Decision Support for Flood Event Prediction and Monitoring

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***Abstract*—In this paper the development of Web GIS based decision support system for flood events is presented. To improve flood prediction we developed the decision support system for flood prediction and monitoring that integrates hydrological modelling and CARIS 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 Web-based GIS that models current flood events and displays satellite imagery and digital elevation model integrated with flood plain area. The system can show how the flooding prediction based on the output from hydrological modeling for the next 48 hours along the lower Saint John River Valley.**

Keywords-flood modelling; Web GIS; floodplain delineation;

I. INTRODUCTION

Floods are common natural disasters in the world. Each year they result in much damage to people's life 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 [1]. At the peak of the flood, private houses and public churches were flooded, and roads and bridges were damaged (see Fig. 1).

Figure 1. The impact of flooding in Fredericton, New Brunswick in 1973.

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 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. 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 the output from hydrological modeling to a Geographic Information System (GIS). GIS has powerful tools that will allow the predicted flood elevations to be displayed as a map showing the extent of the flood inundation. After the interface for the visualization of the impact of flood events is designed, a computerised system is developed that predicts the extent of floods and dynamically display near-real-time flood information for decision makers and the general public.

To improve flood prediction for Saint John River, we developed the 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 interface. Our Web-based GIS model can dynamically display observed and predicted flood extent for decision makers and the general public.

II. STUDY AREA

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 Fig. 2).

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. At 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 [2].

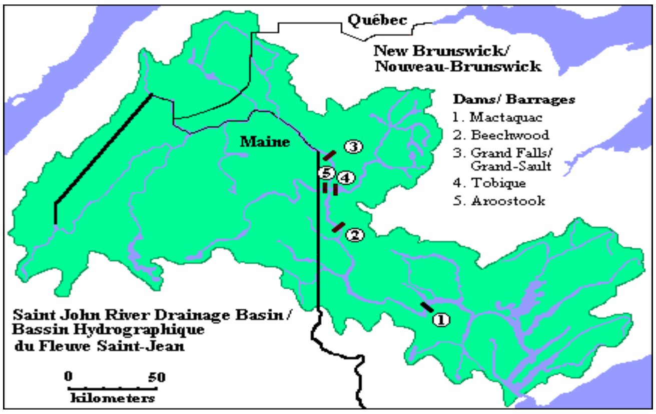

Figure 2. Overview of Saint John River watershed.

III. HYDROLOGICAL MODELLING

The Saint John River forecast system operated by the Department of Environment's Hydrology Centre is monitoring and predicting flood events along the Saint John River. It utilizes a Dynamic Wave Operational model (DWOPER) [3, 4, 5] along with approximately 60 water level gauges in the New Brunswick portion of the river. DWOPER is one-dimensional routing model developed by the Hydraulic Research Laboratory of the United States National Weather Service.

The Hydrology Center team uses hydrologic modelling software (DWOPER) to predict water levels for the next 48 hours along the lower Saint John River Valley by inputting climate data, weather forecast data, snow data, and flow data. The hydrology centre monitors a wide range of information on factors affecting flooding such as snow conditions, temperatures, precipitation patterns, water levels and stream flow conditions by using a wide variety of telecommunication systems ranging from satellites to the telephone. These information and up-to-date weather forecast messages are input to complex computer model to produce forecasts of water levels along the Saint John River. Comparisons of predicted and actual water level observations over the last 10 years, have shown that these forecast river water levels have a 95% confidence level of 0.2 m. This system therefore has very good flood prediction capabilities.

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) [6], Arc/Info MIKE11_GIS [7], and HEC-GeoRAS [8]. All of the above systems are required to combine the output of the hydrological model with the ArcGIS system.

In this project we used CARIS GIS 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 the hydrologic modelling to generate floodplain maps.

IV. FLOOD PREDICTION AND MONITORING SYSTEM OVERVIEW

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

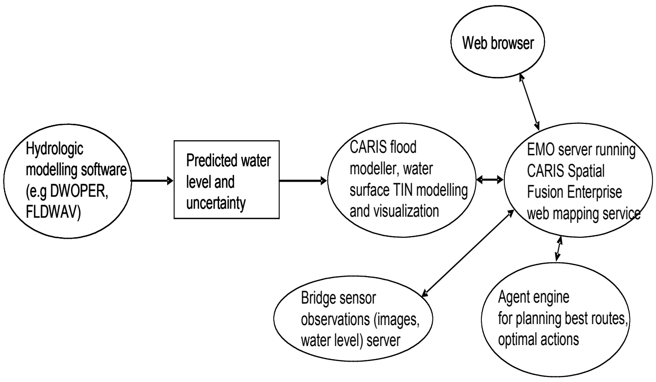

Figure 3. Conceptual model of flood prediction and monitoring system.

