Flood Hazard Mapping for Canada based on Spatial Data Integration and Modeling

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Abstract

Floods are among the most commonly occurring hazards in Canada and around the world. The geospatial community has developed various tools to help create flood zone maps to be used for flood risk assessment, flood mitigation and planning, and emergency response during and after flooding. Despite the numerous options available for flood zone modeling, currently existing tools are typically only suitable for small regions or for producing low resolution datasets due to the high complexity of the modeling process. A nationwide flood hazard map, indicating zones that are susceptible to fluvial flooding, is yet to be created for most countries including Canada. This paper presents the latest results from Intermap's World Flood Model, the only flood model that is available worldwide built on a contiguous, 30-meter spacing Digital Elevation Model (DEM).

Background and Relevance

In Canada, as in many other parts of the world, flooding is a serious natural hazard that occurs seasonally, with an extent and severity that can be difficult to know accurately in advance. The outcome can be catastrophic, often resulting in damage to property and infrastructure, injury to humans, and even loss of life as stated by Natural Resources Canada (NRCan) (2014). The geospatial community has developed various tools to help create flood zone maps to be used for flood risk assessment, flood mitigation and planning, and emergency response during and after flooding as demonstrated by CCRS (2012), Deschamps et al. (2002), and Mioc et al. (2008). Flood hazard mapping is an exercise to define areas that are at risk of flooding under extreme conditions. Despite the numerous options available for flood zone modeling, currently existing tools are typically only suitable for small regions or for producing low resolution datasets due to the high complexity of the modeling process. For example, Alberta SRED has been working on tools to produce flood hazard maps for selected basins for years and have currently produced maps for only the 100 year flood events. Using these existing tools, it would require many years of processing time and extensive computing resources in order to create nationwide flood zone maps. The World Flood Model being developed by Intermap combines the strengths of existing river centerlines, a contiguous, 30-meter spacing Digital Elevation Model (DEM) and an efficient statistical flood model to produce worldwide flood hazard maps. The primary goal of the World Flood Model is to create a global flood model for use as a base layer inside insurance underwriting tools. It is a worldwide flood model covering all areas of latitude between 60^0 N and 60^0 S, and all of Scandinavia in Europe. It is effective for portfolio level modeling where risk can be distributed across an entire portfolio. This paper presents some of our latest flood modeling results for select regions in Canada.

Methods and Data

The input datasets used in this product include: 1) National Hydro Network (NHN); 2) a proprietary DEM specifically designed and purpose-built for flood modeling by Intermap called Flood30; 3) a statistical flood model.

River Centerline Preparation

The National Hydro Network (NHN) provides geospatial vector data describing hydrographic features such as lakes, reservoirs, rivers, streams, canals, islands, obstacles (e.g. waterfalls, rapids, rocks in water) and constructions (e.g. dams, wharves, dikes), as well as a linear drainage network and the toponymic information (geographical names) associated to hydrography (GeoBase, 2011). It was created jointly by the federal government and interested provincial and territorial partners using the best available federal and provincial/territorial data.

In this work, the river centerlines from the NHN database are filtered based on a number of attributes including name, priority, and estimated accumulation area. In some cases the connection relationships are also used in filtering (for example, if an unnamed river centerline is downstream of a named river centerline, it will be included). The accepted river centerlines are then reviewed by our editing team to ensure that they are topologically correct. They are organized into our processing units with Strahler order automatically determined. Detailed watershed boundaries are derived from our input DEM (described in detail in the next section) and they are used to determine the approximate accumulation area of each river centerline. Both Strahler order and accumulation area are two of the main input parameters in our flood model.

DEM Preparation

Elevation data is a key input into any flood model. To help prepare for the creation of the World Flood Model, a new proprietary elevation surface called Flood30 was created. This purpose-built product has been created using a combination of Intermap's World30 DSM, NEXTMap DTM data (where available), as well as some other key enhancements specific to flood modeling.

The base layer of Flood30 is Intermap's World30 DSM, which is a seamless elevation surface data set with 30m posting covering the entire world. It is composed of SRTM data, ASTER Global DEM v2 data, and GTOPO-30 data, which have been combined using a proprietary algorithm and controlled using ICESat data. The proprietary algorithm contains aspects of ASTER pre-conditioning, vertical correction using the ICESat data, and complex-weighted data fusion to blend the data sets together into a final DSM product. Measurements have shown the LE95 vertical accuracy to be in the order of sub-10 meters versus 14 meters for SRTM or 20 meters for ASTER on their own.

