

## **Request for Proposals**

**Climate Change Flood Risk Mapping Study And  
The Development of a Flood Forecasting Service:  
Happy Valley – Goose Bay and Mud Lake**



Water Resources Management Division  
Department of Municipal Affairs and Environment  
Government of Newfoundland and Labrador

Issued for 2018-19

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## 1.0 Background

In Canada, flood plain management falls under the jurisdiction of the provinces, as they are primarily responsible for water resources and land use matters. One of the roles of the federal government is to reduce major disruptions to regional economies and to reduce disaster assistance payments. Traditionally this had been achieved by building structural measures to control flooding. In the 1950s, 1960s, 1970s, and to a lesser extent in the 1980s, the federal government allocated millions of dollars, in conjunction with the provinces, to build dams and dykes. Extensive flood damages across Canada in the early 1970s clearly demonstrated that a new approach to reducing flood damage was needed. These flood events were the catalyst for the federal government to initiate the national Flood Damage Reduction Program (FDRP) in 1975 under the *Canada Water Act*. The FDRP has been carried out under cost shared federal-provincial agreements.

Newfoundland and Labrador joined the Flood Damage Reduction Program in 1981 signing the General and Mapping Agreement and two years later a Studies Agreement. In the 1980s and 1990s a number of communities in the province with a known history of flooding were mapped and the flood risk plains associated with the 1:20 and 1:100 annual exceedance probabilities (AEP) were designated. The last study undertaken in the federal-provincial program was in 1996. In 2008, the province funded a new study for Stephenville and Cold Brook. The Stephenville/Cold Brook study was one of the first in Canada to delineate climate change based flood risk mapping. Following the success of the 2008 study, a partnership with Natural Resources Canada funded climate change flood risk mapping studies for four areas.

In 2011, a new Climate Change Adaptation initiative was announced by the province to update and undertake new flood risk mapping studies. The studies continue to incorporate climate change projections facilitating climate change adaptation. Since their creation, flood risk maps have been incorporated into a wide range of application including: public safety, infrastructure design, water resources management, environmental assessments, land use development, municipal and development planning, setting of structural design criteria, and flood response.

Major flooding occurred along the Churchill River in Central Labrador in May of 2017 and caused the evacuation of residents from Mud Lake to Happy Valley-Goose Bay. As a result of this flood, there was extensive flood damage to properties in the area.

After the flood event, the Government of Newfoundland and Labrador committed to an independent review of the May 17, 2017 flooding event. On June 14, 2017, the Provincial Government announced the appointment of an independent expert, Dr. Karl-Erich Lindenschmidt, to lead an assessment of the cause of extensive flooding at Mud Lake that occurred on May 17, 2017. Dr. Lindenschmidt was supported by

engineering consultant KGS Group in undertaking an independent and specialized review of the flooding. On September 29, 2017, Dr. Lindenschmidt submitted his final report to the Provincial Government. The report is available at [http://www.mae.gov.nl.ca/waterres/flooding/Lindenschmidt\\_review\\_all.pdf](http://www.mae.gov.nl.ca/waterres/flooding/Lindenschmidt_review_all.pdf).

The final report recommended the implementation of a Flood Management Plan that includes Flood Risk Mapping and Flood Forecasting. This Request for Proposals for a Climate Change Flood Risk Mapping Study and the Development of a Flood Forecasting Service: Happy Valley – Goose Bay and Mud Lake is to fulfil this recommendation.

## 2.0 Objective

The Water Resources Management Division (WRMD) has issued this Request for Proposals (RFP) to afford proponents an opportunity to demonstrate their specific expertise and potential for an innovative approach in providing engineering consultant services. The proposed approach must satisfy the flood risk mapping needs in a cost-effective manner. The objective of the RFP is to describe the requirements for a flood risk mapping study, a flood forecasting model and a flood forecasting service that will:

- a) Provide estimates of the water levels and flows associated with;
  - the 1:20 and 1:100 Annual Exceedance Probability (AEP) for current climate and current development conditions.
  - the 1:20 and 1:100 AEP for current climate and a fully developed watershed condition,
  - the 1:20 and 1:100 AEP for climate change and current development conditions.
  - the 1:20 and 1:100 AEP for climate change and a fully developed watershed condition.
- b) Provide flood risk maps indicating flood plains associated with the following scenarios;
  - the 1:20 and 1:100 AEP for current climate and current development conditions.
  - the 1:20 and 1:100 AEP for current climate and a fully developed watershed condition.
  - the 1:20 and 1:100 AEP for climate change and current development conditions.
  - the 1:20 and 1:100 AEP for climate change and a fully developed watershed condition.
- c) Provide maps indicating the change of flood plains associated with the 1:20 and 1:100 AEP for current climate and current development conditions and the 1:20 and 1:100 AEP for climate change and current development conditions.
- d) Provide flood inundation, flood velocity, and flood hazard maps associated with the 1:20 and 1:100 AEP for current climate and current development conditions.
- e) Provide the linked hydro fabric: the datasets and models used in the development of the flood risk maps.
- f) Evaluate and implement a flood forecasting service for the Town of Happy Valley – Goose Bay and the community of Mud Lake using the hydrologic and hydraulic models implemented in this

study. The flood forecasting service must factor in all meteorological, hydrological, and hydraulic factors that trigger flooding.

- g) For the flood forecasting service develop an easy to use real time, custom river ice model or set up an existing non-proprietary river ice model to model flooding during ice generation and ice break up for the period of December to June.
  - One possible non-proprietary river ice model is RIVICE.
    - i. If RIVICE is selected then the RIVICE model implementation must be carried out in consultation with Dr. Karl-Erich Lindenschmidt, PhD, P.Eng, University of Saskatchewan, [karl-erich.lindenschmidt@usask.ca](mailto:karl-erich.lindenschmidt@usask.ca)
      - a. Any anticipated costs for engaging Dr. Karl-Erich Lindenschmidt must be covered in the proposal.
      - b. Further information on the RIVICE model and its application can be found here: Lindenschmidt, K.-E. (2017) RIVICE – a non-proprietary, open-source, one-dimensional river-ice and water-quality model. *Water* **9**, 314. <http://dx.doi.org/10.3390/w9050314>
- h) Setup flood forecasting service in WRMD office in St. John's and train staff on the use of the flood forecasting models by December 2018. Develop a user guide for the flood forecasting service. Flood forecasting service must be integrated with WRMD automated data retrieval systems.
- i) Provide a hydraulic capacity assessment (based on modelling results and field surveys) of all existing hydraulic structures for;
  - the 1:20 and 1:100 AEP for current climate and current development conditions
  - the 1:20 and 1:100 AEP for climate change and current development conditions.

For complete detail on maps, please see section 11.0 of technical document in Appendix B.

The current climate condition will be defined by the latest intensity duration frequency (IDF) curve from Environment and Climate Change Canada and the 2015 report "Intensity-Duration-Frequency Curve Update for Newfoundland and Labrador" available at [http://www.exec.gov.nl.ca/exec/occ/publications/idf\\_curve\\_2015.pdf](http://www.exec.gov.nl.ca/exec/occ/publications/idf_curve_2015.pdf). If the most recent data in the IDF curve is more than 5 years old, the successful proponent must update the IDF curve with the most recent weather data available.

The climate change condition will include both climate change precipitation increase and climate change sea level rise. The climate change precipitation increase will be defined by the climate change IDF curves presented in the 2015 report "Intensity-Duration-Frequency Curve Update for Newfoundland and Labrador" available at [http://www.exec.gov.nl.ca/exec/occ/publications/idf\\_curve\\_2015.pdf](http://www.exec.gov.nl.ca/exec/occ/publications/idf_curve_2015.pdf) and the report

“Projected Impacts of Climate Change for the Province of Newfoundland & Labrador” available at <http://www.exec.gov.nl.ca/exec/occ/publications/NL%20Climate%20Change%20Projections%20-%20Full%20Technical%20Report.pdf>. If a newer version of “Projected Impacts of Climate Change for the Province of Newfoundland & Labrador” is available at project award then that report will be used.

The climate change sea level rise will be defined by the projections in “Past and Future Sea-Level Change in Newfoundland and Labrador: Guidelines for Policy and Planning”, Geological Survey, Report 10-1, pages 129-141 available at [http://www.nr.gov.nl.ca/mines&en/geosurvey/publications/CR2010/2010\\_Batterson-Liverman.pdf](http://www.nr.gov.nl.ca/mines&en/geosurvey/publications/CR2010/2010_Batterson-Liverman.pdf)

The current development condition will be defined by a land cover/land use analysis to be undertaken as a part of this study. Please see Appendix B “Technical Document for Flood Risk Mapping Studies” for more details.

The fully developed watershed condition will be defined by anticipating changes in runoff values based on the stream/river watersheds being fully developed. The successful proponent must factor in feedback from the Town of Happy Valley – Goose Bay and the community of Mud Lake on the anticipated future developments in the watersheds.

## **3.0 Study Requirements**

### **3.1 Study Area**

The study includes the Town of Happy Valley – Goose Bay and the community of Mud Lake.

