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CBCL LIMITED
Consulting Engineers

TRURO FLOOD RISK STUDY
for the Joint Flood Advisory Committee
(County of Colchester, Town of Truro and Millbrook First Nation)

CANADIAN CONSULTING ENGINEERING AWARDS 2016

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Project Team: Joint Flood Advisory Committee, CBCL Limited • Draft Report Completed, Final Report

Visual rendering of model results
https://www.youtube.com/watch?v=ODFrNP0xI28

> Over 160 billion tonnes of water move in and out of the Bay of Fundy, every day, twice a day - more than the combined flow of all the freshwater rivers on our planet. It's also home to the highest recorded tides in the world, according to the Guinness Book of World Records.
>
> http://www.novascotia.com/explore/top-25/bay-of-fundy

Truro, Nova Scotia, is notorious for being subject to flooding at one of the highest frequencies of any developed area in Atlantic Canada. For example in 1979, the community experienced flooding 5 times. Several previous studies conducted for the area highlighted the complex interaction between the highest tides in the world, very large flows from two rivers, extreme levels of river sedimentation and recurring ice jams. With rainfall, tides and sedimentation set to increase significantly as our global climate changes, the community is ill-prepared and extremely vulnerable to these risks.

The Truro Flood Risk Study was commissioned by the Joint Flood Advisory Committee, or JFAC (County of Colchester, Town of Truro and Millbrook First Nation).

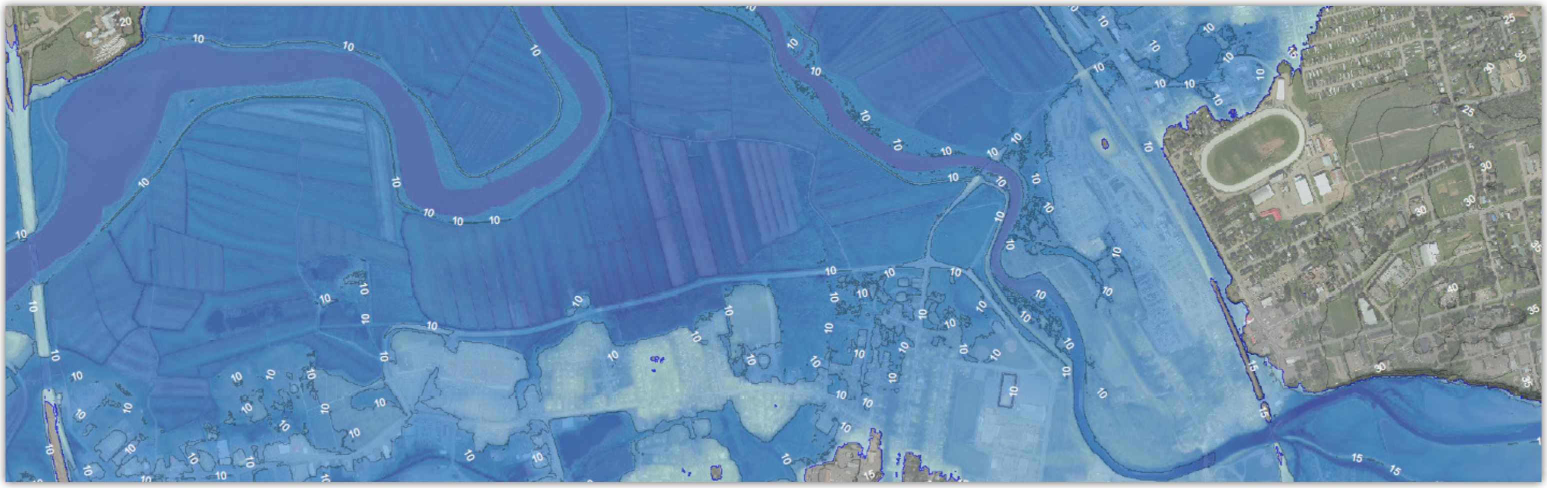
The Goals of the study included:

