility in scalability in systems and services is useful in emergency management operations, which, due to their dynamic, fast-paced nature, require that previously unexpected situations be accommodated.

Weaknesses

To date, considerable effort has been expended toward providing efficient, interoperable solutions for disaster and emergency management. However,

GIS interoperability remains a stimulating field and research is still underway into addressing many aspects of interoperability. The following subsections address specific problems and challenges that remain in this field.

From an operational perspective, there are particular issues related to the degree to which data conversion hinders efficient data interoperability. This may arise if, for example, a particular department is using engineering data that is stored in a Computer Aided Design (CAD) format and another department is using data stored in ArcGIS shapefile formats. These two formats can be made to be compatible by converting CAD data into the shapefile format. The time required for this process depends on data size and system capabilities.

Different processes and techniques are used by different departments. This can create an obstacle to achieving GIS interoperability. A streamlined process and system capabilities are required for effective GIS interoperability. Different departments have specialized staff expertise and technical capabilities, this makes it a difficult and delaying process to comply with GIS interoperability requirements. Another issue is related to bandwidth load. This is very important in securing efficient network performance without overloading a particular network.

Data maintenance and update is another issue that represents an obstacle to achieving GIS interoperability. Where there is no clear policy that identifies roles and responsibilities for each node in an interoperable system, data update, maintenance and management can be a challenge.

Access rights to sensitive information, such as infrastructure and emergency management, represent another issue. Much disaster management data and information are, for a variety of reasons, not meant for public access and as a result are categorized as 'classified.' What are the criteria that should be used to categorize data and information to a specific clearance level? This is a key question and challenge that can represent a serious obstacle to GIS interoperability. Another crucial issue is related to corporate technology procurement policies, which can contribute to delayed implementation.

It is evident from the study that the City of Toronto produces and owns its own data while at the same time using data from other neighboring regions. The level of data sharing in this form doesn't constitute 'interoperability'. However, this could be enhanced by using data exchange standards to make these data useable not only to Toronto and neighboring regions, but to any other institution involved in emergency management operations. The same benefit could be gained by the City of Vancouver, which utilizes its locally produced data along with other non-proprietary data.

Waterloo and Dufferin regions utilize external data sets, indicating a clear need for data standards and GIS interoperability, since both regions use the same web-service and have different problems that could be eliminated through proper GIS data sharing. The region of Waterloo has indicated that, when utilizing the Environment Canada web service, that they had experienced problems related to the level of detail and to layer matching. This indicates heterogeneity that could have been avoided through the use of a standard data model and format.

The Dufferin region emergency manager faced a problem when dealing with the online web GIS service, finding it to be too technical in nature. In contrast, large cities like Toronto and Vancouver have specialized technical departments that are capable of dealing with technical GIS issues. GIS interoperability can help in eliminating the detailed technical expertise required to utilize desk-top GIS packages and can provide a considerable additional benefit that it can be leveraged over the internet for many users simultaneously.

As the case with the City of Toronto indicated, large cities produce, utilize and share data with other users. However, this is performed through procedural data exchange not through a systematic, dynamic process. GIS interoperability achieves this capacity in that it can allow for decentralized data handling and access from different servers.

Waterloo and Dufferin counties are able to access and visualize data from an interoperable web service, which provides them with access to data that they do not own. This level of GIS interoperability helps to provide an efficient solution to the challenge of timely access to emergency management data. At the same time it reduces duplication of data sets in more than one site, thereby saving storage resources.

6 Conclusions

This paper has shown that GIS interoperability is effective at coordinating the emergency management decision-making process by allowing simultaneous data and information access and updates. Two scenarios have outlined how network-centric GIS can best be used in modeling and visualization of disaster management scenarios. Through its integration with other modeling systems, GIS functionality provides decision-makers with tools that can improve the decision-making process. In this sense, a virtual emergency management center can provide near real-time data access to decision-makers in different locations.

One of the limitations of this study is that it has only two integrated earthquake shakemap models and hydraulic simulation models as input into a GIS database. Other models that provide detailed information about cascading effects, escalating failures and systems dynamics could also be included as input into GIS databases and would provide very advanced visualization capabilities. Utilizing other spatially enabled modeling components would significantly help with expanding our understanding of the complex issue surrounding critical infrastructure interdependencies.