Unfortunately, World30 is a Digital Surface Model (DSM), which means that all "first-returns" are included in the product. This is not ideal for flood modeling as buildings and trees are included in the elevation model and impact the flooding profile, often leaving gaps in the model where these features exist. In order to improve the Flood30 input for flood modeling, Intermap has incorporated their NEXTMap 5m DTM in all areas where it is available. The NEXTMap 5m DTM was generated from high resolution airborne IFSAR data and has been manually edited to ensure that all non-ground features such as buildings and trees have been removed. The available DTM coverage includes the USA, Western Europe, and large parts of the Asia-Pacific region, including some of Australia. In order to incorporate the 5m DTM into the Flood30, it was necessary to down-sample the data set, adjust the vertical datum for consistency, re-flatten the water, and seamlessly blend the data set into the World30 DSM. Figure 1 shows a side-by-side comparison of the Flood30 DEM and the SRTM data that are often used in other flood modeling for large areas.

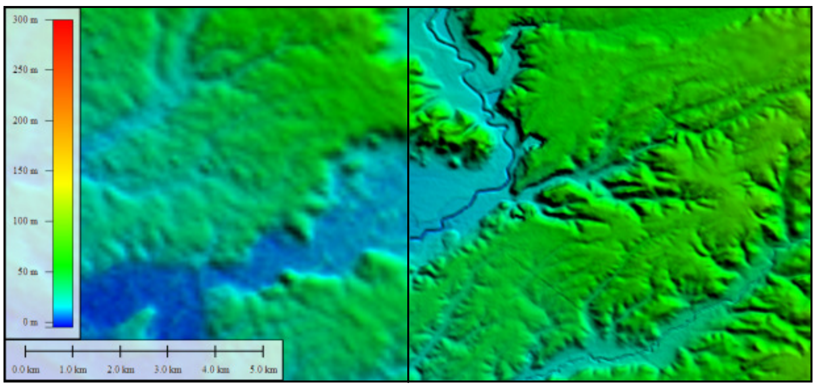

Figure 1. Side-by-side comparison between SRTM (left) and Flood30 (right)

Additionally, the Flood30 DEM was specifically tuned for flood modeling by addressing the ocean-river boundary delineation to ensure the flood model incorporates all of a river mouth or estuary in the fluvial model, but does not use the ocean. In order to make this distinction, the ocean area must be set to null as opposed to zero using either the SRTM water mask or NEXTMap edit mask, depending on the area of the world, to define the boundary. In addition, a technique was developed that automatically filled estuaries beyond the water mask out to the ocean such that they would be included in the flood modeling.

Process

The process starts with pre-conditioning the input data layers to ensure they are complete, consistent and properly attributed to support the modeling. This includes removing vectors that are without a defined flow direction and that are feature-coded as coastal lines. Next, the hierarchical structure of the river network is determined. At this stage, each river/stream segment is assigned a Strahler order and an accumulation area value, which are the two most important parameters in the flooding probability calculation. At the final stage of modeling, a raster grid surface is produced showing flood depth for each location. This is accomplished by associating each 30m posted grid cell with a river vector and calculating the flooding probability for each Return (Time) Period (RTP) using a statistical Multiple Adaptive Regression Splines (MARS) function originally proposed by Friedman (1991). Flood hazard zones for each modeled return period can then be visualized as all locations with a flood depth greater than 0 meters.

Results and Conclusions

Figures 2-3 show examples of flood depth maps generated using the World Flood Model along with the actual flood extents derived from remote sensing imagery. It can be seen from Figure 2 that the model output is in agreement with the actual flooded areas indicated by brown color in the ortho photos that were acquired on June 22, 2013, a day after the peak water level of the 2013 Calgary Flood. The downtown core of Calgary and also Stampede Park (to the southeast of the downtown area) are two areas that were severely affected by the flood. The World Flood modeling results show that these two areas are indeed at high risk of a 100-year flood event from the Bow and Elbow rivers. There are also some areas that are overestimated by the World Flood model, including the area in the southeast corner of Figure 2. Similar observations can be made from Figure 3. At the time of writing, we are in the process of obtaining actual flood extent maps for a number of other historic flood events in Canada to be used as further "ground truth" to quantitatively evaluate the flood modeling results.