The final software products are integrated together within CARIS software as shown on the Fig. 3. Several provincial organisations in New Brunswick have been actively involved in the project developing GIS flood modelling software, additional bridge sensor observations and multi-agent engine for planning best evacuation routes.

V. INTEGRATION OF FLOOD MODELLING AND GIS

The implementation integrates hydrological modelling, Digital Terrain Modelling, and GIS algorithm for floodplain delineation. We will now briefly explain the main stages of the system development.

A. Reconstruction of the DTM from elevation data

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 them and to integrate them in order to obtain high accuracy Digital Elevation Model data. Moreover, the height accuracy of elevation data and the city of Fredericton data are 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 tools 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 can be calculated. Finally, the statistic accuracy is obtained and the control points are plotted on the map.

B. Floodplain delineation

Automated floodplain delineation is an excellent tool for producing floodplain extent maps [9, 10]. As shown in Fig. 4, the most significant inputs for automated floodplain delineation are the DTM and the water levels. The process (shown in Fig. 5) 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.

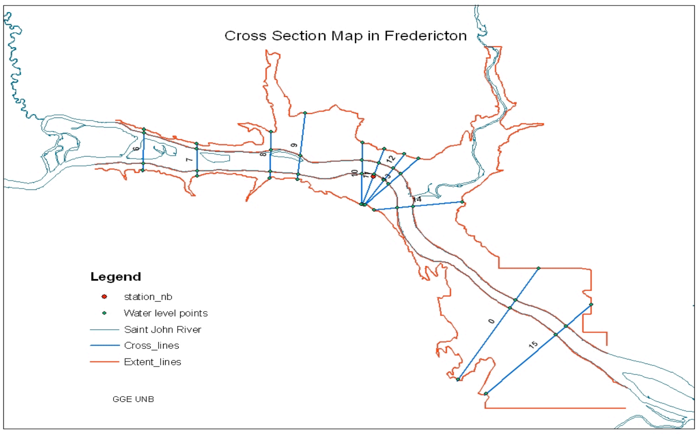

Figure 4. Modelling of water level surface using cross sections.

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.

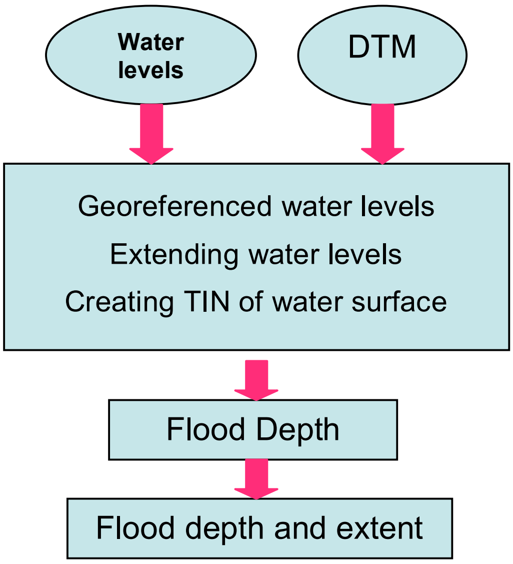

Figure 5. Floodplain delineation process.

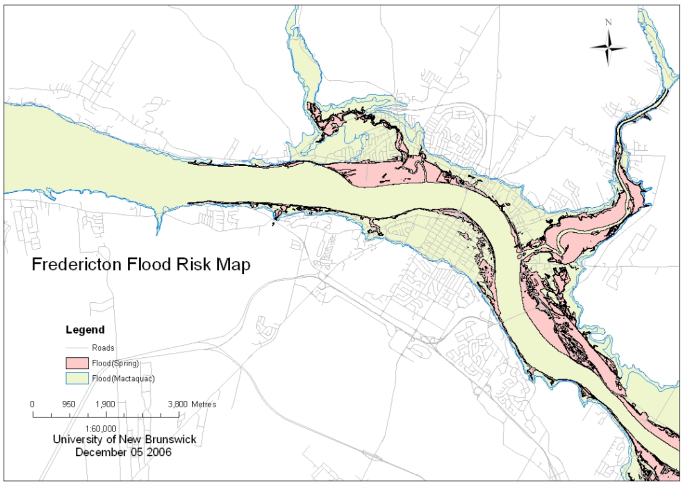

Figure 6. Two flood plain scenarios for City of Fredericton.

The CARIS GIS is an effective spatial analysis tool that calculates floodplain delineation and facilitates the mapping of flood events. As an example of floodplain delineation, Fig. 6 displays the extents of two flooding events, the real flood event occurred in Spring 1973 and the simulated flooding that could happen if the Mactaquac dam will burst.

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

CARIS Spatial Fusion is used to develop software for integration of satellite imagery and dynamic flood maps. Web

Map Interface that dynamically display maps of current and predicted flood events is designed and implemented.

