EARLY WARNING AND MAPPING FOR FLOOD DISASTERS

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ABSTRACT:

In this paper, we present the development of a Web GIS based system for early warning and mapping for flood disasters. To improve flood warning, we developed a decision support system for flood prediction and monitoring that integrates hydrological modelling and GIS. We present the methodology for data integration, floodplain delineation, and online map interfaces. Our Web-based GIS model can dynamically display observed and predicted flood extents for decision makers and the general public. The users can access a Web-based GIS that models current flood events and displays satellite imagery and a digital elevation model integrated with the flood plain area. The system can show the flooding prediction based on the output from hydrological modeling for the next 24 and 48 hours along the lower Saint John River Valley.

1. INTRODUCTION

Floods are common natural disasters in the world. Each year they cause considerable damage to people's lives and properties. In spring 1973, the lower Saint John River in the Fredericton area (New Brunswick, Canada) experienced its worst ever recorded flooding, resulting in economic losses of $31.9 million, and leaving one person dead (Inland Waters Directorate, 1974). At the peak of the flood, private houses and public churches were flooded, and roads and bridges were damaged.

Since 1973 other floods have left another three people dead and caused more than $68.9 million in damage.

The Saint John River Forecast System operated by the Department of Environment Hydrology Centre is monitoring and predicting flood events along the Saint John River. The Hydrology Centre team uses hydrologic modeling software to predict water levels for the next 24 and 48 hours along the lower Saint John River Valley by inputting climate data, weather forecast data, snow data, and flow data.

However, the predicted water levels provided by this system cannot satisfy the requirements of the decision support system for flood events. The system neither directly display the areas affected by flooding, nor show the difference between two flood events. Based on the water levels, it is hard for users to directly determine which houses, roads, and structures will be affected by the predicted flooding. To deal with this problem, it is necessary to visualize the output from hydrological modeling in a Geographic Information System (GIS). GIS has powerful tools that allow the predicted flood elevations to be displayed as a map showing the extent of the flood inundation. After the interfaces for the visualization of the impact of flood events are designed, a computerised system is developed that predicts the extent of floods and dynamically displays near-real-time flood information for decision makers and the general public.

Figure 1. The impact of flooding in Fredericton, New Brunswick in Spring, 2008

Figure 2. Flooding of St. John River in 2008

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Figure 3. The house taken by the flood in 2008

To improve flood prediction for Saint John River, we developed a Web GIS based decision support system for flood prediction and monitoring. In this paper, we present the methods for data integration, floodplain delineation, and online map interfaces. Our Web-based GIS model can dynamically display observed and predicted flood extents for decision makers and the general public.

2. SAIN JOHN RIVER FLOODPLAIN

The Saint John River lies in a broad arc across south-eastern Quebec, northern Maine and western New Brunswick. It extends from a point on the international boundary to the Bay of Fundy. It drains a total watershed area of 54 600 km^2. The river is about 700 km long, and the total fall from its headwaters to the city of Saint John is about 482 m. The slope of river gradually decreases from about 1.5 metres per kilometre in the headwaters to 0.4 metres per kilometre in the reach above Fredericton (see Figure 4).

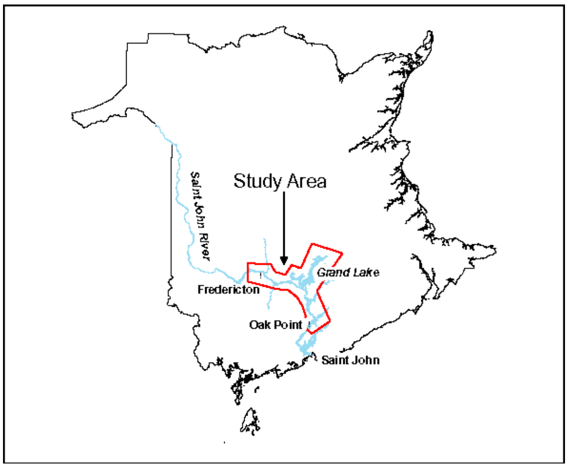

Figure 4. Overview of Saint John River watershed

The study area of this research is the flood plain area along a 90 km long section of the river from Fredericton to Oak Point. Flooding has been a significant problem for these study areas for long time. From the largest and best documented flood occurred between April and May 1973, the greatest flood damage areas are located within the proposed study area and include: a) Fredericton south of the former CNR Bridge, b) Nashwaaksis Subdivision, c) East Bank downstream of the Princess Margaret Bridge, and d) the Lincoln area (Canada-New Brunswick Flood Damage Reduction Program, 1979).