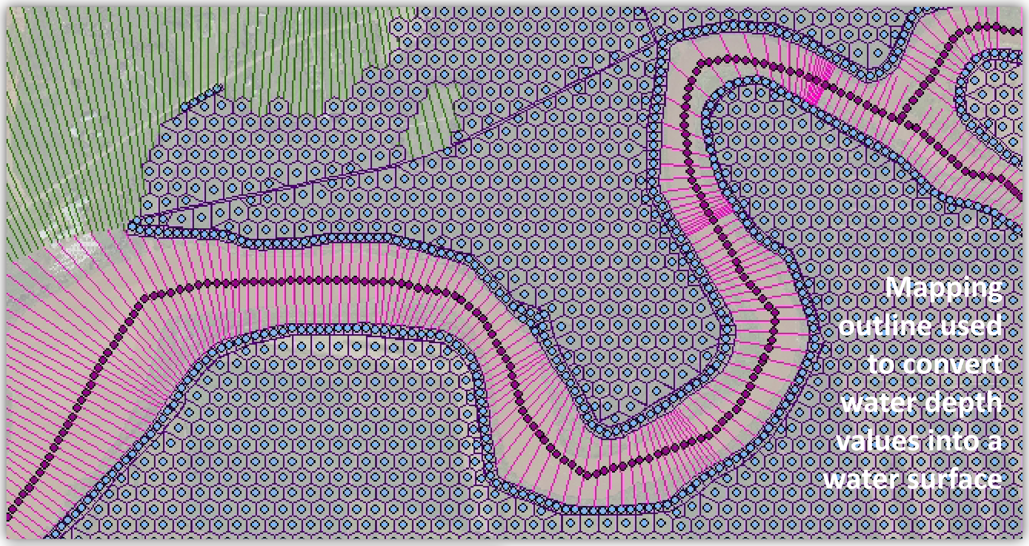
- protection against climate change
- resilience, including safety and sustainability
- affordability

As the most comprehensive flood study ever undertaken in Atlantic Canada, the Committee and CBCL Limited's Water Resources group's goals were to find flood protection solutions where decades- perhaps centuries- of studies had not been able to resolve the complex mechanics underlying flooding risks in Truro.

Complexity called for innovation

No previous study had been able to characterize the full range of risks,





> The Truro Flood Risk Study is the most comprehensive flood study ever undertaken in Atlantic Canada

let alone find solutions to protect Truro residents. With this Study, CBCL Limited's water resources engineers and technicians gathered current, detailed and accurate data, processed it with the most advanced models available and produced a unique representation of the estuary in order to test a wide range of potential options for flood mitigation.

Close to 100 documents investigating potential causes of flooding in Truro were reviewed at the outset of the Study, with many of the documents pointing out that the mechanisms involved were too complex to understand and model with the tools of the time. A completely new approach was necessary. Meaningful information was extracted from previous documents, supplemented with a comprehensive program of field data collection, and analyzed with state-of-the-art modelling.

The Study incorporated the latest computer modelling techniques built upon current Lidar mapping for the entire watershed, aerial photography, bathymetric surveys and satellite imagery. Based on the information collected, computer models were developed for river flows, tides, sediment levels and ice jams. These models were assembled in order to study the relative influences of rainfall, tides, estuary sedimentation and ice jams, all of which are important parameters in defining the flooding risk in the area.

With each of these models, more than 40 flood mitigation options were evaluated, and based on the extensive stakeholder consultations held during the project, each option was ranked by its ability to cost-effectively protect the vulnerable areas that were vital to each stakeholder.

Previous efforts to define the flooding risk and the interactions between all the natural processes had been limited by lack of detail, model quality and resources. Therefore, this Study needed to clearly overcome those limitations in order to produce defendable results that would be acceptable to the community. This project focused so much on improving the detail and modelling depth of analysis that a significant amount of information needed to be collected, stored and managed. Dedicated servers had to be set up to allow the safe storage and rapid access of many large files, and project computers had to be upgraded with the latest processors, graphics cards and hard drives to allow reliable, fast reading and processing of model information. This allowed for complex simulation models to be run within days, as opposed to weeks, as had previously been the case. In essence, current computing technology was pushed to its limits to achieve the highest level of detail and depth of analysis.

Bringing stakeholders together

A fundamental principle of the Study was to include the full range of stakeholders throughout the project. The project team asked stakeholders to identify infrastructure and services that were most valuable to them and rank them by priority. This prioritized list of vital

> Creativity became a constant characteristic of the project as a necessary means to problem-solving


Unique cohesive sediment characteristics

	Results from JFAC Meeting (Decreasing Order of Priority)								
HUMAN HEALTH AND SAFETY	PROTECTION OF LIFE	SOCIAL JUSTICE	PRESERVATION OF ACCESS TO EMERGENCY FACILITIES	MAINTENANCE OF ACCESS TO AN AREA	ACCESS TO NECESSITIES OF LIFE	PROTECTION OF REGIONAL ACCESS ROUTES	PROTECTION OF LIVELIHOOD	SHORT AND LONG TERM IMPACTS	PROTECTION OF ENVIRONMENT FROM CONTAMINATION
LAND USE	PROTECTION OF HOSPITAL	PROTECTION OF SENIOR HOMES	PROTECTION OF SCHOOLS	PROTECTION OF RESIDENTIAL PROPERTIES	PROTECTION OF OFFICE PROPERTIES	PROTECTION OF RETAIL PROPERTIES	PROTECTION OF INDUSTRIAL PROPERTIES	PROTECTION OF AGRICULTURAL LAND	PROTECTION OF RECREATIONAL FACILITIES
INFRA-STRUCTURE	PROTECTION OF COMMUNICATION INFRASTRUCTURE	PROTECTION OF BRIDGES	PROTECTION OF ROADS	PROTECTION OF WATER SUPPLY / TREATMENT	PROTECTION OF POWER SUPPLY	PROTECTION OF POTABLE WATER INFRASTRUCTURE	PROTECTION OF WASTEWATER TREATMENT	PROTECTION OF MARSH LANE INFRASTRUCTURE (DYKES, ABOITEAUX)	