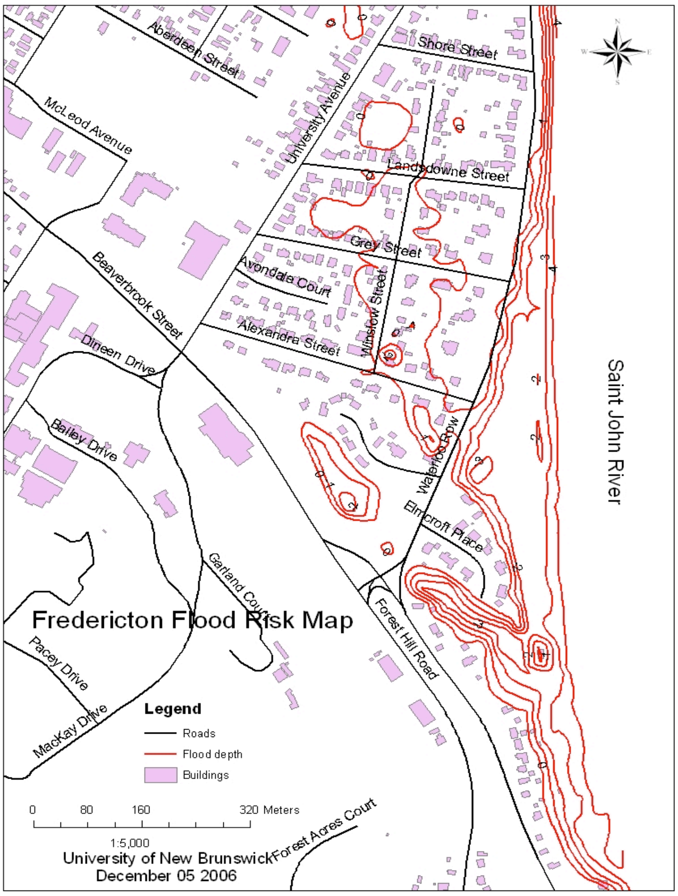

Figure 7. Fredericton flood risk map

This Web GIS software has the capability to allow a spatial query based on 6-digit postal code, so the users will be able to easily locate their area of interest.

The Web-GIS interface is developed to calculate and display the spatial extent of predicted flood plain with the water depths (see Fig. 7). 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.

The Decision Support for Flood Event Prediction and Monitoring implemented with Web-mapping interface facilitates monitoring and prediction of flood events. 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.

VI. CONCLUSIONS

This paper presents integration of the DWOPER hydraulic model with the CARIS GIS system to dynamically display near real time flood information 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.

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.

ACKNOWLEDGMENTS

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REFERENCES

[1] Canada. Inland Waters Directorate. Atlantic Region, New Brunswick Flood, April-may, 1973. Ottawa: Inland Waters Directorate, Atlantic Region, 1974, pp. 114.

[2] MacLaren Atlantic Limited, New Brunswick. Environment New Brunswick and MacLaren Atlantic Ltd (MAL), Canada-New Brunswick Flood Damage Reduction Program: Hydrotechnical Studies of the Saint John River from McKinley Ferry to Lower Jemseg. Fredericton: 1979, pp. 116.

[3] D. L. Fread, "NWS FLDWAV Model: The Replacement of DAMBRK for Dam-Break Flood Prediction, Dam Safety’93," Proceedings of the 10 thAnnual ASDSO Conference, Kansas City, Missouri, pp. 177-184, 1993.

[4] D. L. Fread, "Flow Routing," Chapter 10, Handbook of Hydrology, Editor E.R. Maidment, pp. 10.1-10.36, 1992.

[5] D. L. Fread and J. M. Lewis, "NWS FLDWAV MODEL: Theoretical description and User documentation," Hydrologic Research Laboratory, Office of Hydrology, National Weather Service (NWS), Sylver Spring, Maryland USA, November, 1998, pp. 335, 1998.

[6] Environmental Modeling Research Laboratory (EMRL), "Watershed modeling system (WMS) reference manual and tutorial." 1998.

[7] Danish Hydraulic Institute (DHI), "MIKE11 GIS reference and user manual," 2004.

[8] C. T. Ackerman, "HEC-GeoRAS GIS Tools for support of HEC-RAS using ArcGIS," pp. 204, 2005.

[9] N. S. Noman, E. J. Nelson and A. K. Zundel, "Review of automated floodplain delineation from digital terrain models," J. Water Resour. Plann. Manage., vol. 127, pp. 394-402, 2001.

[10] N. S. Noman, E. J. Nelson and A. K. Zundel, "Improved Process for Floodplain Delineation from Digital Terrain Models," J. Water Resour. Plann. Manage., vol. 129, pp. 427-436, 2003.