3. HYDROLOGICAL MODELLING FOR FLOOD FORECASTING

Flood forecasting on the Saint John River is performed by the Hydrology Centre of the New Brunswick Department of Environment with co-operation from interprovincial and international agencies. Both hydrologic and hydraulic models are utilized in order to forecast water levels in the lower Saint John River. The basic component of the system is the U.S. Army Corps of Engineers' Streamflow Synthesis and Reservoir Regulation (SSARR) model. The Simulated Open Channel Hydraulics (SOCH) model of the Tennessee Valley Authority and the Dynamic Wave Operational (DWOPER) model (Fread, 1993; Fread, 1992; Fread and Lewis, 1998) of the National Weather Service are also used.

The Hydrology Centre monitors the water levels, streamflows and climate with partner agencies, and coordinates a cooperative snow survey with reports for the entire Saint John River Basin. There are networks of 25 streamflow gauges, 16 water level gauges, and 43 climate stations throughout the Saint John River Basin (see Figure 5). The data is being transmitted to the Hydrology Centre through a variety of telecommunication systems. The data is processed and analyzed before being accepted as input data to the models.

Comparisons of predicted and actual water level observations over the last 10 years, have shown that these forecasted river water levels have a 95% confidence level of 0.2 m. Thus, the hydrological modelling has very good flood prediction capabilities (Fread, 1993). However, the predicted water levels obtained from hydrological model cannot satisfy the requirements of the decision support system for flood events. Indeed, they neither directly display the areas affected by flooding, nor show the difference between two flood events. Based on the water levels, it is hard for users to directly determine which houses, roads, and structures will be affected by the predicted flooding. To deal with this problem, it is necessary to interface hydrological modelling with a Geographic Information System (GIS).

Figure 5: The map of existing water gauges in New Brunswick

In the past decades, hydraulic and hydrologic engineers have developed many methods for delineating floodplain boundaries. Most of these methods are manual, tedious, and labour-intensive. With the advent of robust computer tools and high accuracy Digital Terrain Model (DTM), automated floodplain delineation is achievable. Recently, several management systems for floodplain delineation have been developed and applied in the flood event areas. These include floodplain delineation using watershed Modeling System (WMS), (Reference Manual and Tutorial, 1998), Arc/Info MIKE11_GIS (Reference User Manual, 2004), and HEC-GeoRAS (Ackerman, 2005). In this project, we used CARIS software to implement floodplain delineation. CARIS (Computer Aided Resource Information System) develops and supports rigorous, technologically advanced geomatics software for managing spatial and non-spatial data. CARIS software supports Triangulated Irregular Networks and offers advanced algorithms for Digital Terrain models, such as interpolating elevations for given coordinates. In the next sections, we will show how CARIS can be integrated with hydrological modelling to generate floodplain maps.

4. FLOOD PREDICTION AND MONITORING SYSTEM

The design of the system allows near real-time imagery of actual flood conditions to be overlaid on the base mapping and existing imagery, as well as overlays indicating 100-year flood extents. Map layers of transportation networks, hydrographic features, property boundaries, municipal infrastructure (e.g. power lines, natural gas lines) and contour lines can also be visualized.