Decision priority matrix from shareholder consultation meeting

Quantifying rainfall changes across the watersheds is one of the largest sources of uncertainty in hydrologic modelling- to overcome this, the innovative idea of using rainfall radar data was identified

infrastructure then formed the basis for evaluating the efficiency of various flood mitigation options, ensuring that the preferred options protected the most important and most vulnerable infrastructure, services and land for each stakeholder.

The management of this information (previous reports, stakeholder vulnerabilities, field data, model results) was carried out both in GIS (Geographic Information Systems) and Google Earth in order to view and share data easily as well as manipulate and conduct data analyses clearly and efficiently. GIS databases were prepared for:

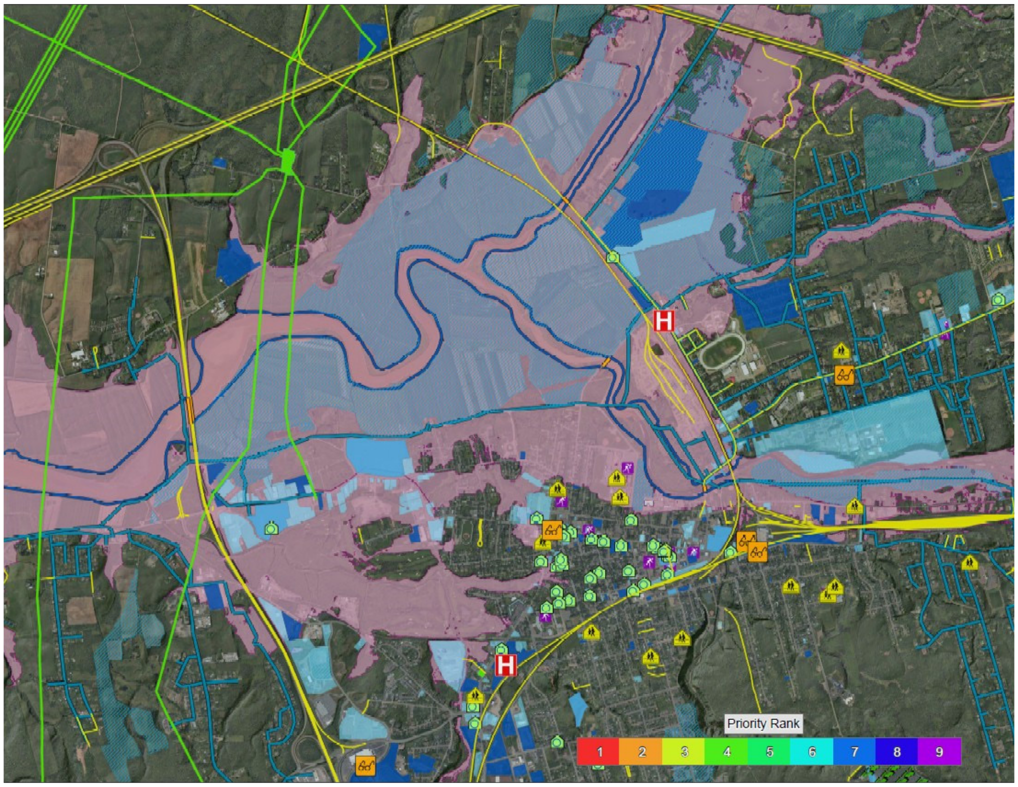
- historical flood events, where photographic records were assembled and organized by event, such that all images of flooding could be accessed and used quickly and compared to model results;
- vulnerable areas, classified by type (infrastructure, service, land) and by stakeholder;
- survey data, including land points, river bathymetry, bridge structure sizes, recent changes to the dyke system, and details of previous river reshaping programs;
- model inputs (hydrologic characteristics, river and land geometry, hydraulic structures); and,
- model outputs, including water levels, flood line delineations and flows for the rainfall, tides, sedimentation and ice models.

Risks that had been identified through stakeholders, public meetings, etc. were represented by mapping vulnerable areas against flooding extents from the various model results. This clearly showed which areas were at risk and where flood mitigation efforts should be concentrated. In addition, ideas from previous studies and new ideas from stakeholders were added to the list of options to test in the models. Overall, more than 40 flood mitigation options were identified that showed potential for reducing floods in vulnerable areas.

