Distributed GIS Approach for Flood Risk Assessment

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Abstract – **Web-based Geographic Information Systems (WbGIS) provides key decision support capabilities for the disaster and emergency management community. Perspective visualization and simultaneous access to emergency management data are important capabilities that WebGIS can provide in support of informed decision-making process. By using a case study on a section of the Don Valley in Toronto, Canada, this paper will present a WebGIS based interdisciplinary approach for flood risk assessment and will demonstrate the utility of WebGIS in simulating different what-if scenarios under different water surface elevations. A visual model of the extent and the impact was published in the web using GeoServNet (GSN), a proprietary WebGIS package. The article highlights the capabilities of WebGIS and addresses some of the key issues that prevent a proper emergency response. Issues like time of geospatial data acquisition, maintenance, processing and update can be a challenge during emergencies. This article is of importance to decision makers in public safety and national security domains, as well as to military personnel working at the operational level.**

1. INTRODUCTION

Numerous fields including environmental planning and management, agriculture, hydraulics engineering, and earth science contribute to flood simulation research and prediction studies. This supports the process of reaching to quantitative understanding and accurate simulation of flooding scenarios based on GIS. The availability of accurate data and efficient modeling tools are bounding factors for effective flood risk assessment [1,2]. Modeling environmental and physical processes for the purpose of disaster and emergency management is a complex process because real-world phenomenon are typically 3D, time dependent and complex [3]. These factors make it difficult to obtain a complete qualitative and quantitative understanding of these processes. Is not a challenge to represent 3D features on a desktop system and publish the output on a webservice [2]. Spatial data collection is further developed by new technologies, such as Light Detection and Ranging (LIDAR), Synthetic Aperture Radar (SAR) and high-resolution satellite imagery by GeoEye and Quickbird has further enhanced 3D spatial information processing, and contributes to making geospatial information acquisition and processing much faster and cheaper [4, 5]. All these developments in computing power, software, internet bandwidth, and data acquisition have enhanced the power of 3D WebGIS and its ability to show change and communicate complex geospatial phenomena. The added dimensionality of 3D WebGIS allows geospatial modelers to move themselves from primitive representation of fence diagrams, isometric surfaces, multiple surfaces, stereo, and block diagrams [6]. The continuous improvements in hardware and software technology will ensure that Web-based 3D GIS become easier to implement, with a wide range of applications.

This study aims at presenting an interdisciplinary approach for publishing and visualizing flood information using GSN and examining the utility and efficiency of 3D WebGIS decision-support capabilities in support of disaster and emergency management operations. What-if simulated scenarios are used in delineating different water surface elevations for the assessment of possible impact on critical infrastructure and land use classes.

An integrated WebGIS approach for flood risk assessment is introduced in the first and the second section of this paper. The third section will introduces an overview of the fundamentals of disaster risk management. A case study will be presented in the fourth section to show the procedures to be used for integrating different data sources and modeling tools to provide hydraulics simulation driven visual models. The fifth section will present the results and discusses the advantages and challenges for using distributed GIS in flood risk assessment. The last section will present findings and conclusions of this work.

2. GEOSPTATIAL INFORMATION TECHNOLOGY

The distribution of geospatial information over a network of connected computing nodes has facilitated effective disaster management operations, through timely access to data and through the ability to effectively interpret and visualize disaster management scenarios. Estimating disaster damage and predicting its impact are among the contributions of the progressive development in Geospatial Information and Communications Technology (GeoICT). WebGIS as a GeoICT element is a centrally managed and distributed computing architecture. Distributed computing is a generic term that includes other terms like Internet, Intranet, the web, network-centric, and more. The growing trend is to distribute computing services across a physical infrastructure of networked data storage devices and computer processors. This environment includes both a two and three tier model where the physical locations of the data storage and application processing are not on the same machine.