The Town of Happy Valley – Goose Bay is the largest population centre in central part of Labrador on the coast of Lake Melville. The town was established by incorporating the former town of Happy Valley and the local improvement district Goose Bay in 1973. The town is home to the largest military air base in northeastern North America. The southern part of the Town of Happy Valley – Goose Bay is in the Churchill River watershed and northern part is in the watersheds of Otter Creek, and seven other small unnamed creeks.

The community of Mud Lake is situated on the south bank of the Churchill River adjacent to the outlet to Lake Melville.

The Churchill River is a river in Newfoundland and Labrador which flows east from the Smallwood Reservoir in Labrador into the Atlantic Ocean via Lake Melville. The river is 856 km long and drains an area of 94,258 sq-km to Lake Melville. A significant portion of drainage area of the river is regulated at

two different locations to generate hydroelectric power. One at Churchill Falls about 335 km upstream and another at Muskrat Falls about 45 km upstream from the mouth of Churchill River. Every year some flooding occurs along the Churchill River, while usually minor, the potential for significant flooding exists, as occurred in December 2006, May 2012 and May 2017.

The flood plains are to be developed for the Town of Happy Valley – Goose Bay and the community of Mud Lake. The study area will include both the Town of Happy Valley – Goose Bay and the community of Mud Lake. The area is shown in Appendix A: Study Area Maps. This includes the mapping of the Churchill River watershed, the Otter Creek watershed, and seven other small unnamed watersheds which encompasses the Town of Happy Valley – Goose Bay and the community of Mud Lake.

Within or adjacent to the study area, previous studies undertaken by WRMD include the:

- The Hydrology of Labrador, June 1997  
[http://www.mae.gov.nl.ca/waterres/reports/hydrology\\_lab/hydrol\\_lab\\_toc.pdf](http://www.mae.gov.nl.ca/waterres/reports/hydrology_lab/hydrol_lab_toc.pdf)
- Flood Risk and Vulnerability Analysis Project, June 2012  
<https://atlanticadaptation.ca/en/islandora/object/acasa%253A446>
- Regional Flood Frequency Analysis for Newfoundland and Labrador Using the L-Moments Index-Flood Method, 2016  
<http://www.mae.gov.nl.ca/waterres/reports/rffa/2014/RFFA%20NL%20and%20Labrador-%20Lu%20Yang%202016.pdf>
- Regional Flood Frequency Analysis for Newfoundland and Labrador - 2014 Update  
<http://www.mae.gov.nl.ca/waterres/reports/rffa/2014/RFFA%202014%20Users%20Guide%20-%2006-05-2015.pdf>
- Independent Review of Flooding at Mud Lake-2017  
[http://www.mae.gov.nl.ca/waterres/flooding/mud\\_lake\\_flooding.htm](http://www.mae.gov.nl.ca/waterres/flooding/mud_lake_flooding.htm)

### **3.2 Study Outline**

Conceptually, a flood risk mapping study consists of three major components: hydrology, hydraulics, and topographic mapping. The hydrologic component involves the determination of the response of a watershed to major climatic events such as rainstorms, rapid snowmelt, or a combination of both. The output from the hydrologic component, in the form of flood flows for specified probabilities, serves as the major input in the hydraulic analysis. The hydraulic analysis will define the response of the selected river reaches to the hydrologic input and take into account flow regulation from Muskrat Falls Hydroelectric Power Plant and any other pertinent factors. The output from the hydraulic analysis, in the form of water surface profiles for the 1:20 and 1:100 AEP is applied to a detailed topographic map to delineate the extent of flood water levels on the flood plain.

To ensure that the flood risk mapping study is carried out accordingly technical guidelines were developed. The guidelines are reproduced within as Appendix B: Technical Document for Flood Risk

Mapping Studies. The proponent must adhere to the document. For additional general guidance, the proponent is to refer to Appendix C: Hydrologic and Hydraulic Procedures for Flood Plain Delineation developed under the Canada-Newfoundland Flood Damage Reduction Program by Environment Canada. All deviations from these documents are to be approved by the Technical Committee and must not result in any increases in costs associated with the completion of this study.

## 4.0 Study Administration

Throughout the study, the successful proponent must:

1. Provide assurance that no extra funds will be expended before obtaining approval for any additional work. All anticipated expenditures are to be included in the initial cost estimate.
2. Structure the project schedule so that the work is completed by March 31, 2019.
3. Develop a work schedule and description of work output such that study milestones and associated outputs may be monitored for both time and costs. Updates are to be provided with monthly progress reports.
4. Provide a project presentation on project award at the project kickoff meeting that describes in detail the work the successful proponent will do to deliver on the tasks in the RFP.
5. Take meeting minutes at the project kickoff meeting and all other meetings that will be held at WRMD's offices in St. John's, NL. Detailed meeting minutes must be provided to the Technical Committee within one week of the meetings.
6. Provide a field survey plan with details for the Technical Committee's review and approval before initiating the field program.
7. Provide progress reports and discuss the various aspects of the investigation with the Technical Committee, as required or requested.
8. Provide progress presentations to the Technical Committee at the following stages:
  - i. When the field work is completed, such as, LiDAR survey, stream cross-section survey, and bridges, culverts, and other hydraulic structures survey.
  - ii. During the development of the hydrologic model.
  - iii. When hydrologic model is completed; successful proponent must provide the model results along with all associated model files and a short report to the Technical Committee for their review and approval
  - iv. During the development of the hydraulic model.
  - v. When hydraulic model is completed; successful proponent must provide the model result along with all associated model files and a short report to the Technical Committee for their review and approval; this will also include the all existing hydraulic structures' capacity evaluation for 20 and 100 year return period flows for existing climate condition and for future climate change condition.

- vi. On completion of the flood plain map delineation and implementation of map to map workflow; successful proponent must provide the flood plain maps in ArcGIS and AutoCAD format for the Technical Committee's review and approval.
  - vii. On the selection of the existing non-proprietary river ice model or during the development of custom river ice model.
  - viii. On development of the flood forecasting service. The successful proponent must provide the model results along with all associated model files and a report to the Technical Committee for their review and approval.
  - ix. On completion of the report, flood risk mapping and flood forecasting service, prior to the submission of the report for review.
9. Provide a field report upon completion of the field program:
- i. The field report must be provided on a USB flash drive in Microsoft Word and Adobe PDF format.
  - ii. The field program must provide sufficient detail of the technical aspects of the field program.
  - iii. The USB flash drive must include all files relevant to the field program.
10. WRMD has developed expertise in ESRI ArcGIS (not AutoCAD). All mapping work must be done in the latest version of ESRI ArcGIS and then it is to be converted to AutoCAD.
11. Provide two (2) printed copies of the draft version of the final report and two (2) printed copies of the technical appendices. Along with the printed copies of the draft report, the successful proponent must provide the following digital documents on USB drive:
- i. The text of the draft report and technical appendices must be in Microsoft Word and Adobe PDF format.
  - ii. 1 in 20 year and 1 in 100 year existing condition and future climate change condition flood plain mapping in ESRI ArcGIS file geodatabase and AutoCAD format; provide velocity, inundation depth, and hazard map in ESRI Raster file format and provide all hydraulic structures, such as, bridges, culverts database in ESRI ArcGIS file geodatabase format.
  - iii. Existing condition and future climate change condition flood plain mapping in geotiff format at reasonable viewing scale (exact scale to be determined based on mapping extents).
  - iv. Hydraulic capacity evaluation of all bridges and culverts with respect to 1 in 20 year and 1 in 100 year existing condition and future climate change condition scenarios.
  - v. LiDAR survey data, DEM derived from LiDAR survey, aerial photograph, specified contour data derived from LiDAR survey, DEM used for hydrologic model. All data must be in ESRI compatible file format.
  - vi. All input and output files for all computer models, HEC-HMS, HEC-GeoHMS, HEC-RAS, and HEC-GeoRAS used in the study. All documentation required to operate the models must also be provided.
  - vii. All input and output files along with Map to Map Workflow; any issues applying Map to Map Workflow must be resolved before submitting the draft final report.

- viii. Provide all technical drawings and graphics in AutoCAD file format and as an ESRI ArcGIS file geodatabase.
12. The successful proponent must provide ten (10) printed copies of the final report and ten (10) copies of the technical appendices. The successful proponent must make a realistic estimate of the printing cost for the final report based on the anticipated number of pages. No claim for extra printing costs will be accepted. In addition to the printed copies of the final report:
  - i. The text of the final report and technical appendices must be on a USB flash drive in Microsoft Word and Adobe PDF format.
  - ii. While some products are digital, these must also be printed and included in the report or its appendices. The report and the technical appendices must be standalone in the sense that it does not reference or rely upon material that is not contained within it.
  - iii. All input and output files for all computer models used in the study and all documentation required to operate the models must be provided on the USB flash drive.
  - iv. All technical drawings and graphics must be provided on the USB flash drive in AutoCAD file format and as an ESRI ArcGIS file geodatabase.
  - v. A complete digital copy of all data, information, and files used in the study.
13. The proponent must provide a detailed PowerPoint presentation outlining all steps of the study, including: the processes followed, the software used, the field program, the methods used, the assumptions made, products developed, and the recommendations made. The presentation must use relevant photos, graphics, maps, and work flow charts; it must not exceed 100 slides. The presentation, or a portion of it, will be used by WRMD for public information sessions, conference presentations, and will be made available on its website.
14. Throughout the study, the proponent must comply with all applicable federal, provincial, and municipal legislation, regulations, and by-laws including but not limited to the most current version of applicable occupational health and safety requirements.
15. The flood risk maps and associated reports will be made publicly available by the Technical Committee through the WRMD's webpage on flood risk mapping (<http://www.mae.gov.nl.ca/waterres/flooding/frm.html>).