Creative engineering design

Since the project aimed at reaching a new understanding of flooding processes and associated risk levels, creativity became a constant characteristic of the project as a necessary means to problem-solving. Remote sensing tools were widely used

Frozen Mud Deposits in Salmon River (4m thick)



throughout the Study to provide quality information at the highest resolution available.

Lidar data was obtained for the entire watershed (770 km^2) and supported the watershed delineation and watershed slope calculations using customized automated tools. The watershed needed to be broken down by land surface cover to assign a surface roughness to each of the 127 sub-watersheds studied, from roads to dense forests – 20 categories in total. Standard manual approaches would have been lengthy, arduous and expensive to carry out. This led to the search for a creative solution, which was found by customizing a GIS tool that allows surface roughness to be assigned based on a range of specific geographic characteristics, differing by land cover. Lidar point density (which varies with the thickness of vegetation), Lidar return signal strength (which varies with the type of vegetation), high resolution aerial photography and Near Infra-Red LandSat imagery (which demarcates vegetative surfaces) were combined in this analysis to automatically produce a detailed map of land cover for the entire watershed.

> Though few ice jam models exist, CBCL Limited's water resources group took up the challenge in order to study the risks of formation of ice jams at various locations and various flow and winter conditions

Another example in which innovation allowed significant savings in time and budget was the survey of the river bed elevation (bathymetry). An eco-sounding bathymetric survey was conducted from a boat within the short window between the record-breaking rising and falling tides of the Bay of Fundy. This technology was used to collect higher resolution data more safely and at a lower cost and resulted in the production of more dependable results than a standard survey.

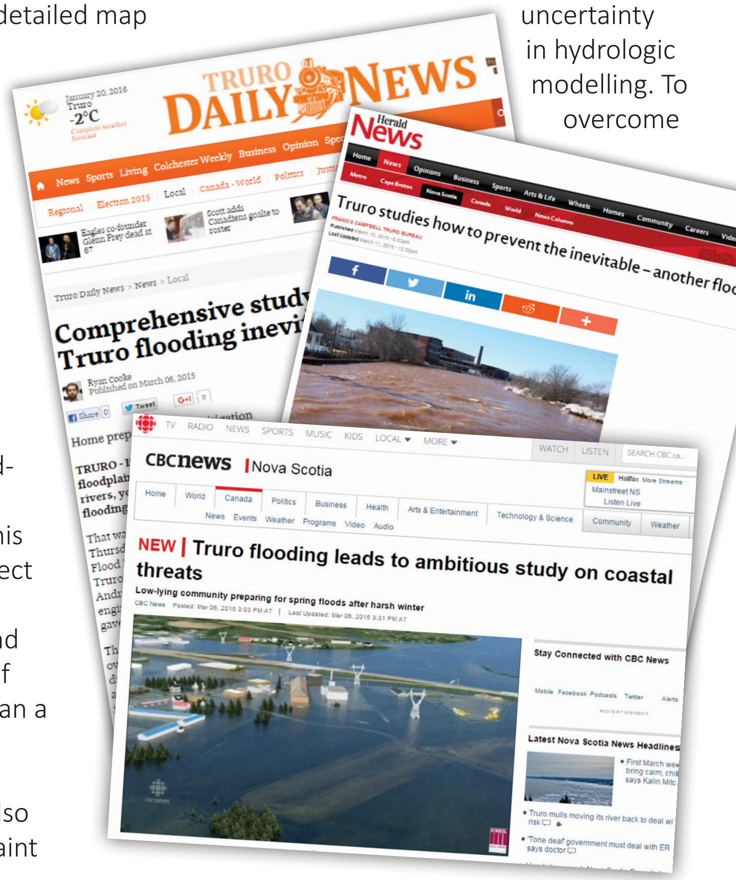
Advanced equipment was also applied with the help of a Saint Mary's University research group, who collected tidal velocity data and sediment concentration measurements. This was used to characterize sediment movement through the tidal and seasonal cycles to support computer models of sediment transport.