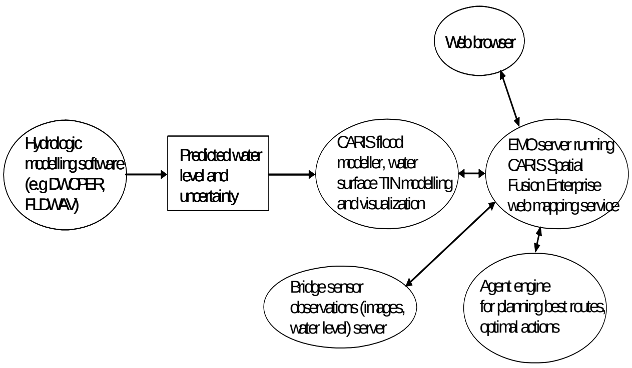

Figure 6. Conceptual model of flood prediction and monitoring system

The final software products are integrated together within CARIS software as shown on the Figure 6. Several provincial and research organisations in New Brunswick (University of New Brunswick, Emergency Measures Organization, NB Department of Environment, etc.) have been actively involved in the project. University of New Brunswick participation was in developing flood modelling software, additional bridge sensor observations and multi-agent engine for planning best evacuation routes. In this project, CARIS GIS software was used to implement floodplain delineation and online mapping.

5. INTEGRATION OF HYDROLOGICAL MODELLING AND GIS

The implementation that integrates hydrological modelling, Digital Terrain Modelling, and GIS algorithm for floodplain delineation will be presented in the following section.

Floodplain delineation requires a high precision ground surface DTM. Analysis of available datasets showed that there are range and accuracy limitations among these datasets. It is therefore necessary to test and integrate these datasets in order to obtain a high accuracy Digital Elevation Model data. For this research, the accuracy of provincial elevation data and the city of Fredericton data were analyzed. High accuracy control points can be used to evaluate the accuracy of DTM data. This procedure is implemented by using CARIS GIS tools. Firstly, CARIS software is used to generate the TIN model from elevation data. Then using comparative surface analysis tool, the differences between the elevations of the control points and the interpolated elevation of the corresponding points were calculated. Finally, the statistic accuracy was obtained and the control points were plotted on the map.

As shown on Figures 7, 8 and 9, the most significant inputs for automated floodplain delineation[1] are the DTM (see Figure 8) and the water levels shown on Figure 7. The process considers the DTM and water levels at different locations to determine the direction and extent of flow over a floodplain for a given hydrologic event.

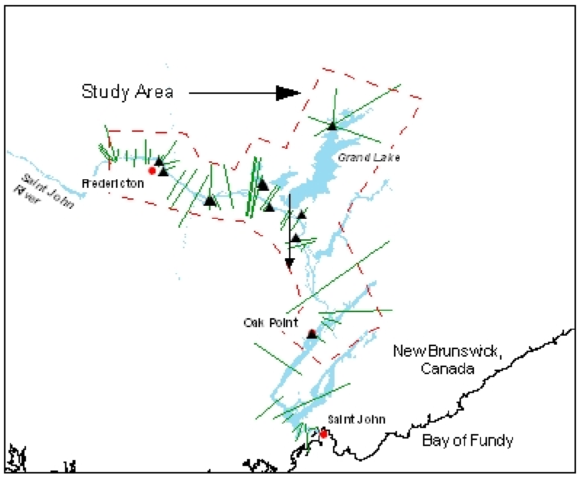

Figure 7. Modelling of water level surface using cross sections.

The floodplain depth dataset is the primary output of this process. It indicates the high water mark and the depth of water over the floodplain, and is generated by comparing the water surface TIN with the ground surface DTM data. Based on this depth data, the floodplain extent and depth maps can be generated. The intermediate parts of the process involve geo-referencing the water levels, extending the water levels to the floodplain area, and creating a TIN of the water surface. CARIS GIS allows users to create an irregular TIN or regular gridded DTM, to perform the comparison between two DTMs, to interpolate contours using a DTM, and to display the DTM using the CARIS 3D VIEWER program. These functions or modules were used for development of the algorithm for floodplain delineation.

[1] Automated floodplain delineation is an excellent tool for producing floodplain extent maps (Noman et al., 2001; Noman et al., 2003).