## 5.0 Technical Committee

A Technical Committee will be responsible for the technical supervision and overall administration of the study. The Manager of the Water Rights, Investigations, and Modelling Section will be the Project Manager; the Senior Engineer of the Water Rights, Investigations, and Modelling Section will be the Project Engineer; the Environmental Engineer, the Senior Environmental Scientist and the Environmental Scientist of the Water Rights, Investigations, and Modelling Section will be Technical Committee members. Additional members may be added to the Technical Committee.

The successful proponent must report to the Project Engineer regularly and maintain liaison with the Project Engineer on all aspects of the study. If needed, the successful proponent will be required to attend meetings with the Technical Committee to discuss the technical aspects of the study. The meetings are to be held at Provincial Government offices in St. John's, NL.

The successful proponent must provide monthly progress reports to the Project Engineer. Clarification may be requested by the Project Engineer on any item in the progress report. The successful proponent will be expected to respond to any reasonable request of the Project Engineer in a thorough and diligent manner.

Any deviation in the methodology, scope or assigned staff for the study described in the successful proponent's proposal must be reviewed and approved by the Technical Committee. The Technical Committee will be available to provide, when possible, technical advice and reasonable assistance to the successful proponent.

## **6.0 Financial Consideration**

The Study budget is \$1,000,000 (not including HST). Submitted proposals with a budget above \$1,000,000 (not including HST) will not be considered. Under no circumstance shall the total project cost exceed this amount. The study will be undertaken for the fiscal year 2018-19. An itemized study budget shall be submitted by the proponents with their proposal as per the Mandatory Proposal Requirements, Section 9.0.

The successful proponent must keep proper records of the work performed and expenses incurred during the study. Progress reports, that relate progress to the work program and output schedule, must be submitted with the invoices.

The successful proponent shall submit invoices for amounts payable to the successful proponent, subject to a work schedule and description of work output, as required by the terms of a formal contract with the Department of Municipal Affairs and Environment (MAE). Payments will be made on a monthly schedule based on milestones. Additional detail governing the contract and study are provided within *Appendix E: Additional Terms and Conditions of Final Contract*.

## **7.0 Submission of Proposals**

### ***7.1 Inquiries and Communication***

All inquiries and requests for clarification are to be directed in writing and addressed to:

Mohammad Khayer, M.Eng., P.Eng.

Senior Engineer, Water Resources Management Division  
Department of Municipal Affairs and Environment  
4th Floor, West Block, Confederation Bldg.  
PO Box 8700, St. John's, NL, A1B 4J6  
Telephone: (709) 729-1229  
Email: [mohammadkhayer@gov.nl.ca](mailto:mohammadkhayer@gov.nl.ca)

Written inquiries and requests for clarification will be accepted up to five (5) working days prior to the proposal submission deadline date. Inquiries and requests for clarification received after this date will not be addressed. Verbal information or representations shall not be binding upon MAE. Only written changes, alterations, modifications or clarifications are binding. In order to be valid all such changes, alterations, modifications or clarifications shall be issued in the form of addenda and all such addenda shall become a part of this RFP.

All addenda that have been issued in relation to this RFP will be available on the Public Procurement Agency website at [www.gpa.gov.nl.ca/availabletenders.stm](http://www.gpa.gov.nl.ca/availabletenders.stm). Proponents can either access the website at their own discretion for addendum, or may use the registration process available on the site to receive notification of addendum. Proponents are responsible for ensuring that they have received all addenda pertaining to this RFP and shall be deemed to have received same through their submission of a proposal in response to this RFP.

## ***7.2 General Instructions***

**Five (5)** printed and **five (5)** digital copies (in Adobe PDF format on a USB flash drive, CD-ROM or DVD-ROM) of the proposal are to be submitted to:

Mr. Haseen Khan, P.Eng.  
Director, Water Resources Management Division  
C/o Public Procurement Agency  
30 Strawberry Marsh Rd.  
St. John's, NL, A1B 4R4

- a) Proposals must be received at the address above no later than 3:00pm NDT on the date of the proposal submission deadline.
- b) Proposals received and not conforming to the general instructions will not be considered.
- c) Proposals received via facsimile machine or e-mail will not be accepted.
- d) Proponents are entirely responsible for any costs or expenses related to the preparation and submission of proposals.

- e) After the closing time on the proposal submission deadline date, all proposals received become the property of MAE.
- f) The laws of the Province of Newfoundland and Labrador shall govern this proposal and any subsequent contract resulting from this proposal.
- g) The Province of Newfoundland and Labrador reserves the right to cancel this solicitation at any time. The lowest, or highest ranking, or any bid may not necessarily be accepted.

## 8.0 Proposed Study Schedule

The following table provides the timeframe given for the completion of this study:

**Table 1: Study Timeframe**

Event	Date
RFP Issue Date	April 25, 2018
Proposal Submission Deadline Date	May 22, 2018
RFP Public Opening	10:00 AM NDT, May 23, 2018
Contract Award Date (estimated)	June 7, 2018
Consulting Services Start Date (based on award date)	June 14, 2018
Draft Final Report Submission Date	January 2, 2019
Final Report Submission Date	March 1, 2019
Contract Completion Date	March 1, 2019
Submission of Invoices Deadline Date	March 15, 2019

Acceptance of the contract after the estimated contract award date is acceptance of the study schedule. Under no circumstance will the study be extended beyond March 31, 2019.

After the close of RFP submission deadline on May 22, 2018, the received proposals will be opened on May 23, 2018 at 10:00 AM NDT at;

Water Resources Management Division  
 Department of Municipal Affairs and Environment  
 4<sup>th</sup> Floor, Confederation Building, West Block  
 St. John's, NL.

(Please call Mohammad Khayer at (709) 729-1229 to escort you into the Confederation Building)

A 20% holdback will be applied.

## 9.0 Mandatory Proposal Requirements

The Technical Committee will consider only proposals meeting the following mandatory criteria:

1. **Five (5)** printed and **five (5)** digital copies (in Adobe PDF format on a USB flash drive, CD-ROM or DVD-ROM) of the proposal received on time.

2. **Proposed methodology:** The proposal cannot simply list the RFP tasks without any details on the proponent's proposed methodology. The format and contents of the proposal must provide sufficient detail so that a technical evaluation of the proposal can be made. The proposed methodology must be properly presented to provide a clear picture of the level of effort and appropriateness of the methodology.
3. **Organization chart:** The chart must indicate the names of the individuals to be involved in the study and the lines of responsibility. The Project Manager must be a water resources engineer with at least ten years of experience in water resources projects. CV's of all project staff must be provided.
4. **Work schedule:** The work scheduled is to be in compliance with the proposed study schedule.
5. **Non-proprietary model(s):** For the hydrologic and hydraulic analysis, the proponent is to use the standard non-proprietary hydrologic and hydraulic models listed in this RFP (HEC-HMS, HEC-GeoHMS, HEC-RAS, and HEC-GeoRAS). Only where this is not possible, the proponent may use proprietary models but must provide a working copy with supporting files to the Technical Committee.
6. **Assumptions:**
  - i. All assumptions made by the proponent throughout the proposal must be summarized again in one section of the proposal.
  - ii. Any proposed deviation from Technical Document for Flood Risk Mapping Studies and/or the Hydrologic and Hydraulic Procedure for Flood Plain Delineation must also be summarized in one section of the proposal. If there are no deviations this must be categorically stated in this section of the proposal. If deviations are noted elsewhere in the proposal but not in this section, the technical committee will not accept the deviations and the work will have to be undertaken as outlined in the RFP.
7. **Estimate of costs:** The cost estimates must reflect the level of effort. The proponent is to include and identify all anticipated expenditures in table 2 (items must not include tax (HST)). All prices quoted in the proposal must be in Canadian funds and are not to include tax (HST). It is imperative that the proponent clearly provide the details of any additional anticipated costs. This includes costs due to uncertainties, inadequate information at the time of submission of the proposal, or any other reason.