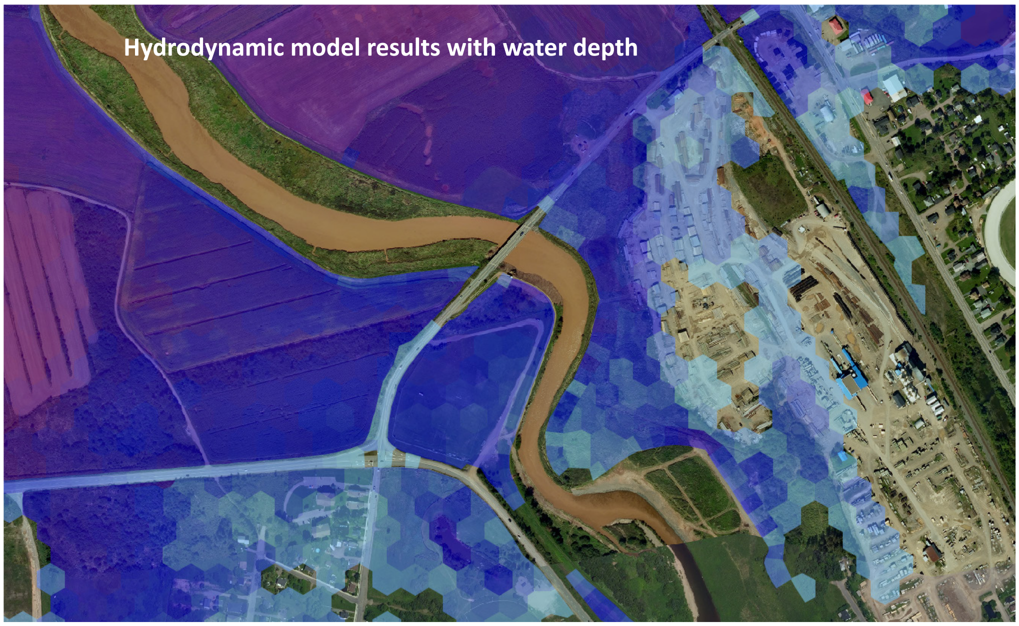
Dynamic modelling

To identify and demonstrate the capacity of various options to protect vulnerable infrastructure, the best available computer modelling techniques (1D, 2D and 3D models, with ice jam and cohesive sediment transport capabilities) were used to develop a meaningful understanding of the dominant forces underlying Truro's flooding risks. Climate change impacts were analyzed, and innovative flood mitigation options such as ice barriers, actively controlled aboiteaux that flush sediments, or floodways that bypass the river could be realistically tested with this suite of comprehensive models.

Novel modelling features

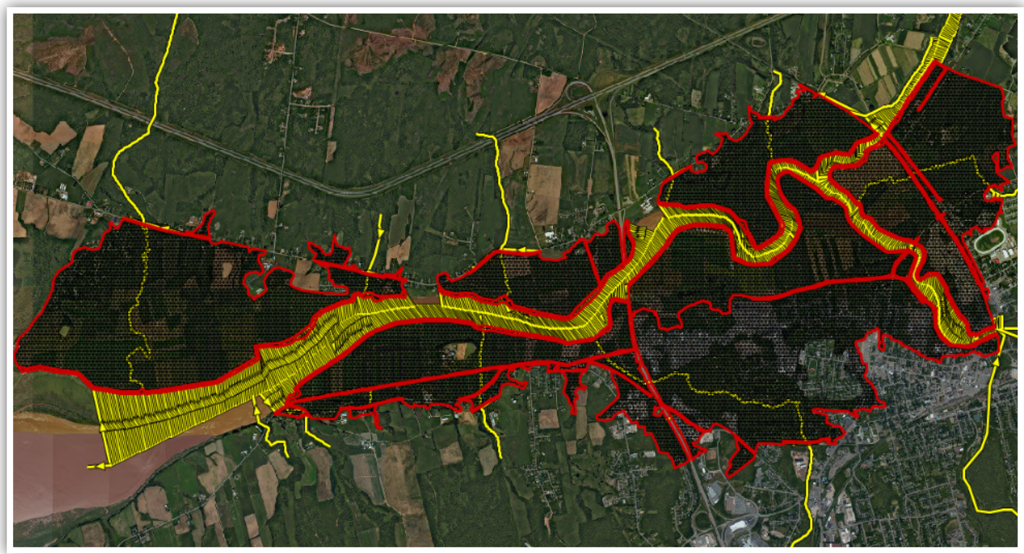
Since rainfall within large watersheds is not uniformly distributed, quantifying rainfall changes across the watersheds is one of the largest sources of uncertainty in hydrologic modelling. To overcome





this, the innovative idea of using rainfall radar data was identified. This data was representative of the variation of rainfall across watersheds, and needed to be calibrated on ground rain gauges to produce rainfall amounts across watersheds.

Although not previously possible in Canada outside of academia, CBCL Limited worked with University of Guelph staff and software developers to enable the model to process Canadian Radar Station data. Radar information was then obtained from Environment Canada in 10 minute increments and calibrated on a network of Environment Canada rain gauges, supplemented by a network of privately owned rain gauges identified in the area. This operation was a success, and individual rainfall records were derived for each of the 127 sub-watersheds to produce more representative rainfall and runoff patterns in the model.