3. DISASTER MANAGEMENT

Many researchers including [18, 23, 24] have struggled to define disaster. Although disasters have the common result of leaving behind devastation and loss, there is no precise definition for the term "disaster". The bottom line in disaster management is that loss of life and property should be eliminated or minimized, basic needs should be ensured, and business continuity should be secured. The basic requirements for disaster management can be achieved only through interdisciplinary efforts and there are no research methods that are unique to this field [14]. According to [21, 22] modern disasters are complex and diverse phenomena with a greater potential for adverse impact. For many years the effects, impacts, and issues pertaining to protection from disasters have been the focus of many researchers including [15- 20]

Flood disasters impact the economy, natural resources, lives, property and physical infrastructure. The magnitude of the impact depends on the emergency measures and the steps taken by the concerned authorities during the preparedness and the response phases. Providing accurate and quick information over the internet could help reduce the loss. A standardized community-based risk assessment protocol was developed by Emergency Management Australia [24]. This framework is based on six major elements as shown in Figure 1 and discussed below:

1- Risk Context: The first phase is related to the establishment of risk context. Issues related to the problem at hand and the approaches of solving it are discussed in this phase.
2- Hazard Vulnerability: The second phase involves identifying risks in terms of hazard and vulnerability. The scope and nature of a hazard must be identified, as well as the setting of the community at risk.
3-Risk Analysis: The third phase in this process is risk analysis. In this phase, tools of problem analysis, for instance modeling software, are used to analyze risks associated with the problem identified in the risk context phase.
4-Risk Evaluation: The fourth phase is risk evaluation, which involves prioritizing the risk and comparing it against risk evaluation criteria. Risk thresholds are also established in this phase.
5-Communication: The last phase in this process deals with treating risks according to the result of the evaluation. Results obtained from the risk evaluation phase will be communicated to the concerned stakeholders to allow them to implement disaster management measures.

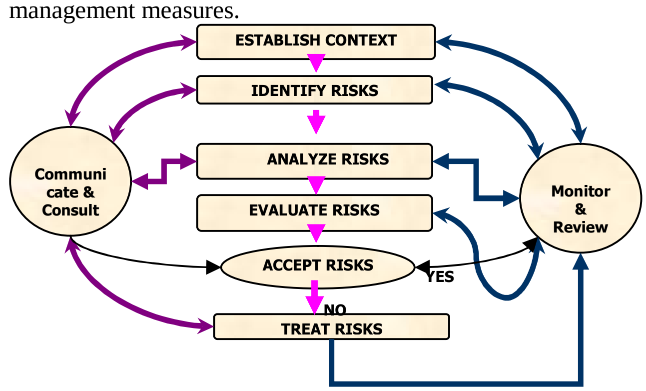

Figure 1 Flowchart showing the elements of risk assessment process (after EMA, 2002)

4. WEBGIS FOR DISASTER AND EMERGENCY MANAGEMENT

Disasters are dynamic processes [8] and are spatially oriented [9]. According to [10] most current tools that are used for disaster management focus on the temporal component of the four phases of disaster management, leaving an obvious gap in dealing with the spatial element. Emphasis on the spatial dimension makes GIS technologies ideal for simulating the complex spatial relationships during extreme situations, while still being able to integrate other modeling tools.

The importance of WebGIS stems from its accessibility to many users. There are many authorities involved in planning, decision-making, and communications during disaster management operations. Desktop GIS does not provide instant and effective multi-user platforms for the same project, which require distributed GIS capability. .WebGIS provide ease of use in terms of the technical background required from user perspective.. Many decision-makers with limited or no GIS background can access geospatial information simultaneously. Decision-makers are generally divided into two general groups: response teams working in the field and decision-makers working in emergency operation centers (EOC). The EOC group works in different subgroups; communications, planning, and prediction, various sources of information can be gathered and used for disaster response and WebGIS is mostly used by the planning group as well as by field personnel and relief workers who need to access information about the current situation.