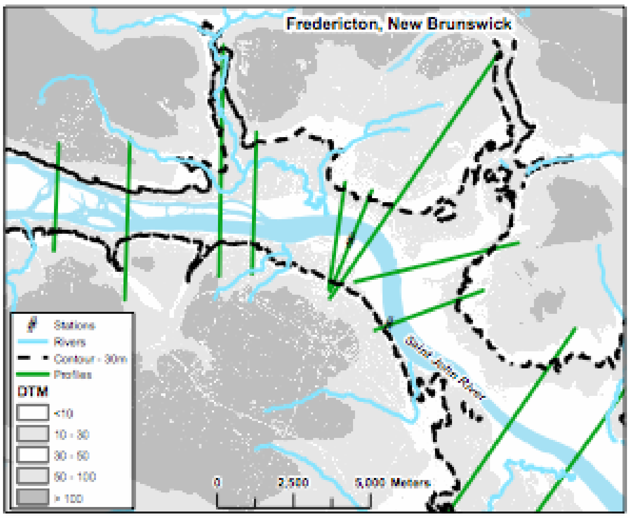

Figure 8. DTM and the floodplain of the area

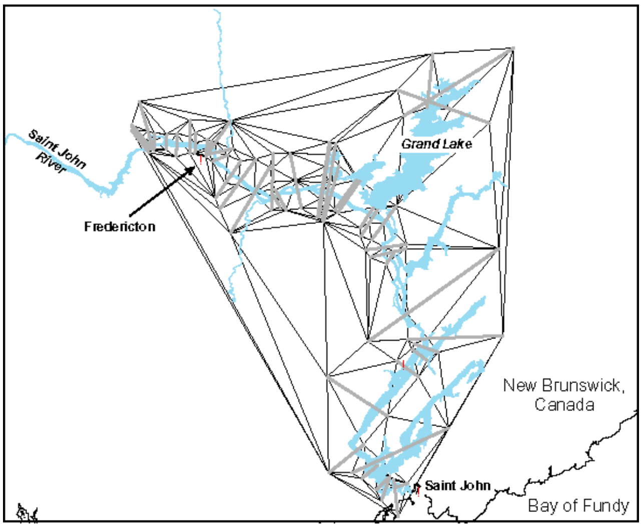

Figure 9. Floodplain delineation process

The CARIS software provides effective spatial analysis tool that calculates floodplain delineation and facilitates the mapping of flood events. As an example of floodplain delineation, Figure 8 displays the extents of the flooding event that took place in Spring 1973.

5.1 Development of a Web-based interface for dynamic flood prediction monitoring and mapping

CARIS Spatial Fusion was used to develop software for integration of satellite imagery and dynamic flood maps. Web map Interfaces that dynamically display maps of current and predicted flood events were developed and implemented.

This Web GIS software we developed, allows for a spatial query based on 6-digit postal code (see Figure 10), so the users will be able to easily locate their area of interest.

The Web-GIS interface is designed to calculate and display the spatial extent of existing and predicted flood plains (see Figure 11). Each layer of the web map is separate, allowing the overlay and visualization of transportation networks, hydrographic features, property boundaries, municipal infrastructure and contour lines.