Dyke failure posed another challenge

Another challenging aspect of flooding in Truro is the potential for the existing dykes to fail at any moment and at any number of locations, which would ultimately accentuate damage within the community. Since standard models are not able to represent dyke failure during a simulation, the dyke system had to be modelled in 20 m-long sections, then customized to allow any number of them to breach at any moment during the simulation, if the water was to overtop any dyke section by more than 300 mm. This allowed dykes to fail realistically, whether due to the river flowing over them, or as a result of water accumulating behind and overtopping them.

Unique ice jam modelling process

Ice jam modelling is a rarely undertaken challenge, as the underlying processes are complex, uncertain and variable. Few models exist, and results can be highly uncertain, which may be the reason no previous attempt at ice jam modelling was made in Truro. To address this challenge, CBCL Limited developed customized programs to convert the geometry of the river into an ice jam model in order to study the risks of

Extensive stakeholder consultations were held at the beginning of the project. Stakeholders included:

- The Public
- County of Colchester
- Town of Truro
- Millbrook First Nation
- Nova Scotia Environment
- Nova Scotia Department of Agriculture
- Nova Scotia Transportation and Infrastructure Renewal
- Nova Scotia Department of Natural Resources
- Environment Canada
- Canada National Railway
- Nova Scotia Power Inc.

formation of ice jams at various locations and various flow and winter conditions.

This information could then be analyzed with a specialized ice-jam software, developed by the United States Army Corps of Engineers Ice Engineering and Research Laboratory, which is the most recognized authority for this purpose. Risks of ice jams were assessed for the Salmon and North Rivers and included in the overall analysis of flooding risks.

Bay of Fundy hydrodynamics and sedimentation modelling

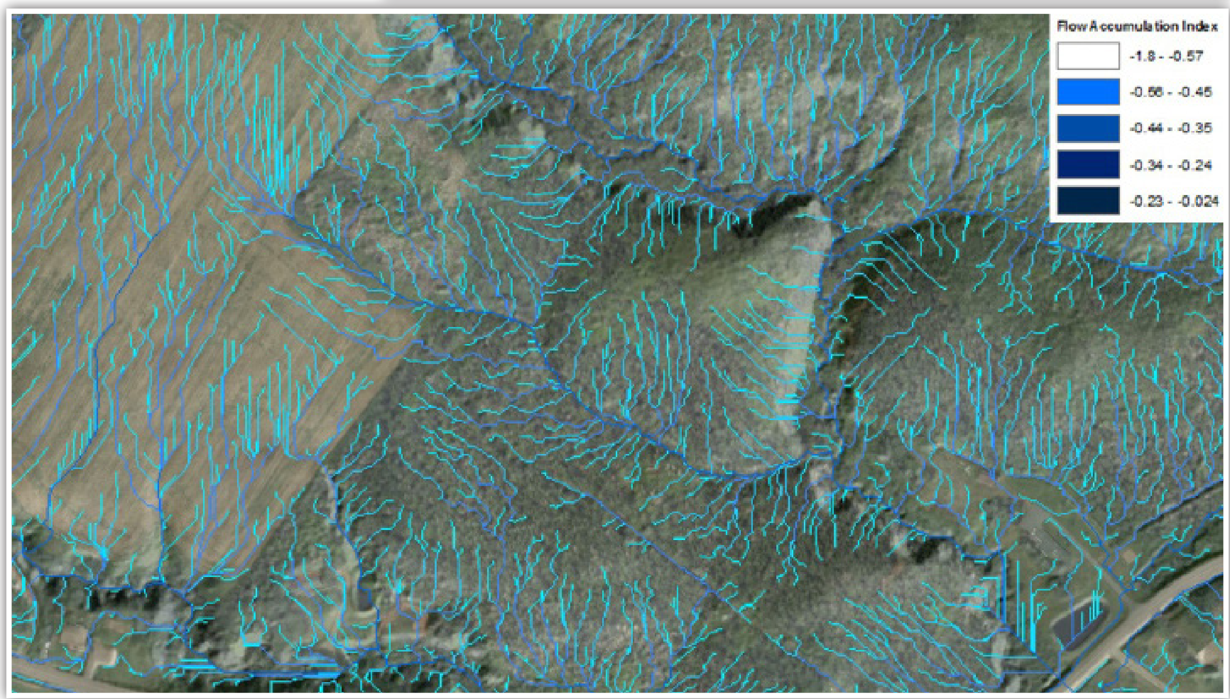
Perhaps surprisingly, elevations of tides in Truro are not known or recorded, even though they are among the highest in the world. Since this is a critical element to assess flooding risks, the CBCL water resources team decided to resolve this issue in a comprehensive effort. A 3D model of the recorded breaking tides of the Bay of Fundy was assembled to analyze how tides move into the Cobequid Bay. The Bay of Fundy model was adjusted to match measurements at the Burntcoat Head and Saint John tide gauges, as well as 4 tide gauges installed by CBCL during a field program. This improved our understanding of how tides grow as they move into the Truro area. It also allowed us to calculate current normal and extreme tide levels, as well as estimate the impacts that climate change will have on extreme water levels.

