Estimating flood inundation caused by dam failures

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The failure of large and small dams can have catastrophic consequences due to the ensuing flood waters. The threat to life and infrastructure is especially magnified where those failures occur upstream of urban centres. In order to ensure public safety in the event of a dam breach, it is important for water resource managers to educate the public on the potential consequences and provide effective emergency preparedness planning.

Recent advancements in modeling inundation due to dam failures have allowed much easier and more illustrative analyses of the potential outcomes of sudden failures. This project demonstrates the latest modeling and mapping capabilities available using the state-of-the-art HEC-RAS hydraulic model in concert with GIS.

The study area included the upper reaches of Canagagigue Creek and the Woolwich Dam near Elmira, Ontario. A hydraulic analysis of the hypothetical dam failure was developed using HEC-RAS and HEC-GeoRAS based on the summer Probable Maximum Flood (PMF) event.

This study extends the previous dam breach analysis that was evaluated using the National Weather Service's Flood Wave (FLDWAV) model for an insufficient distance downstream of the dam. In this study, the limits extend from Woolwich Dam to downstream of the Town of Elmira in order to provide inundation information for local emergency planning purposes. In addition, digital GIS inundation maps and animations have been produced for the Canagagigue Creek reach through Elmira.

Reservoir operating characteristics

The Woolwich Reservoir is relatively small since it covers an area of about 1 km^2 and provides a maximum storage volume of just over 6 million cubic metres. It is located approximately 2.5 km upstream of the Town of Elmira in the Grand River Watershed and was constructed to provide low-flow augmentation to Canagagigue Creek.

The outlet structure of the spillway consists of four oogee-type concrete spillways, which are each equipped with radial gates. In addition, a low-level 4-ft square concrete pipe located within the spillway structure provides spillage for maintenance purposes. The full flow capacity of the spillway structure is approximately 297 m3/s at full supply level.

Hydraulic model setup

The model of choice for this dam breach analysis is the U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center HEC-RAS model, Version 3.1.3. HEC-RAS was selected for this analysis because of its various applications and also its compatibility with GIS. In addition, it is the most commonly used open channel hydraulic model in North America and is continually supported and updated by the USACE.

Dam breaches in HEC-RAS can be

specified to occur as a piping or overtopping failure. Further detailed information is required to describe the breach, such as trigger time of failure, formation time, final geometry, and piping (orifice) coefficients used for piping failures. Since the actual method of failure cannot be predicted, it is suggested that the modeler consider an array of possibilities and report accordingly.

The original GRCA HEC-RAS model was extended from upstream of the reservoir to the downstream limit of Elmira. The dam spillway was modeled as an inline structure with a calculated weir coefficient of 2.14, a spillway approach height of 5.67 m and a design energy head of 6.33 m.

The incoming summer PMF hydrograph was set as the upstream boundary condition in the upstream HEC-RAS model. The total duration of the hydrograph was six days and the peak flow was 402 m^3/s at 1900 hrs of the fourth day. Several other boundary conditions were specified for the Elmira Reach model. For instance, the downstream boundary condition was set to normal depth, as determined from the bed slope at the downstream limit. The initial condition at the upstream boundary was simply set as the first discharge point from the summer PMF hydrograph.

One of the most important parameters in the dam breach analysis is the trigger at which the dam begins to fail. For conservative purposes, the trigger was set as the maximum reservoir level due to the inflow hydrograph. Based on a "no breach" model simulation, the trigger time was set to 2030 hrs of the fourth day. A summary of the dam breach parameters used in this study are listed in Table 1.

Table 1. Summary of Dam Breach Parameters.

Breach Parameter	Value
Elevation of Top of Structure	366.52 m
Trigger Reservoir Level	365.11 m
Breach Formation Time	1 hr
Piping Coefficient	0.8
Breach Bottom Width	30
Breach Bottom Elevation	355 m
Shape	Trap.
Side Slope (H:V)	1:6

Several important simulation parameters that were chosen included simulation time-step, implicit weighting factor, water surface calculation tolerance, and output calculation interval.

The hydraulic analysis through the Town of Elmira consisted of a re-created HEC-RAS model that was developed using the HEC-GeoRAS *v*.3.1.1 extension in ArcView *v*.3.3. The Elmira Reach model was re-created as a result of updated high-resolution terrain data that was provided by the GRCA in the form of a triangulated irregular network (TIN). Using the GeoRAS extension in ArcView, high-resolution cross sections were extracted from the TIN, which ultimately created a much higher quality geometric data file. Once the cross sections were extracted, they were exported to the HEC-RAS geometric editor for further refinement and inclusion of hydraulic structures.

Results

As indicated above, the HEC-RAS model was used to simulate the effects of the dam failure based on the sum-

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mer PMF event. Results from the dam breach run indicate a peak flow of 1,452 m^3/s at the spillway structure, when compared to a peak inflow of 402 m^3/s from the summer PMF event. The corresponding flood inundation results through the Town of Elmira are presented in Figure 1, which represents the maximum water surface profile caused by the flood wave of the hypothetical dam failure.