The temporal dimension is very important in quantifying and understanding damage magnitude, peak flood spatial extent and the impact on each of the interdependencies between various infrastructure sectors and systems. In this dissertation, the temporal aspects of disaster management scenarios have been discussed, and only the peak flood extent has been used in building the knowledgebase. Explicit study of the temporal aspects associated with disaster management would be of great benefit to the disaster management community.

References

- Allen, E., Edwards, G. and Bedard, Y., 1995. Qualitative causal modeling in temporal GIS. *Spatial Information Theory*, 988: 397-412.
- Bishr, Y., 1998. Overcoming the semantic and other barriers to GIS interoperability. *International Journal of Geographical Information Science*, 12(4): 299-314.
- Briggs, D., 2005. The role of GIS: Coping with space (and time) in air pollution exposure assessment. *Journal of Toxicology and Environmental Health-Part a-Current Issues*, 68(13-14): 1243-1261.
- Christakos, G., Bogaert, P. and Serre, M., 2002. *Temporal GIS: Advanced Field-Based Applications*. Springer Verlag, Berlin, Heidelberg, New York, 217 pp.
- Dietzel, C., Herold, M., Hemphill, J.J. and Clarke, K.C., 2005. Spatio-temporal dynamics in California's central valley: Empirical links to urban theory. *International Journal of Geographical Information Science*, 19(2): 175-195.
- ElAwad, Y., Chen, Z., G., H., Tao, C.V. and Abdalla, R., 2005. An Integrated Approach for Flood Risk Assessment for the Red River in Southern Manitoba, Annual Conference of the Canadian Society for Civil Engineering, Toronto.
- Emergency Management Ontario (EMO), 2003. *Emergency Plans Act*. Government of Ontario.
- Erharuyi, N. and Fairbairn, D., 2003. Mobile geographic information handling technologies to support disaster management. *Geography*, 88: 312-318.
- Farley, J., 1999. *Disaster Management Scenarios*, Univ. of Arkansas, OGC Discussion Paper.
- Giardino, M., Giordan, D. and Ambrogio, S., 2004. GIS technologies for data collection, management and visualization of large slope instabilities: two applica-

- tions in the Western Italian Alps. *Natural Hazards and Earth System Sciences*, 4(2): 197-211.
- Glover, J., 1995. The Need for Open GIS - Part 1: The Integration Challenge. *Mapping Awareness*, 9(8).
- Goodchild, M.E., 2003. Geographic information science and systems for environmental management. *Annual Review of Environment and Resources*, 28: 493-519.
- Goodchild, M.F., Parks, B.O. and Steyaert, L.T., 1993. *Environmental Modeling with GIS*. Oxford University Press, New York.
- Gupta, P.K. and Singh, A.P., 2005. Disaster management for Nandira watershed district Angul (Orissa) India, using temporal Remote Sensing data and GIS. *Environmental Monitoring and Assessment*, 104(1-3): 425-436.
- Langran, G. and Christman, N.R., 1988. A framework for temporal geographic information. *Cartographica*, 25(3): 1-14.
- Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W., 2005. *Geographic Information Systems and Science*. Wiley, 517 pp.
- Mennis, J.L. and Fountain, A.G., 2001. A spatio-temporal GIS database for monitoring alpine glacier change. *Photogrammetric Engineering and Remote Sensing*, 67(8): 967-975.
- OGC, 2002. *OpenGIS Reference Model*.
- Peuquet, D., 2001. Making Space for Time: Issues in Space-Time Data Representation. *Geoinformatica*, 5(1): 11-32.
- Peuquet, D.J., 2002. *Representation of Space and Time*. The Guilford Press, New York, London, 380 pp.
- Sperry, L., Claramunt, C. and Libourel, T., 2001. A spatio-temporal model for the manipulation of lineage metadata. *Geoinformatica*, 5(1): 51-70.
- Tobler, W., 1959. Automation and Cartography. *Geographical Review*, 49: 526-534.
- Visser, U., Stuckenschmidt, H. and Schlieder, C., 2002. Interoperability in GIS – Enabling Technologies, 5th AGILE Conference on Geographic Information Science, Palma (Balearic Islands, Spain).
- Waugh, W.L., 1995. Geographic Information-Systems - the Case of Disaster Management. *Social Science Computer Review*, 13(4): 422-431.