**Table 2: Cost Proposal**

<b>Budget Item</b>	<b>Cost</b>
Information review	
Field Program	
LiDAR and Aerial Photography	
Remote Sensing	
Hydrologic Investigations and modelling	

Hydraulic Investigations and modelling	
Climate Change and Sensitivity Analysis	
Flood Risk Mapping Preparation	
Map to Map Workflow	
Development, testing and commissioning of Flood Forecasting Service	
Report Preparation and Printing	
Study administration and expenses	
Additional anticipated costs	
<b>Total (not including tax)</b>	

8. Provide **3 (three) examples** of work related to the flood risk mapping study and flood forecasting service demonstrating experience in successfully completing flood risk mapping and flood forecasting studies. Please provide details of what the project budgets were and were the projects completed on time and on budget.
9. Provide 3 references on the 3 (three) examples of work related to the flood risk mapping study and flood forecasting service demonstrating experience in successfully completing flood risk mapping and flood forecasting studies.
10. Proposals must clearly show the complete company name, nearest office location to the study area, and name and telephone number of primary contact person(s).
11. Provide details of successfully completed flood risk mapping and flood forecasting studies, what the project budgets were, and were the projects completed on time and on budget. (Proponent to provide 3 references).
12. A digital copy of the proposal must also be submitted in the portable document format (PDF) on a USB flash drive, CD-ROM or DVD-ROM.
13. Proposals must contain a copy of a Letter of Clearance from the Newfoundland and Labrador Workplace Health Safety & Compensation Commission.
14. All proposals must remain valid for a period of at least 120 days after the date of closing.

## 10.0 Evaluation Procedure

As flood risk mapping studies are technical in nature, the technical quality of the proposal, the experience of the study team, and the total cost of the study each will be important criterion in evaluating and selecting the successful proponent to undertake the study. The Technical Committee will use the evaluation criteria and weighting factors, identified in the table below to evaluate the proposals submitted:

**Table 3: Evaluation Criteria**

Item	Evaluation Criteria of the proposal in response to the RFP
<b>1.0</b>	<b>Quality of Submission Relative to outline in RFP (50%)</b>
1.1	All tasks identified in the RFP addressed comprehensively. (12.5%)
1.2	Detailed insight specific to this study and study area. (12.5%)
1.3	Specific information/details provided to assess and rank each proposal. (12.5%)
1.4	Strategy for executing all tasks identified in the RFP. (12.5%)
<b>2.0</b>	<b>Relevant Experience (25%)</b>
2.1	Project Manager is a water resources engineer with at least 10 years' experience in flood risk mapping and flood forecasting study management. (6.25%)
2.2	Project team experience in flood risk mapping and flood forecasting. (6.25%)
2.3	Demonstrated experience in ESRI ArcGIS, Arc-Hydro, HEC-GeoHMS and HEC-GeoRAS. (6.25%)
2.4	Demonstrated experience in successfully completing flood risk mapping and flood forecasting studies. (6.25%)
<b>3.0</b>	<b>Cost Proposal (25%)</b>

## 11.0 Disclosure of Respondent Information

Government of Newfoundland and Labrador (“GNL”) is subject to the Newfoundland and Labrador *Access to Information and Protection of Privacy Act, 2015* (“ATIPPA”), which gives people the right of access to records in the custody or control of GNL, with certain exceptions.

Once a proposal is submitted to GNL, it is subject to ATIPPA, and may be released, in whole or in part, further to an access to information request. The ATIPPA can be accessed as follows: <http://www.atipp.gov.nl.ca/>.

By submitting a proposal, the Proponent represents and warrants to GNL that the Proponent has complied with applicable laws, including by obtaining from each person any required consents and authorizations to the collection of information relating to the individual and to the submission of such information to GNL, and the use, distribution and disclosure of such information as part of the Proposal for the purposes of, or in connection with, this RFP and the selection process. The procurement is subject to trade agreements, if applicable.

The financial value of a contract resulting from this procurement process will be publicly released as part of the award notification process.

The bidder agrees that any specific information in its bid that may qualify for an exemption from disclosure under subsection 39(1) of the ATIPPA has been identified. If no specific information has been

identified it is assumed that, in the opinion of the bidder, there is no specific information that qualifies for an exemption under subsection 39(1) of the ATIPPA.

## **12.0 References**

Previous flood Risk Mapping Studies undertaken by WRMD are publicly available on its website:

<http://www.mae.gov.nl.ca/waterres/flooding/frm.html>

## **Appendix A: Study Area Maps**

Figure 1: Churchill River Watershed

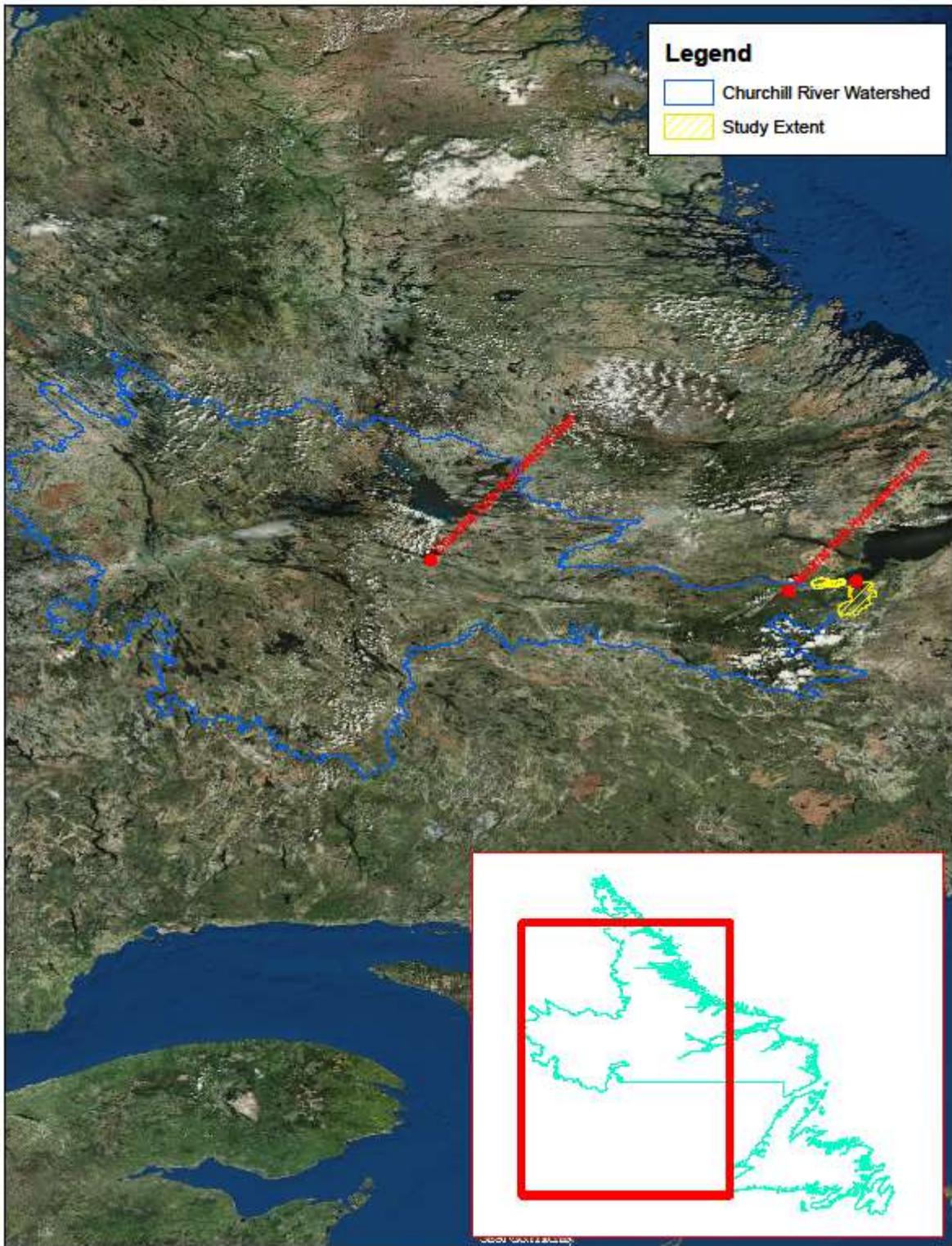


Figure 2: Study Area



## **Appendix B: Technical Document for Flood Risk Mapping Studies**

**Technical Document for  
Flood Risk Mapping Studies**



Water Resources Management Division  
Department of Municipal Affairs and Environment  
Government of Newfoundland and Labrador

Issued for 2018-19

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## 1.0 Study Outline

This document was prepared by the Water Resources Management Division (WRMD), Department of Municipal Affairs and Environment (MAE). The document is to guide the successful proponent through the hydrologic, hydraulic, and mapping components of the study. It is the intent of the Technical Committee that the successful proponent adheres to the document. Additional direction will come from the following:

- The technical guidelines, *Appendix C: Hydrologic and Hydraulic Procedures for Flood Plain Delineation*, developed under the Canada-Newfoundland Flood Damage Reduction Program by Environment and Climate Change Canada.
- Previous Flood risk mapping studies that are publicly available on the Department's website. The Technical Committee recommends that the successful proponent refer to recent studies to ascertain the Technical Committee's expectations for this study. All studies are available at <http://www.mae.gov.nl.ca/waterres/flooding/frm.html>.