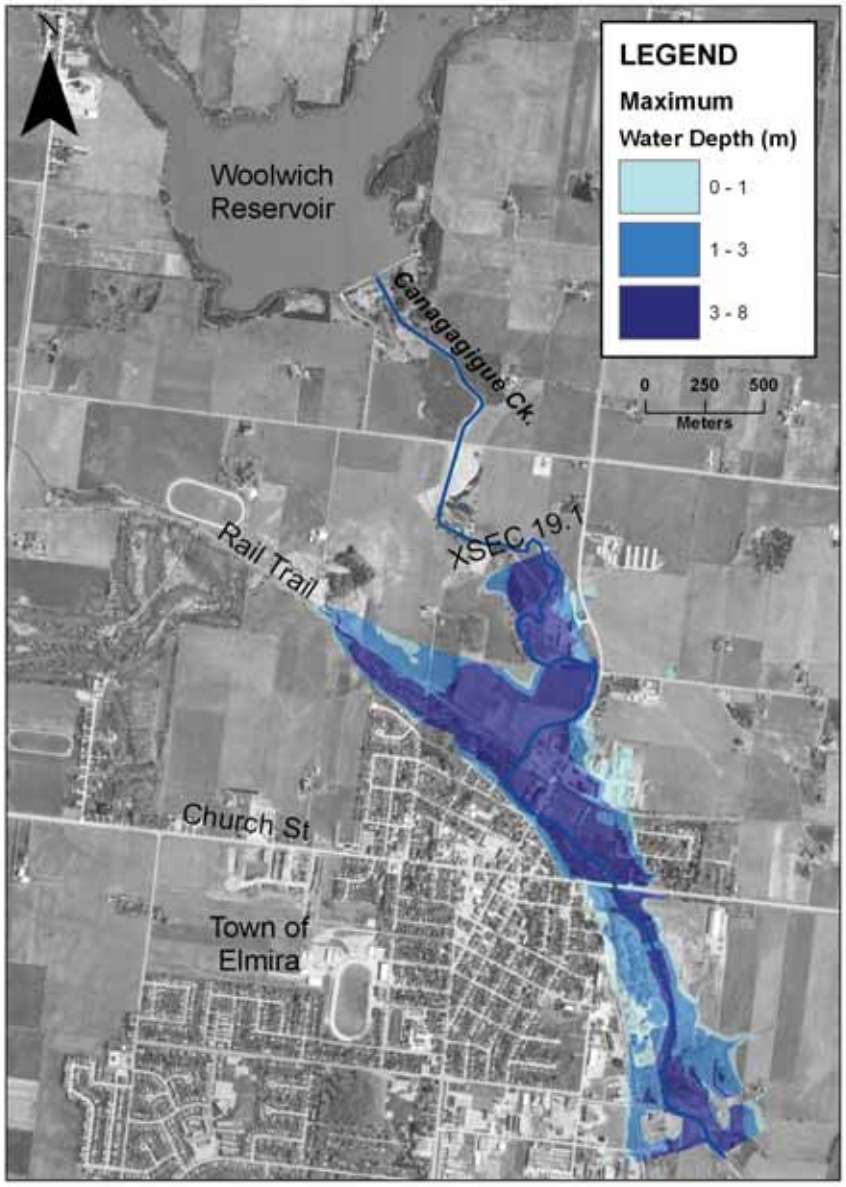
For comparison purposes, steady flow runs of the Regional, 100, 50, 25, 20, 10, 5, 2, and 1.25-Year storms were simulated. Figure 1 also provides a comparison of the water surface profiles from the unsteady dam breach run and the steady flow runs of the Regional and 100-year storm events. It is evident that the magnitude of the flood wave from a dam failure dwarfs the inundation from a Regional or 100-year storm event.

In order to develop inundation maps for emergency management planning, the hydraulic model results were exported to GIS for post-processing using the HEC-GeoRAS extension in ArcView. Results from the post-processing included inundation maps for each of the simulated time-steps as well as an inundation animation for the duration of the dam breach. The most important of the maps created was that of the maximum water depths calculated throughout the Town of Elmira, as illustrated in Figure 2.

Conclusion

This project was developed to demonstrate the capabilities of simulating flood inundation due to hypothetical dam failures using HEC-RAS in concert with GIS. Failure of Woolwich Dam was analyzed for the summer PMF conditions and several spatial and temporal inundation maps were produced to illustrate the consequences of such failure. Modeling tools presented in this case study can be applied to other dam safety assessment projects in order to develop effective and efficient emergency preparedness plans through public consultation and by establishing various impact zones.*1*

FIGURE 2. GIS flood inundation map of dam breach flood through the Town of Elmira.



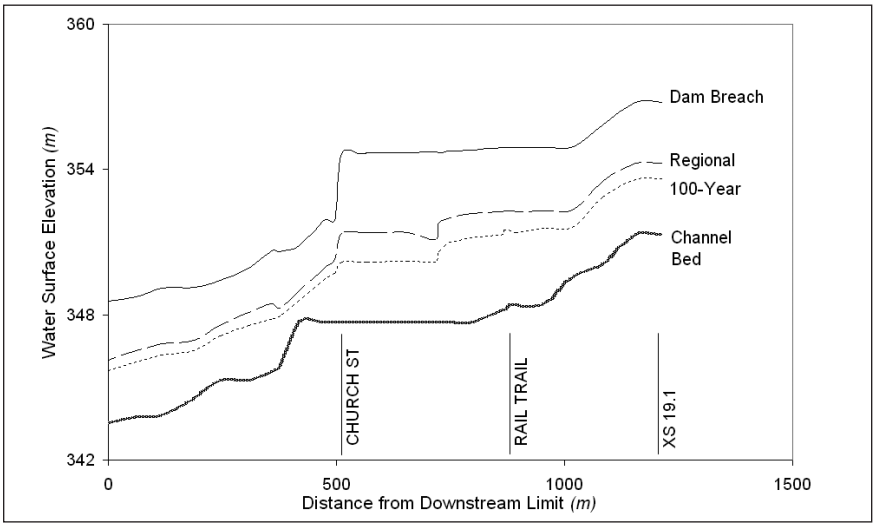


FIGURE 1. HEC-RAS water surface profiles through Town of Elmira.

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