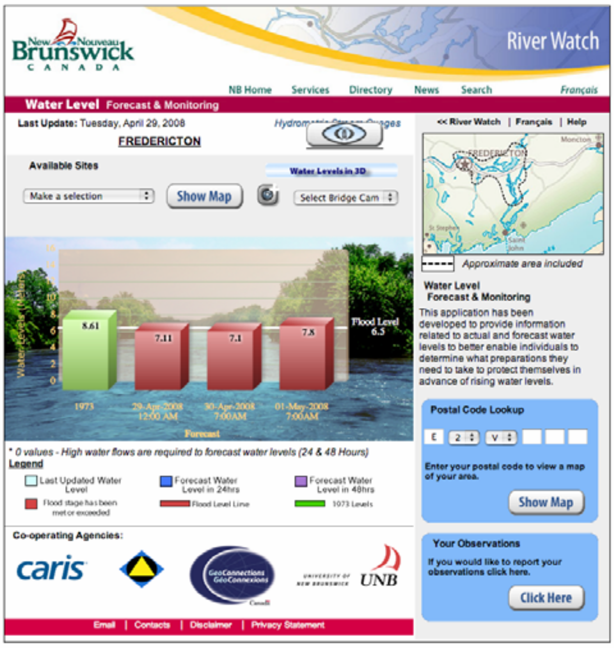

Figure 10. Web site for flood warning

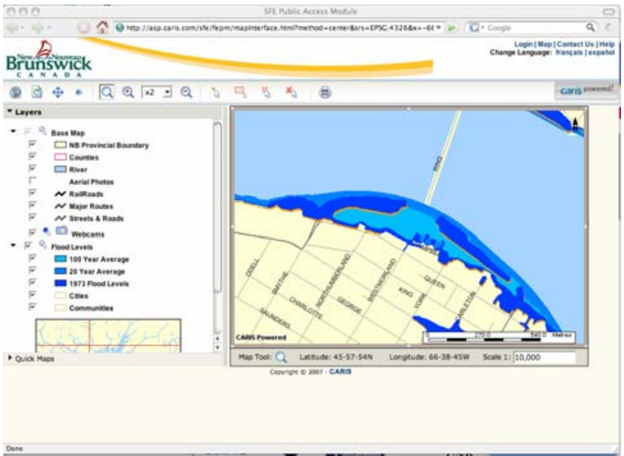

Figure 11. Existing flood maps

Three dimensional visualization of the flood in Spring 1973 was implemented (see Figures 12 and 13) using IVS3D software.
It allows users to visualize the major flood event that happened in Spring1973 via “fly-through” animation. In this application the advanced software (from Interactive Visualization Systems) for dynamic visualization is used to interactively show the areas affected by the record high flooding in 1973.
The basic map layers are integrated with orthophotos and flood areas to create this realistic visualisation tool using IVS3D[2].

[2] The software (IVS3D) has been developed to allow the users to explore, analyze, manipulate and gain knowledge from their data by representing very large complex information in the best possible way - in an intuitive fashion - in the way that we perceive the real world everyday. This virtual reality allows new insight to be rapidly gained and more information to be extracted from the underlying data. (Source: http://www.ivs3d.com/companyinfo/about_ivs.html)

Figure 12. 3D visualization of the flood in 1973 – Fredericton area

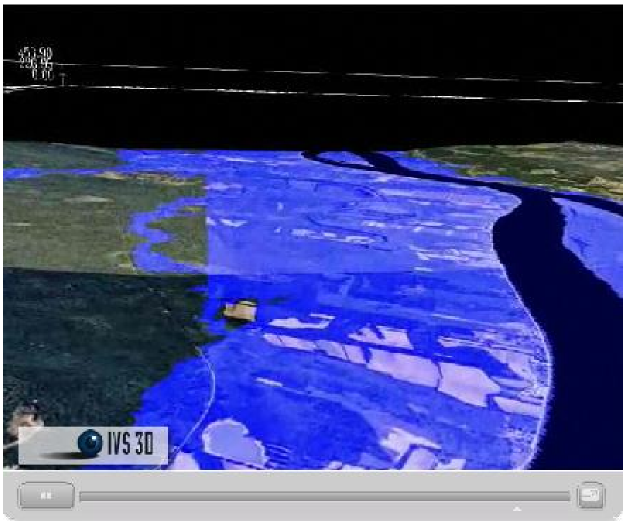

Figure 13. 3D visualization of the flood in 1973 – rural area

6. CONCLUSIONS

This paper presents the integration of the DWOPER hydraulic model with the CARIS GIS system to dynamically display near real time flood warning in the lower Saint John River valley. The main phases of development and implementation of Web-based GIS software for flood monitoring and prediction are presented as well.

With satellite imagery and digital elevation model of the flood plain area, we can access web-based prediction that models current flood events, and can show how the water progresses based on the output from hydrological modelling for the next 24 and 48 hours along the lower Saint John River Valley.

The Decision Support System for Flood Event Prediction and Monitoring implemented with web-mapping interfaces facilitates monitoring and prediction of flood events. It provides a basis for early warning and mapping of flood disasters. General public can access the web site and browse the information in their area of interest. They can also visualize the impact of the flood events on the area where they live.

This research provides the foundation for a revised decision support system that can result in improvements in the prevention, mitigation, response, and recovery from flood events along the lower Saint John River.

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