5. CASE STUDY

This section demonstrates the utility of GIS interoperability for enhancing emergency management operations. The focus here is not in showing modeling results; rather it provides demonstration scenario that addresses various issues related to how GIS interoperability can be used for emergency management. In particular, issues related to data and systems heterogeneity.

The Don River is a unique river system, as it flows through the core of the Greater Toronto Area (GTA). The origin of the Don River is located at the Oak Ridges Moraine where the headwaters are fed by numerous aquifers. The river then flows for 38 kilometers to Lake Ontario and provides drainage for 360 square kilometer of land [11]. The section used for this study is part of the huge watershed in the province of Ontario. This section is located within the extent of North York municipal boundaries. The location of the study area is shown in figure 2.

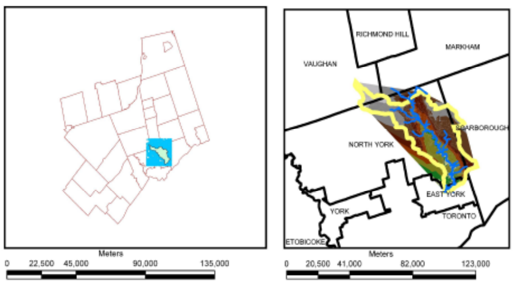

Figure 2. Map of Greater Toronto Area showing the study area.

Topographic digital maps in the form of shapefiles and a 10 meter spacing Digital Elevation Model (DEM) were collected. Topographic sheets of the area were used as reference for conducting the study. Hypothetical flow data were simulated using Canadian Hydrographic Service (CHS) data as a reference. The land use classes of the study area were used in flood analysis especially to know the extent of flood damage with respect to different classes in study area. The detailed land use map of the study area is show in figure 3.

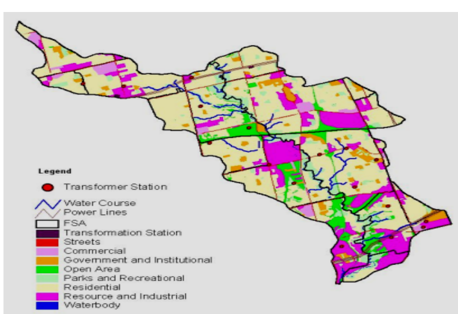

Figure 3. Detailed Land use of the Don Valley Watershed Area, Toronto, Canada

6. METHODOLOGY

ArcView GIS, Hydrologic Engineering Centre-River Analysis System (HEC-RAS) produced by the US Corps of Engineers used in the present study. HEC-RAS is a one dimensional, steady state modeling software for hydraulics intended for calculating water surface profiles at cross-sections along a stream, for both steady and unsteady flow. HEC-GeoRAS is an ArcView GIS extension specifically designed to process geospatial data for use with HEC-RAS[5]. GeoServNet (GSN) is a distributed web-based 3D GIS developed by GeoICT Lab from York University. GSN is of three main modules: GSN Builder, GSN Administrator, and GSN Publisher. The Builder is used to build and index the raw data prior to its visualization. The Administrator is used to register the layers built under builder and to complete the server and security setting before their publishing. The Publisher is used for setting visualization parameters, layer display and rendering functions in addition to the 3D perspective visualization capability. The system architecture of GSN makes it an ideal WebGIS Java technology, which provides reliable, fast, secure, and cutting-edge interoperable GIS capabilities. The system architecture of GSN is shown in figure 4[12].

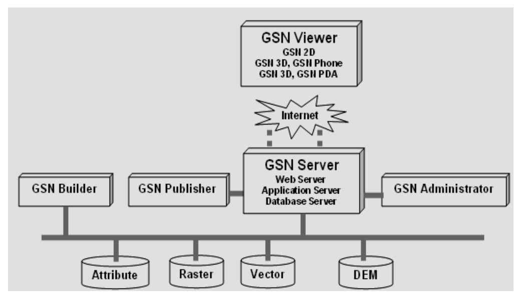

Figure 4. GSN Architecture

The methods followed in this study are: 1) Preparation
The methods followed in this study are: 1) Preparation
of different data layers, 2) Prediction of flooding Scenarios, 3) Preprocessing 4) Postprocessing 5) Calculating the flood damage 6) Publishing and visualization of data using GSN.