Where deviation in methodology is required or there is uncertainty in the appropriate approach, it is required that the successful proponent contact the Technical Committee for approval and clarification. Deviation from Technical Document for Flood Risk Mapping Studies and/or the Hydrologic and Hydraulic Procedure for Flood Plain Delineation must also be summarized in one section of the proposal. All instances of such must be clearly indicated in the final report.

## 2.0 Information Review

### 2.1 Collection

As part of the study, the successful proponent must carry out a thorough review of existing data and information to obtain an understanding of the flooding problem in the study area and the factors responsible for past floods. This will involve the collection of data and information including; but not limited to:

- Streamflow data collected under the Canada - Newfoundland Water Quantity Surveys Agreement.
- Meteorological data collected under the Canada - Newfoundland Climate Stations and Programs Agreement.
- Meteorological and streamflow data collected by third parties.
- Records of historical floods from various information sources including the WRMD's updated Flood Events Inventory.
- Drawings for any hydraulic control structures in the study area, a starting point is the Dam Inventory Database maintained by WRMD and, for this study, Churchill Falls and Muskrat Falls Hydroelectric Power Generation Authority.
- Community scale (1:2,500) topographical mapping.
- Operating rules and curves from dam owners to determine how these structures would operate during high flow events.
- Aerial/satellite photographs.
- Mapping data.
- Lake and sea levels.

- Stream cross sections.

The successful proponent is required to make maximum use of all available sources of data and information, including existing hydrotechnical studies. It is the responsibility of the successful proponent to collect all data and information and ensure it is not outdated and that it is still valid for use in this study.

Data and information may be available from some or all of the following sources:

- A field program
- Dam operators
- Environment and Climate Change Canada
- Meetings with municipal officials and residents
- Memorial University of Newfoundland
- Municipal Council files
- Newspapers, television/radio stations, and websites
- Various government departments, including MAE, and Transportation and Works
- Water Survey of Canada

Water level and streamflow records are to be obtained from the Water Survey of Canada for the streams and tributaries in both the region and the watershed. Stage-discharge curves must also be obtained. Any hydrometric data used by the successful proponent shall be of suitable accuracy and reliability to meet the needs of this study. Liaison should be maintained with Water Survey of Canada regarding the use of data obtained by them at the hydrometric stations and the collection of hydrometric data by the successful proponent.

The successful proponent must contact every community in the study area and obtain a detailed understanding of flooding issues in the community along with a understanding of the future development plans for each community. The successful proponent will contact the communities directly with an introduction letter from WRMD. The successful proponent must keep a record of the communication with each community. The successful proponent must enquire if any of the communities have undertaken any flood risk mapping or modelling studies that can be of use in the current study. On completion of the flood risk mapping the successful proponent must have the maps reviewed by the communities to identify any obvious issues.

All field surveys and data compilation must be carried out using metric units of measurement. In the final report and its appendices, all data, equations, calculations and results shall be given using the International System of Units (SI) and presented using the Canadian standards for writing SI units and numbers. All data converted from other units of measurement shall be identified with a note identifying the conversion factors used.

The successful proponent must obtain operating rules and curves for any streams in the study area with regulated flows. The information is to be used to determine how these structures would operate during high flow events. This information must be incorporated into the hydrologic and hydraulic modelling components of the study and must be reflected in the final flood risk mapping. This information may be obtained from the owner of the dams. All diversions, if any, have to be identified and their effect on the watersheds and flooding clearly outlined and discussed.

## **2.2 Analysis**

### **2.2.1 Data**

The successful proponent must review all pertinent data and undertake office studies as necessary to fill data voids. It will be the responsibility of the successful proponent to ensure that all data and information either collected by them or provided by other agencies are of acceptable accuracy for the purpose of the study.

- Further review and analysis must be done by the successful proponent to detect any errors or determine any necessary adjustments to the data.
- In the final report or its appendices, references must be provided for all published data used in the study. Also, any data derived for the study must be presented.
- The methods and conditions under which the data were collected and used must be discussed.

The successful proponent is to ensure all information that is to be used as inputs in the study are based on the most-up-to-date data and follow any guidelines or standards that are relevant. This is to be achieved through a thorough review and analysis of all available datasets. Where it is technically acceptable to do so, the successful proponent is to update the information. If new data is available from Environment and Climate Change Canada, or any third party, the intensity-duration frequency (IDF) curve should be updated. The current climate condition will be defined by the latest intensity duration frequency (IDF) curve from Environment and Climate Change Canada and the 2015 report “Intensity-Duration-Frequency Curve Update for Newfoundland and Labrador” available at [http://www.exec.gov.nl.ca/exec/occ/publications/idf\\_curve\\_2015.pdf](http://www.exec.gov.nl.ca/exec/occ/publications/idf_curve_2015.pdf). Also, if the most recent data in the IDF curve is more than 5 years old, the successful proponent must update the IDF with the most recent weather data available.

The climate change condition will include both precipitation increase and sea level rise. The climate change precipitation increase will be defined by the climate change IDF curves presented in the 2015 report “Intensity-Duration-Frequency Curve Update for Newfoundland and Labrador” available at [http://www.exec.gov.nl.ca/exec/occ/publications/idf\\_curve\\_2015.pdf](http://www.exec.gov.nl.ca/exec/occ/publications/idf_curve_2015.pdf) and the report “Projected Impacts of Climate Change for the Province of Newfoundland & Labrador” available at <http://www.exec.gov.nl.ca/exec/occ/publications/NL%20Climate%20Change%20Projections%20-%20Full%20Technical%20Report.pdf>. If a newer version of “Projected Impacts of Climate Change for the Province of Newfoundland & Labrador” is available at project award then that report will be used.

### **2.2.2 Historical Flooding**

The successful proponent is to compile a comprehensive listing of flooding, in the study area, going back to 1900. This is to be summarized in the report. The successful proponent will enter these records into the WRMD’s Flood Events Inventory Excel Spreadsheet which will be provided by WRMD after the study is awarded. Source documents are to be scanned by the successful proponent and provided with the final report.

WRMD’s Flood Events Inventory and an analysis of its records are available at <https://atlanticadaptation.ca/en/islandora/object/acasa%253A446>.

Based on the compiled information, the successful proponent is to then evaluate the significance of the various factors contributing to flooding in the study area. The successful proponent is to consider all collected data and the limitations in the database and other constraints. The successful proponent is to design a strategy to produce the required flood profiles considering the following factors:

- Coastal Flooding: Tides, wind, waves, and freshwater inflow combine in a complex manner to produce high water levels and flooding. It will be necessary to consider sea level and storm surge in the determination of the 1:20 and 1:100 AEP flood profiles.
- High Flows: Determine the significance of runoff in contributing to the 1:20 and 1:100 AEP flood profiles.
- Ice or Debris Jams: The appropriate analyses of river ice systems are complex and require specialized expertise. The study must address this factor and include it in the determination of the 1:20 and 1:100 AEP flood profiles.
- Meteorology: It will be necessary to identify and evaluate the influence of various meteorological factors alone, and in combination, to make a reasonable forecast of the possibility of flooding.
- Morphology: Rivers and their tributaries have morphological features, such as rapids and constrictions, which make the area susceptible to ice accumulation and blockages.
- Physiographic and Cultural Influences: The influence on flooding of all natural and man made features of the study area must be noted. Factors to be considered include, but are not limited to: structures across the river, reservoirs, lakes, infilling, existing dykes and road bed elevations, changes which would affect the flood plain, particularly changes which would affect ice formation and movement, must be identified and their impact evaluated.

### **3.0 Field Program**

The successful proponent is to design, coordinate, and manage a field program for collection of data and information which may be required to:

- Establish the historical flood levels.
- Calibrate and verify the model(s) taking into full consideration the availability and quality of existing data.

#### **3.1 Ground Survey**

- The field program must include ground surveys to determine the nature and extent of the features which affect the exchange of water between the river and the flood plain.
- The successful proponent must relate all surveyed data including cross sections, measured water data, simulated water surface profiles, and high water marks to the Geodetic Survey of Canada geodetic control datum.
- All files are to be provided in provincial MTM projections (NAD83).
- The successful proponent must use standard surveying equipment and methods.

##### **3.1.1 Cross Sections and Hydraulic Structures**

- Cross sections must be surveyed at all locations where there can be expected changes in discharge, slope, shape, or roughness. The cross sections must include the below water portion of the channel.

- The whole river reach below the Muskrat Falls dam up to the outlet to Lake Melville is to be surveyed to consider for ice freeze up and ice breakup flooding analysis in the Town of Happy Valley – Goose Bay and the community of Mud Lake.
- The successful proponent should also develop a stage/discharge/storage relationship for Muskrat Falls dam operation.
- Sufficient surveyed sections must be obtained to adequately define representative river geometry and the interval between them should be such that the assumption of uniform flow within a section should be reasonable.
- All cross sections must be photographed. Water levels, flows where possible, and time of measurement must also be recorded for each cross section.
- Sufficient points along each cross section must be established to accurately define the geometry of the cross section.
- The successful proponent will be responsible for surveying the river cross sections extending to the full extents of the flooding of the main channel and any tributaries that are likely to experience backwater effects.
- The successful proponent must ensure adequate overlap with the LiDAR data, surveyed cross sections are to extend a minimum of five metres from the river's edge on either side of the river bank.
- To aid with HEC-RAS modelling, additional cross sections can be derived from the LiDAR data. The successful proponent can augment surveyed cross sections with sections derived from LiDAR data.
- A minimum of two surveyed cross sections upstream and two downstream must be obtained at all hydraulic structures.
- All hydraulic structures must also be surveyed, photographed and captured in the hydraulic model. The photograph should be attached in the HEC-RAS model.
- In the final report or its appendices, the successful proponent must present a table of all the hydraulic structures summarising their current flow capacity, condition, and indicate whether the structure will be overtopped during floods associated with
  - the 1:20 and 1:100 AEP for current climate and current development conditions
  - the 1:20 and 1:100 AEP for climate change and current development conditions

Overtopped structures should be flagged in red.