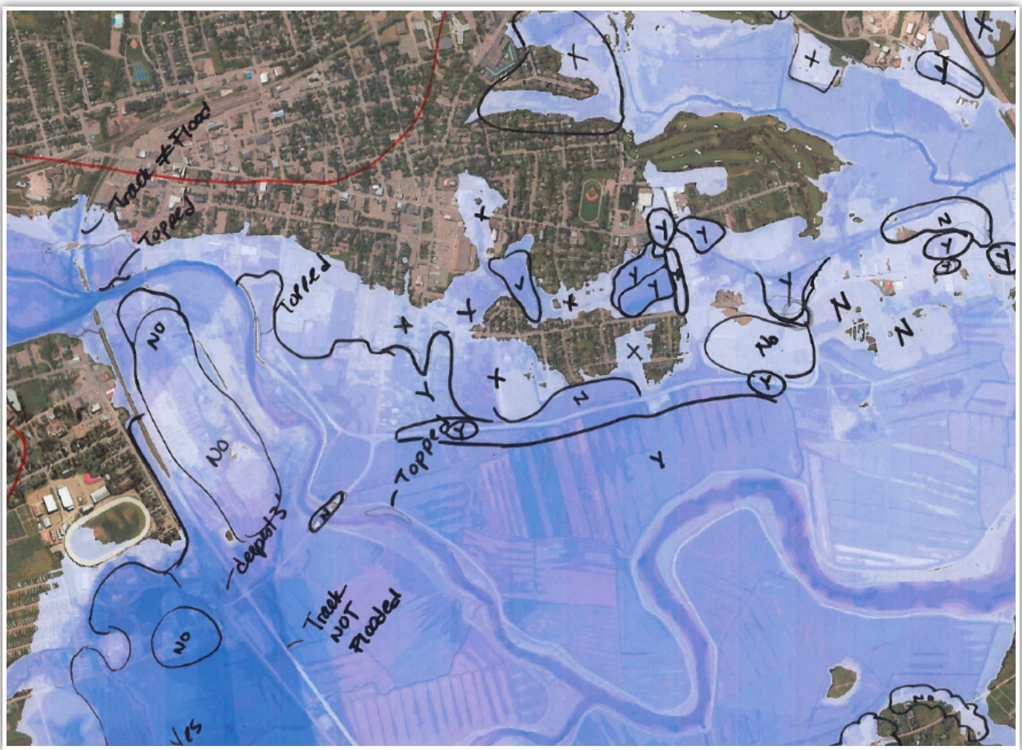
Reduced river flows during the summer months cause more than 2 m of tidal sediment to accumulate in the estuary. This diminished the capacity of the Salmon River to drain peak flows within its banks, which often leads to flooding. To address this challenge unique to the Bay of Fundy, a 3D sediment transport model was assembled for the Truro estuary study area. It was adjusted to reproduce detailed measurements of flows and sediments at varying locations along the length and width of the estuary, during different seasons. This in-depth characterization of the locally unique sediment processes led to a thorough and realistic model that was able to confirm the natural sediment patterns and test the influence of various flood mitigation measures that can affect or disrupt the natural balance of erosion and deposition.

Model automation

With over 40 options, and each with 4 models to run, an efficient approach to deal with model runs and results was needed. Models were set up in a dedicated framework to organize and access output files.

A custom-built automation tool was used to draw floodlines by accessing results





and organizing water level output into specific point and line databases. The tool then interpolated values between model point results and extrapolated data within tight constraints outside the model grid to produce a continuous water surface with a resolution as precise as the Lidar grid (1m grid). This surface could then automatically be intersected with the Lidar ground surface to produce not only highly detailed and representative floodlines, but also a map of the depth of water for each square meter in the floodplain, which was very helpful to evaluate risks to public safety and infrastructure within the floodplain.