The preparation of an accurate database is imperative for successful WebGIS-based disaster and emergency management decision-making. This helps with providing accurate and timely flood information. In this phase, different data layers of the Don Valley in the form of shapefiles, grids or Digital Elevation Model (DEM) were inputted into the GIS database. The DEM was processed to produce a Triangulated Irregular Network (TIN) and a complete dataset was visualized using a standard web browser.

The analysis that was performed to simulate the Don Valley Watershed involved two major processing stages, preprocessing and postprocessing. Preprocessing is the first stage in the delineation of flooding scenarios. It involves a number of tools that are used for the creation of files used in developing the geometry of the Don Valley model. Five themes were created in this step; the stream centerline, banks, flow path, cross-sectional cutline, and land use themes. The stream centerline theme is used to establish the river reach network. It was necessary to create upstream endpoints before creating the reach in the downstream. River reach was labeled as an identifier and a reach name was assigned. Then it was possible to write the River Analysis System (RAS) GIS import file. The RAS GIS import file was created, and a complete file with a header, stream network, and cross section information was generated. After completing the process of developing stream network, five direct major steps were completed for conducting hydraulic simulation. The first step involved creating a new project for river simulation; the second step involved utilizing the GIS data. The GIS imported information is in the form of detailed geometry data that displays geometry derived. The third step was modeling the flow data; this was achieved in two different stages, the first was by entering flow profiles for the cross sections generated for the section of the study area, hypothetical flow rates were used in this research in order to support the concept of the approach, the second was entering water surface profiles.

Postprocessing is the final phase in conceptualizing the Don Valley watershed flood model. It is performed in three separate steps. The first step is the generation of a bounding polygon and cross section alignments. These are read directly from the GIS export file. Then, a water surface theme was created with the extent defined by the bounding polygon. The water surface elevations at each cross section were applied along the cross section alignments and the cross sections were treated as break-lines in the elevations, creating the TIN. The final step is to mesh the water surface TIN with the terrain TIN to produce the floodplain. Different flooding scenarios were predicted using different water surface profiles in the postprocessing step. Different water surface profiles were created from different water surface elevations using water flow rate parameters. Thus, it was possible to identify the affected settlements, affected population, and affected infrastructure, which is of special importance in emergency management. Immediately after a flood, the responsible authorities or organizations need the information about the affected area, affected people, affected infrastructure i.e. roads and rail networks, for evacuating or transportation of the required relief material.

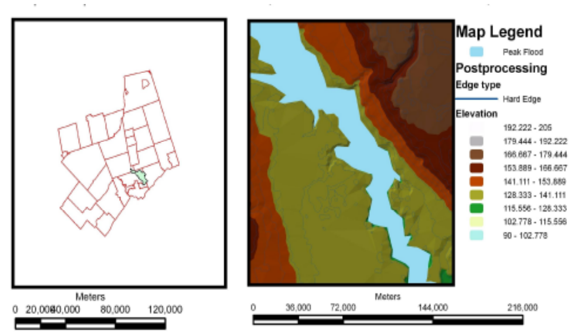

Figure 5. Triangular Irregular Network (TIN) Model for the study Area.

When the flood scenarios under different flood water surface elevation levels were predicted and damages assessed, the results were published and visualized in 3D web environment using the GSN.

7. RESULTS AND DISCUSSION

As discussed in the first section, WebGIS has become increasingly popular in disaster management. However, the integration of GIS data with remotely sensed information has posed a challenge in many occasions [13]. Determination of which type of data required for GIS modeling is a crucial issue. In this case, the first question considered was what is the data required for building this model? Is it a simple vector data for drawing maps or a complete set of data for this type of analysis? Is it specific data for specific software or data to be digitized directly?