- In the final report or its appendices, the successful proponent must present carefully drawn and well identified cross sections with photos. The end points of all cross sections should be described and the positions of all cross sections plotted on available maps.

## **4.0 Watershed Characteristics**

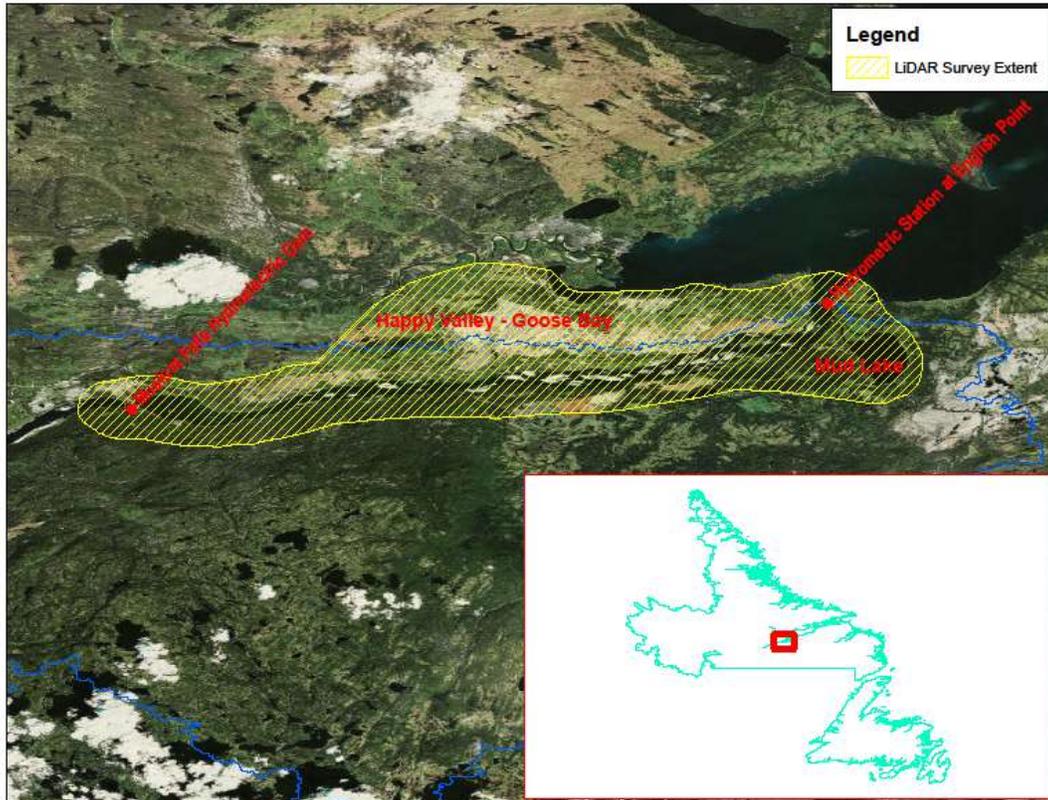
### **4.1 Topography**

The successful proponent is to create an accurate digital elevation model (DEM) of the flood watershed for use in the hydrologic modelling component of the study. The DEM is to be based on the best available data. The 1:50,000 Canadian Digital Elevation Data (CDED) can be used.

For the hydraulic modelling component of the study, the successful proponent is to create an accurate DEM of the entire flood plain using only LiDAR. LiDAR data is to be acquired from Muskrat Falls dam to the outlet of Churchill River at Lake Melville maintaining a 3.0 km buffer on both side of the Churchill River. LIDAR data is also to be collected for the watershed of Otter Creek and seven other small unnamed streams situated on the northern part of the Town of Happy Valley – Goose Bay and the

watershed of Mud Lake outlet tributary to Churchill River which encompasses the community of Mud Lake as shown in Figure 1. All collected and processed data will be the property of the WRMD. The following figure is to clarify the data source for DEM.

Figure 1: DEM Data



#### 4.1.1 Flood Plain DEM

The successful proponent will be responsible for undertaking, acquiring, processing and delivering LiDAR mapping of the entire above-water floodplain. Described below are the LiDAR requirements:

- The successful proponent must include an adequate buffer on the perimeter of the entire flood plain to ensure that the entire area of the floodplain is fully collected.
- Federal Airborne LiDAR Data Acquisition Guideline, Version 1.1, 2017 is the reference guideline for LiDAR survey. LiDAR survey specifications for the Flood Risk Category – High, specified in Table B2 of the Federal Airborne LiDAR Data Acquisition Guideline, Version 1.1, 2017 will have to be met.
- The LiDAR accuracy will be of sufficient accuracy to produce 0.25 meter contours.
- The successful proponent will be responsible for ensuring that LiDAR and surveyed data are in agreement, and field verification of the LiDAR mapping against the surveyed data is required. A report on this verification must be included in the report appendices.
- The horizontal and vertical accuracy of the collected data must meet the stated sensor accuracy claims. The successful proponent is to ensure that accuracy statements (manufacturer technical data) and examples of previous work demonstrating accuracy are adequate.

- The successful proponent must ensure that the vertical and horizontal accuracy of the LiDAR data is sufficient to create a DEM or TIN, to be used for plotting 1:20 and 1:100 AEP flood lines and for inundation mapping.
- Every effort should be made to configure the LiDAR data collection to maximize vegetation penetration to produce high point density returns from the ground. LiDAR flight lines should be planned and undertaken to avoid data gaps. Data gaps are not acceptable. For the purpose of simultaneously collecting aerial photography, LiDAR is to be collected during cloud-free conditions.
- The successful proponent must clearly document the match between the LiDAR data and ground-surveyed sections in a technical appendix to the report.
- The successful proponent must follow the “Federal Airborne LiDAR Data Acquisition Guideline” available at <https://doi.org/10.4095/306354>. Any deviations must be cleared by the Technical Committee

Following completion of the LiDAR component of the study, the successful proponent must provide the Technical Committee with:

- A bare earth DEM in LAS, ACSII (delimited x,y,z,i), and Esri grid format. The bare earth DEM should be stripped of at least 90% of vegetation/features.
- Vertical contours at 0.25 meter intervals in Esri Geodatabase and as AutoCAD DWG Files.
- A survey and accuracy report detailing methodology and results of data collection and processing. Report should content detail of the project boundary, aircraft specification, survey flight line, base station and control GPS receivers, horizontal and vertical reference coordinate system, GEOD model used, data coverage, LiDAR systems, LiDAR processing, aerial photography system, aerial photography processing, GPS validation summary both for static and kinematic, validation of vertical and horizontal accuracy of the survey, etc. The report should be a complete standalone document (to be included in appendices of the report) that can be used by anyone using the LiDAR data.
- Indexes, LiDAR index and ortho index, are to be provided for all delivery data types using the same index/tiling scheme.

#### **4.1.2 Flood Watershed DEM**

In development of the flood watershed DEM, the successful proponent must use the best available topographical data. The data is to be, at a minimum, obtained from CDED.

The successful proponent will be responsible for verifying and delineating accurate flood watershed boundaries after appropriate ground truthing. In particular, all water control structures, such as dams, spillways, diversions, etc., have to be identified and their effect on the watersheds and flooding clearly outlined and discussed.

#### **4.2 Flood Plain: Aerial Photography**

During the LiDAR acquisition, the successful proponent will also be responsible for acquiring high-resolution ortho-photography. The primary purpose of the aerial photography is for use as backdrop/base mapping for the flood risk mapping. The successful proponent must ensure that sufficient imagery is obtained for these purposes.

- The aerial photography must cover the entire developed area that is surrounding the flood plain.

- To ensure the entire developed area is collected, the successful proponent should include a buffer on the perimeter of the developed area. The successful proponent must ensure the Trans Canada Highway is shown on the flood risk maps, if any exits within the study area. This helps locations for flood plain management.
- White space on the flood risk maps resulting from uncollected aerial imagery will not be accepted.
- All photography should be acquired in cloud-free conditions.
- All photography is to be ortho-rectified with the LiDAR data that was collected.
- All imagery is to be colour balanced.
- For small areas, imagery is to be provided as a single mosaic.
- All provided imagery is to be in GeoTIFF format.
- For larger areas, provided imagery is to be tiled. Tiled data will be in one-square kilometre (1kmx1km) tiles. Tile numbering will start at min x, max y (upper left) and end at max x, min y (lower right) (see below). Starting tile grid coordinates will be rounded to nearest 1000 meters (x and y).