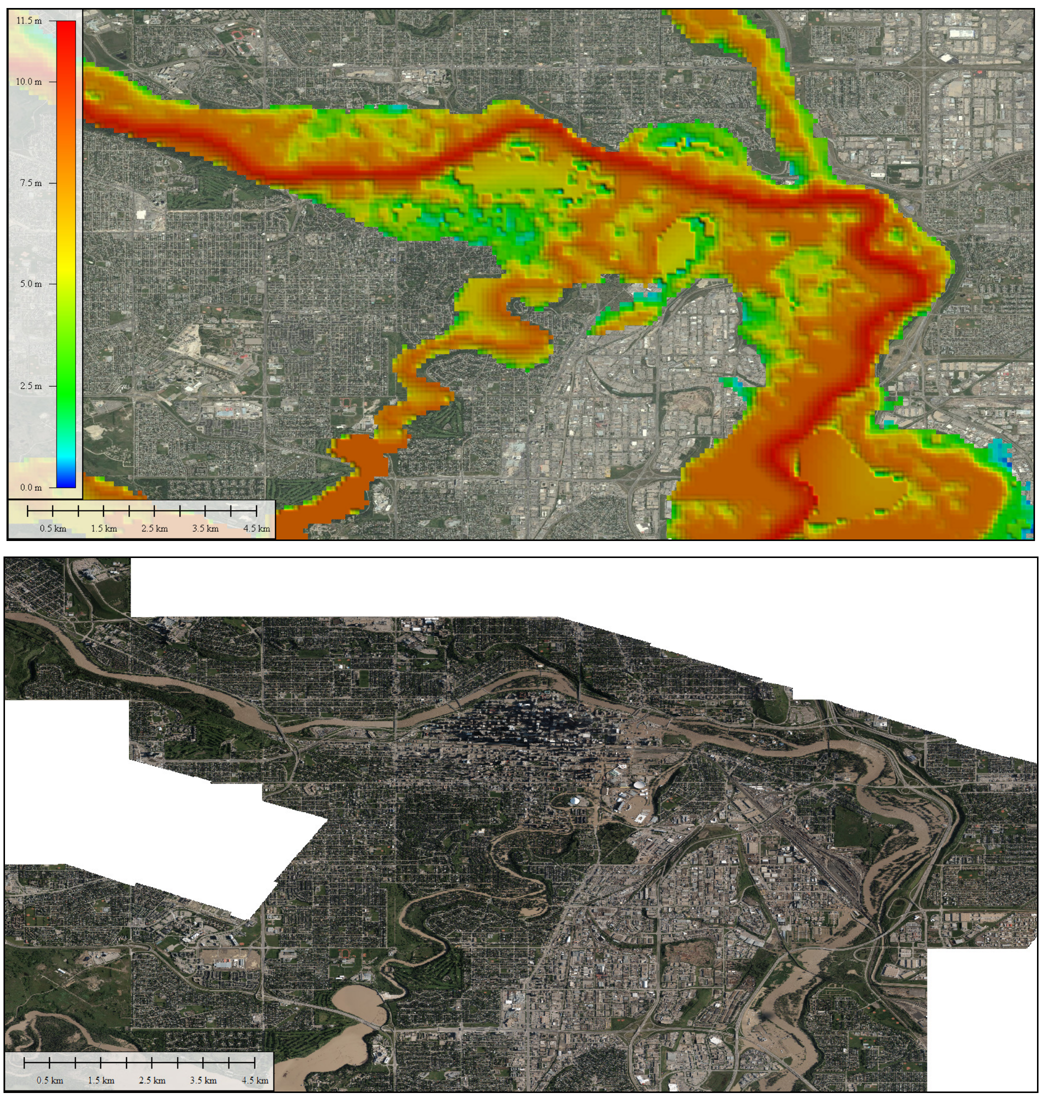

Figure 2. 100-year flood depth map for Calgary, AB (Top). Ortho photo showing the flood extent of the 2013 Calgary Flood (Bottom, image source: cityonline.calgary.ca)