At the preprocessing stage, RAS themes were generated. The attribution of these shapefiles according to "from - to" vector topology parameters were very important in keeping the flow direction and the DEM elevation details prior to the step of extracting the details of the model. The information gathered from the DEM integration with the digitized cross section allowed for the represention of the channel geometry. This was achieved for twelve different cross sections and provided the 3D stream channel parameters. HEC-RAS is used to represent the stream channel in 3D. Figure 6 is showing the geometric data of the Don Valley Watershed. These geometric data can be also edited in HEC-RAS.

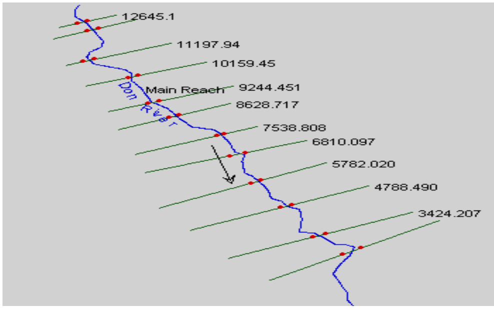

Figure 6. Geometric data of Don Valley Watershed.

Figure 7 summarizes the parameter used and a cross section output at a station of Don River, which contain i.e. elevation, slope, steady flow data, velocity, and channel depth. Different steady flow data at different stations of Don River are shown in respect of different profiles. These steady flow data can be edited and updated in HEC-RAS.

Plan: Plan 01 Don River Main Reach RS: 12645.1 Profile: PF 1					
E.G. Elev (m)	144.29	Element	Left OB	Channel	Right OB
Vel Head (m)	0.93	Wt. n-Val.	0.030	0.030	
W.S. Elev (m)	143.36	Reach Len. (m)	303.22	293.13	312.01
Crit W.S. (m)	143.15	Flow Area (m2)	10.06	333.37	
E.G. Slope (m/m)	0.004997	Area (m2)	10.06	333.37	
Q Total (m3/s)	1451.00	Flow (m3/s)	18.36	1432.64	
Top Width (m)	149.83	Top Width (m)	14.67	135.16	
Vel Total (m/s)	4.23	Avg. Vel. (m/s)	1.83	4.30	
Max Chl Dpth (m)	3.36	Hydr. Depth (m)	0.69	2.47	
Conv. Total (m3/s)	20525.8	Conv. (m3/s)	259.7	20266.1	
Length Wtd. (m)	294.02	Wetted Per. (m)	14.75	135.36	
Min Ch El (m)	140.00	Shear (N/m2)	33.41	120.69	
Alpha	1.02	Stream Power (N/m s)	61.00	518.67	
Frctn Loss (m)	1.19	Cum Volume (1000 m3)	349.07	3813.27	58.49
C & E Loss (m)	0.11	Cum SA (1000 m2)	236.34	1470.57	83.07

Figure 7. Cross section output at a River Station of Don River.

At the Postprocessing stage, the floodplain was delineated using the RAS GIS export file generated by HEC-RAS. In this stage, Water Surface TIN was created from the cross sectional cutline themes and the bounding polygon theme for the respective water surface profile names. Then from the Water Surface TIN, the respective floodplain was delineated. As shown in Figure 8, three different flooding situations under different water surface profiles are shown. The flood Scenario 1, 2 and 3 were calculated using water surface profiles PF 1, PF 3 and PF 5 respectively.

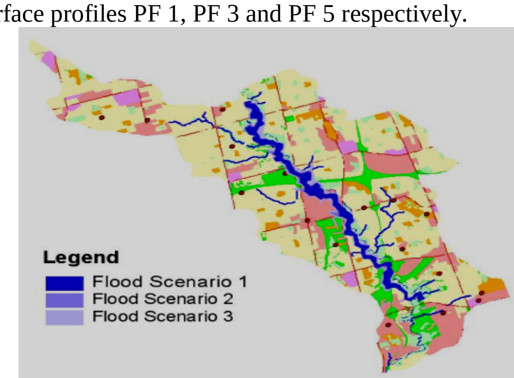

Figure 8. Different Flood Scenario at different flood situations.