1	2	3
4	5	6

### 4.3 Flood Watershed: Curve Number

For the hydrologic modelling component of the study, it is the intent of the Technical Committee that the successful proponent uses the Curve Number (CN) method developed by the (former) U.S. Soil Conservation Service (SCS). The CN is based on soil type, land cover, and Antecedent Runoff Conditions (ARC). A higher CN indicates a higher runoff potential. The CN numbers should be generated using the following procedure:

#### Soil Type

Soil type is to be based on soil surveys from the National Soil Data Base (NSDB). NSDB soil classes are:

Soil Type	Class
Very rapidly	VR
Rapidly	R
Well	W
Moderately Well	MW
Imperfectly	I
Poorly	P
Very poorly	VP

NRCS soil types have been defined as follows:

Soil Type	Description
A	These soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission.
B	These soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	These soils have low infiltration rates when thoroughly wetted and consist chiefly of soils

	with a layer that impedes downward movement of water and soils with moderately fine to fine texture.
D	These soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material.

The following table correlates soil classes from the NSDB to the soil types used by the NRCS:

Soil Type*	Class	Type
Very rapidly	VR	A
Rapidly	R	A
Well	W	A
Moderately Well	MW	A
Imperfectly	I	B
Poorly	P	C
Very poorly	VP	D

Where soils data does not exist, assume the soil type is “B”.

### **Land Cover**

Land cover created with high-resolution imagery is to be divided into the following classes:

WRMD Land Cover	Examples
Forest	Forests.
Residential	Small homes and subdivisions.
Commercial	Large building and parking lots, schools, shopping malls, industries, plants, etc.
Deforested areas	Patches of treed and un-treed areas adjacent to forest roads, areas with open green fields in forested zones.
Barren land	Non-vegetated areas.
Fields/pastures/open spaces	Agricultural areas, farmer fields; parks, cemeteries, golf courses, etc. within urban area, low lying grass areas near airport, vegetated areas.
Swamps/wetlands/waterbodies	Swamps; wetlands; lakes, ponds, and rivers.
Unclassified	No data, cloud, shadow, snow/ice.

### **Antecedent Runoff Conditions (ARC)**

Assume ARC condition III

### **Curve Number**

NL’s land cover classes have been correlated to those of the NRCS. Land cover classes created with high resolution imagery, using ARC III, are provided in the following table:

Land Cover	A	B	C	D
Forest	50	74	85	89
Residential	78	88	94	96

Commercial	96	97	98	98
Deforested areas	75	87	92	94
Barren land	89	94	97	98
Fields/pastures/open spaces	59	78	88	91
Swamps/wetlands/waterbodies	100	100	100	100
Unclassified	NA	NA	NA	NA

The successful proponent will be required to collect and analyze data on land cover and soil type. The successful proponent is to estimate subbasin CNs using the most current version of published values. There must be a discussion on the initial soil conditions used. The CN information is to be provided as a GIS file along with tabular results and graphed. A map of the subbasin CNs must be included in the final report or technical appendices.

### 4.3.1 Flood Watershed: Land Cover

The successful proponent must undertake a new land cover classification using Sentinel-2 imagery, which is freely available from the European Space Agency (<https://scihub.copernicus.eu/>). All imagery must be acquired during the peak of the vegetation period (generally late July to mid-September) and must be as recent as possible. All images should be collected within the same year and shall be screened for minimum cloud cover. In the case of missing data or data quality issues over the area of interest, the Sentinel-2 coverage can be complemented with other suitable data sources available to the successful proponent (e.g. LANDSAT-8 imagery). The extraction of land cover categories shall include appropriate methods for atmospheric and geometric correction. All land cover information extracted from satellite imagery shall be compatible with Canadian National Topographic System (NTS) 1:50,000 topographic maps.

Aerial photography, where it was collected, may be used for the land cover analysis. Once the satellite imagery is collected and used for land cover classification, it will become the property of the WRMD and successful proponent has to submit the imagery and resulting land cover to the WRMD with the final report.

For the land-cover analysis, the successful proponent is to follow established remote sensing standards and practices. Land cover created is to be divided into the following classes:

WRMD Land Cover	Examples
Forest	Forests.
Residential	Small homes and subdivisions.
Commercial	Large building and parking lots, schools, shopping malls, industries, plants, etc.
Deforested areas	Patches of treed and un-treed areas adjacent to forest roads, areas with open green fields in forested zones.
Barren land	Non-vegetated areas.
Fields/pastures/open spaces	Agricultural areas, farmer fields; parks, cemeteries, golf courses, etc. within urban area, low lying grass areas near airport, vegetated areas.
Swamps/wetlands/waterbodies	Swamps; wetlands; lakes, ponds, and rivers.
Unclassified	No data, cloud, shadow, snow/ice.

The procedures used for the land cover analysis are to be comparable to recent flood risk mapping studies completed for WRMD and available on its webpage. The procedures must be clearly documented in the report or its technical appendices. It is the intent of the Technical Committee to use these procedures to monitor long-term changes in land cover and for undertaking other flood risk studies.

### **4.3.2 Flood Watershed: Soil Type**

The following are the requirements for soil classification:

- The successful proponent is to use the best available geological survey of the area. Soil type information for the area may be obtained from the National Soil Data Base (NSDB) available from Canadian Soil Information Service (CanSIS), Agriculture Canada.
- The soil type information is to be provided as a GIS file along with tabular results and graphed. A map of the soil types in the watershed must be included in the final report or technical appendices.

## **5.0 Hydrology**

The successful proponent will be required to undertake both a stochastic and deterministic (hydrologic modelling) approach in the estimation of the 1:20 and the 1:100 AEP for current condition and climate change condition. The successful proponent is to compare the results of each method and then, based on using good engineering judgement and in consultation with the Technical Committee, the successful proponent is to provide an estimate of the 1:20 and the 1:100 AEP for current condition and climate change condition. These values are to be used in the hydraulic modelling.

### **5.1 Stochastic Analysis**

At least two applicable statistical methods, including a flood frequency analysis and a regional flood frequency analysis, are to be undertaken by the successful proponent. In these estimates, the successful proponent is to consider the effects of regulated flows, the assumption of a stationary record, and the extension of the streamflow records. The successful proponent must contact Water Survey of Canada to ensure they have the most up-to-date hydrometric records. Wherever possible, instantaneous peak flows should be analysed rather than mean daily values. As flooding can occur from both snowmelt and rainfall, the successful proponent must determine if it is appropriate to undertake a combined probability analysis of the two datasets.

#### **5.1.1 Flood Frequency Analysis**

Based on good engineering judgement, the successful proponent is to determine the most suitable distribution for the estimate of the 1:20 and the 1:100 AEP. The preferred method of estimating distribution parameters is that of maximum likelihood. The theoretical probability distributions that the successful proponent is to consider are: extreme-value distribution (Gumbel 1), lognormal distribution, three parameter lognormal distribution, the generalized extreme value, and log pearson type 3. If no maximum likelihood solutions can be found, the method of moments should be used, computed or graphical estimates on empirical plotting positions should be avoided.

## 5.1.2 Regional Flood Frequency Analysis

Depending on the availability and quality of data, a regional flood frequency analysis may provide a better estimate of the 1:20 and the 1:100 AEP. Where a regional flood frequency analysis is undertaken, the successful proponent is to include data from hydrometric stations that are within a hydrologically homogeneous region of the study area. All methods and techniques used are to be fully discussed in the report.

## 5.2 Hydrologic Modelling

For simulating the hydrologic behaviour of the study area, the successful proponent is to use the non-proprietary US Army Corps of Engineers Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) and the Geospatial Hydrologic Modeling Extension (HEC-GeoHMS). The successful proponent must use the latest versions of the software:

- HEC-HMS 3.5 (or higher).
- HEC-GeoHMS 10 for ArcGIS 10.0 (or higher).

If the successful proponent determines that a proprietary model has to be used for a portion of the hydrologic analysis, the successful proponent must provide a copy of the model to the Technical Committee.

### 5.2.1 Hydrologic Inputs

The Technical Committee requires that the successful proponent must use the HEC-GeoHMS extension for preparation of geometric data in Esri ArcGIS and the creation of the hydrologic inputs for import into HEC-HMS. The best available data is to be used and where the successful proponent had collected data, this is to be used. The successful proponent is to use the extension for:

- Pre-processing DEM.
- Delineating the watershed.
- Delineating the sub-basin.
- Determining watershed characteristics.
- Determining watershed parameters.
- Creating the HEC-HMS project.

### 5.2.2 Modelling Methods

The following are the basic requirements for the hydrologic modelling component:

- The best available data and good engineering judgement is to be used.
- Reservoir storage is to be taken into account. Dam operators are to be contacted for operating levels and procedures for high-flow events.
- The successful proponent must include a table summarizing the technical methods used for the various components of the HEC-HMS model (e.x. loss method, transform method, base flow method, routing method, and precipitation method).
- Technical methods that the Technical Committee has accepted are: SCS Curve Number, SCS Unit Hydrograph and the Muskingum-Cunge routing method. The successful proponent may use other methods after justifying the need to the Technical Committee.