Public interest

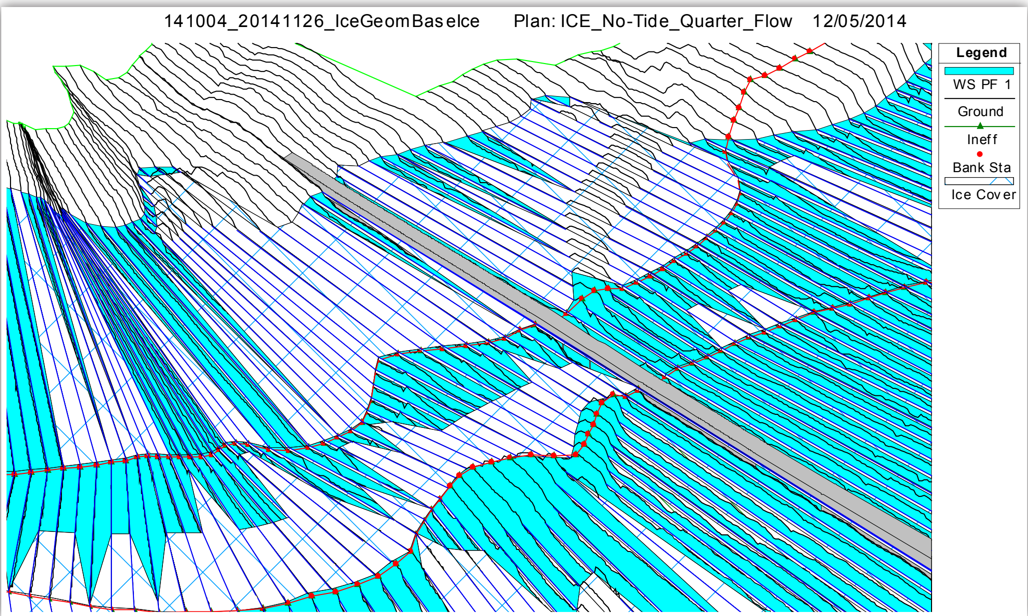
Due to the importance, timeliness and use of innovative modelling, the Study attracted the attention of Nova Scotia Environment and NRCan, who publicized it during the 2015 Atlantic Flood Management Conference. Several media sources were present and the project received significant attention: two televised interviews were given (CBC news and ATV news) and news articles were published in print and online in CBC News, the Chronicle Herald and the Truro Daily News.

Changing the face of flood assessments

This project used fundamental engineering principles to further current understanding and capabilities in the realm of flood assessments. It was necessary to change previous habits of flood assessments (steady state analyses, 1D modelling of floodplain, ignoring the dynamics of tidal intrusion, sedimentation /erosion and ice jams) and bring together proven, albeit disconnected knowledge of relevant processes that are typically analyzed separately in different engineering fields. Each aspect influencing flooding risks was evaluated through this Study with advanced dedicated models based on high quality data at a high level of detail, and results were brought together to build a representative picture of flooding risks. Compared to the ranked vulnerabilities, each resulting option could be evaluated for its cost-effectiveness in protecting the most valued vulnerable areas and a plan could be devised for going forward in the most cost-effective manner.

An important aspect of this analysis is that it acts as a benchmark to understand the local flood mechanisms and to predict how future weather events will affect the community

An important aspect of this analysis is that it acts as a benchmark to understand the local flood mechanisms and to predict how future weather events will affect the community. It demonstrates as well an approach to design flood protection



infrastructure in a defendable and reliable manner.

The project has already been widely presented to decision makers and engineers, and a plan to present this project to many more is underway. To date, presentations have been made to:

- The Union of Nova Scotia Municipalities (UNSM), April 2014
- The Provincial Flood Management Group (November 2014)
- The Atlantic Flood Management Conference (March 2015)
- Internally to CBCL Limited Engineers
- Adaptations Canada 2016 conference in Ottawa

Further exposure of the profession to this Study is planned through the following:

- A paper has been peer-reviewed and being published in the Coastal Zone of Canada journal
- An abstract has been written and is being peer-reviewed for the CHI International Water Modelling Conference
- An abstract has been accepted for the Coastal Zone Canada conference
- An abstract will also be sent to the Atlantic Canada Water and Wastewater Management conference in September
- Engineers Nova Scotia Lieutenant Governor's Award for Excellence in Engineering (Honourable Mention)

was received for this project

A safe environment promotes a healthier economy

The Study aims ultimately to reduce the costs of flood protection, protect infrastructure and keep Truro residents safe from harm caused by flooding. Short term and long term measures include changes to planning and policy regulations and emergency management operations, going from low profile lot scale measures to large scale heavy infrastructure projects. Some key examples include creating permeable pavement and rain gardens, widening and raising the dyke system to restore the natural floodplain and salt marsh,

Ultimately, a safer environment will promote a healthier economic environment, where stakeholders will be more confident investing in the future

and implementing a flood forecasting and warning system to allow residents to better prepare for flooding. Included in the assessment was the delineation of a zone assigned for future commercial development in the fringe of the floodplain that can be raised, which was shown by the model to have a minimal impact on flooding risks.

Counterbalancing this with leveraging funds to implement best management practices such as stormwater infiltration will ultimately reduce flooding risks while allowing an increase in economic development of the area.

Ultimately, a safer environment will promote a healthier economic environment, where stakeholders will be more confident investing in the future.

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