Figure 8 describes the different flooding scenarios under different water surface profiles which contain different parameter e.g. water surface elevation, water discharge, and velocity. It shows the nearby infrastructure that is at risk.

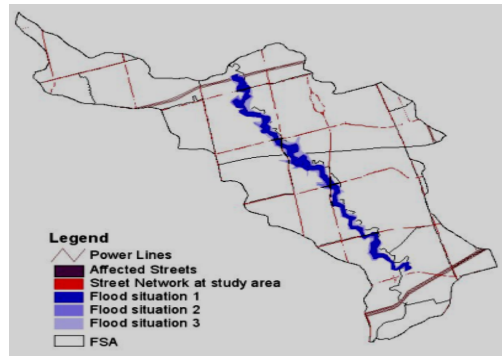

Figure9. Affected Roads under different flood situations

Once a flood hits an area, different organizations and authorities are engaged in emergency response and immediate measures are taken to manage the flood efficiently. Important information such as which areas are affected severely, affected population, affected infrastructure, and affected land use classes affected and detailed information about the affected area In this case study. The roads and rail networks are of special importance because it is used to evacuate people to shelters or safer places and to transport relief materials to relief centers in the shortest amount of time. Roads and different land use classes affected by different flood levels were calculated, which will provide the relevant organizations to know the locations of roads and other land use classes affected for emergency relief operation and efficient flood management. The 3D visualization capability of GSN is useful for better visualizing the flood-affected area in 3D web environment especially in the response phase emergency management. The published flood data was visualized over the Web, as shown in figure 9 and figure 10 respectively.

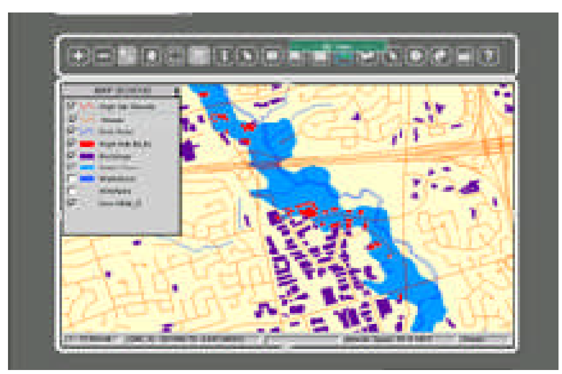

Figure 10. The flood extent of the study area. The purple polygons represent the building footprints. The red polygons are the buildings, which affected by the flood.

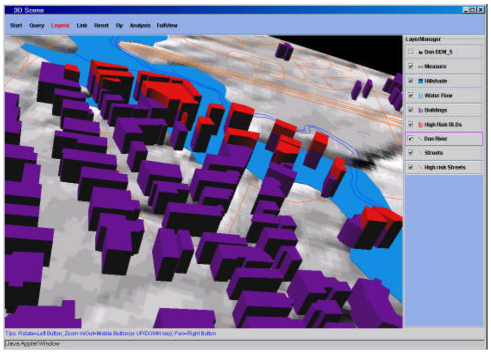

Figure 11. 3D view of the flood extend and impact shown in figure (10). The difference between 2D shown in Figure 8 and 3D is very obvious.