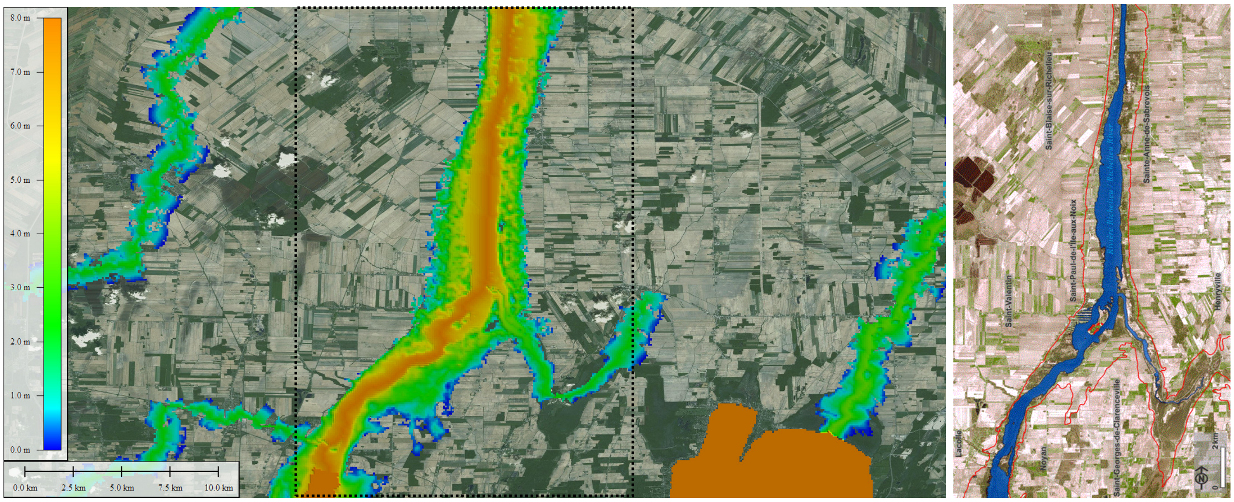

Figure 3. 100-year flood depth map for Richelieu River near Henryville, QC (Left). Red polygon showing the extent of flooding in a portion of the Richelieu River in 2011 (Right, reference polygon produced by CSA in 2011).

Producing nationwide flood hazard maps is challenging but is an essential component of flood insurance underwriting and land planning for local or provincial governments. By integrating existing river centerlines and a medium resolution purpose-built, proprietary DEM into a statistical flood model, we are able to generate continuous flood hazard maps globally. This provides a global portfolio-level flood risk assessment solution for most populated regions of the world, including Canada.

References

Alberta Environment and Sustainable Resource Development (ESRD). (October 14, 2014). Flood Hazard Mapping. Retrieved November 14, 2014, from http://esrd.alberta.ca/water/programs-and-services/flood-hazard-identification-program/flood-hazard-mapping.aspx

Canada Centre for Remote Sensing (CCRS). (2012). CCRS emergency management activities in Canada. Retrieved November 14, 2014, from http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earth-sciences/files/pdf/hazards/11-0433-Emergency-mngt-canada_eng.pdf

Canadian Space Agency (CSA). (May 24, 2011). RADARSAT-2 featured images archives in North America. Retrieved November 14, 2014, from http://www.asc-csa.gc.ca/eng/satellites/radarsat2/featured-image/featured-north-america.asp

Deschamps, A. ; Greenlee, D. ; Pultz TJ ; Saper, R. (2002). Geospatial data integration for applications in flood prediction and management in the Red River Basin. Proceedings of IEEE International Geoscience and Remote Sensing Symposium (IGARSS '02). June 24-28, 2002: Toronto, Canada

Friedman J.H. (1991) Multivariate adaptive regression splines. Annals of Statistics, 19, 1–141.

GeoBase. (April 11, 2011). National Hydro Network (NHN). Retrieved November 14, 2014, from http://geobase.ca/geobase/en/data/nhn/description.html;jsessionid=987989F026A618CD26FA9F32FBE1F396.geobase2

Mioc, D., Nickerson, B., MacGillivray, E., Morton, A., Anton, F., Fraser, D., Tang, P., Liang, G. (2008). Early Warning and Mapping for Flood Disasters. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B4. Beijing 2008

Natural Resources Canada (NRCan) (February 4, 2014). Floods. Retrieved November 14, 2014, from http://www.nrcan.gc.ca/hazards/floods