WebGIS provide important interoperability capabilities for emergency management departments, in form of data exchange between local, provincial and federal decision making authorities, in particular for data sharing specifications and standards. The City of Toronto demonstrated the need for using GIS Interoperability in handling many emergency management situations including the modeling of West Nile Virus, and Severe Acute Respiratory Syndrome (SARS) and in planning for two major mass festivals on World Youth Day in 2001 and the rolling stones concert in 2003. [17]

Ontario Emergency Management Doctrine [25] is the two major resources used when dealing with a disaster and or emergency. According to the Ontario Emergency Management Act 2005, there are many stakeholders responsible for deploying resources for emergency management. The Toronto and Region Conservation Authority (TRCA) is responsible for flood simulation, floodplain mapping, and water surface measurement. All hydraulics and hydrology data are under the custody of the TRCA. During emergency management situations, the TRCA will provide flood models and data through interoperable access to all decision-makers involved. Semi-real time situational awareness models can be generated and accessed on-demand based on stakeholder needs.

The City of Toronto emergency services is responsible for providing services in a variety of situations, ranging from simple road maintenance closure to extreme disastrous situations, e.g. civil infrastructure collapse.

In emergency situations the city police department utilizes GIS interoperability in a very efficient way. This includes accessing data provided by the emergency mapping department of the city and the data provided by the TRCA.

Toronto Emergency Medical Services (EMS) utilizes 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 interoperability for EMS is that, in emergency situations, it is not easy to prioritize your response to calls from different parts of the city.

A key role for the provincial authorities represented by Emergency Management Ontario (EMO) is to monitor emergency situations and provide support on an as needed bases. GIS interoperability could provide EMO with improved situational awareness models by assembling data from all different departments and make the data available for basic analysis and visualization.
GIS interoperability provides key benefits in support of effective disaster and emergency management operations. It also allows different decision-making authorities to access information at the same time and provide transparent open access to different data sources. This benefit helps decision-makers to access multiple servers, thereby obtaining data and services that are not within organizational boundaries. Through GIS interoperability, it is possible for the sharing of a standardized data format that can be used for data transfer and information sharing in a simple manner

GIS interoperability helps to provide a simple and accessible means of integration. This is crucial since emergency management operations stand to benefit considerably from a process that allows for timely gathering, modeling and analysis of information. GIS interoperability, through its standardized protocols has allowed GIS users to utilize a simple and standard service. Through the transparency of GIS interoperability, emergency management stakeholders can readily access external GIS data and systems. Transparency here refers to the process of accessing and sharing data between systems without complicated protocols. Scalability is another advantage for GIS interoperability, as it allows for data expansion. 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.

The weaknesses with GIS interoperability are related to policy and procedures. 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 in a Computer Aided Design (CAD) form and another department is using data in GIS shapefiles formats. These two formats can be made to be compatible by
converting CAD data into shapefiles format. However, the time required for this process depends on data size and system capabilities. Data maintenance and data update is another issue that represents an obstacle for implementing 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. On the management side, issues related to implementing GIS interoperability are related to corporate technology procurement policies, which can contribute to delayed implementation. Access rights to sensitive information, such as infrastructure and emergency management, represent another issue.

8. CONCLUSIONS

The discussed approach was dedicated to describing an integrated approach for using GIS as a tool for spatial analysis and visualization in flood simulation. This integrated approach utilizes GIS as a core technology for spatial analysis and visualization, and also integrates with other tools such as HEC-RAS for hydraulics modeling software. The dedicated approach is of special importance because it provides an interdisciplinary solution for solving real world problem. Linking WebGIS with environmental hydraulics and disaster management results in an integrated, collective, and interdisciplinary solution for addressing the reason for disaster and emergency management, which is the protection of life and property.

Despite the hypothetical nature of the scenario, it has shown the benefits that disaster management decision-makers can gain by adopting advanced and integrated WebGIS solutions in their day-to-day operations. An additional factor is the utility of 3D aspects to the simulation scenario. The contribution of the 3D visualization perspective demonstrates that WebGIS is efficient and useful for showing the impact of flooding, with particular emphasis on spatial extent of flood impact, and making it accessible for multiple users, simultaneously. This can aid decision-makers and planners to have efficient counter disaster measures and effective response plans.

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