- All model parameters, their values and method of estimation must be thoroughly explained in the reports for review by the Technical Committee.

### **5.2.3 Precipitation**

In the HEC-HMS model, the successful proponent is to use precipitation inputs based on the most up-to-date IDF's in the region for the 1:20 and 1:100 AEP rainfall events for current condition and climate change condition. The following are the requirements:

- In the absence of site specific rainfall data and studies, the synthetic rainfall distribution to be used is the alternating block method.
- Where site-specific rainfall studies or data exist or there are obvious limitations in applying the alternating block method, in consultation with the Technical Committee, the successful proponent may use an alternative method for deriving the rainfall hyetograph.
- Assumptions on spatial distribution (e.x. uniform distribution) should be based on the availability of data in the region and clearly indicated in the report.
- Rainfall durations including the 6, 12, and 24 hour are to be considered in determining the most severe event.
- Hyetographs for all events considered are to be provided in tables and graphed in the report or in the technical appendices.

## **6.0 Hydraulics**

The successful proponent will be required to undertake hydraulic modelling to determine the aerial extents and inundation depths of flooding based on the estimated 1:20 and the 1:100 AEP for current condition and climate change condition. The successful proponent is to undertake a sensitivity analysis on various modelling parameters to determine the effects on the flood profiles.

### **6.1 Hydraulic Modelling**

For simulating the hydraulic behaviour of the study area, the successful proponent must use the non-proprietary HEC-RAS model and the HEC-GeoRAS extension. The successful proponent must use the latest versions of HEC-RAS and HEC-GeoRAS. HEC-GeoRAS must be used for the export of HEC-RAS results into GIS. If a proprietary model has to be used for any hydraulic analysis that cannot be undertaken using HEC-RAS, the successful proponent must provide a copy of the model to the Technical Committee.

All model parameters, their values, and method of estimation must be thoroughly explained in the reports for review by the Technical Committee. The successful proponent must include a table summarizing the technical methods used for the various components of the HEC-RAS model (e.x. flow regime, boundary conditions). Justification for the technical methods used must also be provided in the final report.

The model must contain a background image of the study area and photos of all hydraulic structures attached to their cross section. Also, appropriate tables of elevations versus distance of all section points used in the model(s) should be provided, either in the report or in digital form.

With the Draft and Final Report, the successful proponent is to provide all input and output files for all computer models used in the study and all documentation required to operate the models must be

provided on the USB flash drive. Please use a mixed flow simulation unless there is a valid reason for assuming sub-critical or super critical flow.

## 7.0 Calibration and Verification

All models must be calibrated and verified, to the fullest extent possible, using a split-sample technique. The successful proponent must ensure the collection of adequate field data/observation for this purpose. Documentation on recent floods must be used to the fullest extent possible. All models must take into consideration the level of accuracy required to produce flood risk mapping. The Technical Committee accepts that calibration for the hydrologic model will be undertaken primarily on the CN values. The successful proponent must ensure that all calibrated values are within an accepted range of published values.

## 8.0 Climate Change

The successful proponent is to undertake an analysis on the impacts of climate change projections on the flood profiles. To undertake this analysis, the successful proponent must evaluate climate change scenarios for both the 1:20 and the 1:100 AEP flood profiles. The requirements for the climate change flood risk mapping are the same as those for the historical case. The climate change flood plains will be in accordance with the 1:20 and 1:100 AEP flood lines and as per the feature codes provided by the Technical Committee.

## 9.0 Flood Hazard Mapping

The successful proponent is to undertake an analysis on the flood hazards associated with the 1:20 and the 1:100 AEP flood profiles for current climate and current development conditions. The reference document for the development of the flood hazard mapping is:

- Mercedes Uden (Royal Haskoning) and Hamish Hall, (Royal Haskoning), Application of Remote Sensing (Digital Terrain Models) in Flood Risk Assessments, presentation at the National Hydrology Seminar 2007: GIS in Hydrology.]

Flood Hazard mapping is to be developed in accordance with the following figure:

Figure 2: Flood Hazard Matrix (Uden et al, 2007)

Velocity (m/s)	Depth (m)											
	0.05	0.10	0.20	0.30	0.40	0.50	0.60	0.80	1.00	1.50	2.00	2.50
0.00	Green	Green	Green	Yellow	Yellow	Yellow	Orange	Orange	Orange	Orange	Red	Red
0.10	Green	Green	Green	Yellow	Yellow	Orange	Orange	Orange	Orange	Red	Red	Red
0.25	Green	Green	Yellow	Yellow	Orange	Orange	Orange	Orange	Orange	Red	Red	Red
0.50	Green	Green	Yellow	Orange	Orange	Orange	Orange	Orange	Orange	Red	Red	Red
1.00	Green	Green	Yellow	Orange	Orange	Orange	Orange	Orange	Orange	Red	Red	Red
1.50	Green	Green	Yellow	Orange	Orange	Orange	Orange	Orange	Orange	Red	Red	Red
2.00	Green	Yellow	Yellow	Orange	Orange	Orange	Orange	Orange	Orange	Red	Red	Red
2.50	Green	Yellow	Yellow	Orange	Orange	Orange	Orange	Orange	Orange	Red	Red	Red
3.00	Green	Yellow	Yellow	Orange	Orange	Orange	Orange	Orange	Orange	Red	Red	Red
3.50	Green	Yellow	Yellow	Orange	Orange	Orange	Orange	Orange	Orange	Red	Red	Red
4.00	Green	Yellow	Yellow	Orange	Orange	Orange	Orange	Orange	Orange	Red	Red	Red
4.50	Green	Yellow	Yellow	Orange	Orange	Orange	Orange	Orange	Orange	Red	Red	Red
5.00	Yellow	Yellow	Yellow	Orange	Orange	Orange	Orange	Orange	Orange	Red	Red	Red

Degree of flood hazard	Colour Code	Description
Low		<b>Caution</b>
Moderate		<b>Danger for Some</b> Includes children, the elderly, and the infirm
Significant		<b>Danger for most</b> Includes the general public
Extreme		<b>Danger for All</b> Includes the emergency services

## 10.0 Map To Map

To facilitate re-running the historical case model for the climate change scenarios, the successful proponent must use the Map To Map workflow. This workflow was developed for WRMD by Esri for modelling the effects climate change projections have on the flood plain. The successful proponent must use the workflow for climate change modelling. To ensure proper model development, the successful proponent must review the report in Appendix F: Map To Map Implementation Workflow prior to beginning any modelling.

While the Technical Committee is to be made aware of any issues in applying the workflow it will not be providing any training or guidance on “Map to Map” and will not be responsible to respond to queries or issues relating to applying the system.

It is therefore mandatory that the successful proponent enter into a contractual arrangement with Esri Canada for the training and support needed in working with the Map to Map workflow. All costs incurred by the successful proponent to engage Esri must be incorporated into their proposal.

Esri Canada Contact: Craig MacLachlan  
 Esri Canada Limited  
 Manager, Professional Services  
 606-1496 Bedford Highway  
 Bedford, Nova Scotia B4A 1E5  
 902-423-5199  
[cmaclachlan@esri.ca](mailto:cmaclachlan@esri.ca)

## 11.0 Flood Risk Mapping

Based on the modelling results and using the HEC-GeoRAS extension, the successful proponent is to produce flood risk mapping. The successful proponent will be responsible for:

- Producing the base case 1:20 and 1:100 AEP flood maps.
- Producing the climate change 1:20 and 1:100 AEP flood maps.
- Producing flood inundation maps for the 1:20 and 1:100 AEP.
- Producing flood velocity maps for the 1:20 and 1:100 AEP.
- Producing flood hazard maps for the 1:20 and 1:100 AEP.

The set of 1:2,500 scale maps to be delivered by the successful proponent is summarized in the following table:

Table 1: 1:2,500 Mapping Summary

Backdrop	Ortho- photography		Community Mapping	
	1:20	1:100	1:20	1:100
AEP Event				
Current Climate And Current Development Condition (CC-CD) Flood Zone (FZ)	Y	Y	Y	Y
CC-CD Inundation			Y	Y
CC-CD Velocity			Y	Y
CC-CD Hazard			Y	Y
Current Climate And Fully Developed Condition (CC-FD) FZ	Y	Y		
Climate Change And Current Development Condition (CLC-CD) FZ	Y	Y	Y	Y
Climate Change and Fully Developed Condition (CLC-FD) FZ	Y	Y		
Comparison of CC-CD with CLC-CD FZ	Y	Y	Y	Y

The set of overview maps (1:2,500 or smaller scale (upto 1:25,000) that allows the complete sub watershed/watershed to be shown) to be delivered by the successful proponent is summarized in the following table:

Table 2: Over-view Maps Summary

Backdrop	Ortho- photography		Community Mapping	
	1:20	1:100	1:20	1:100
AEP Event				
Current Climate And Current Development Condition (CC-CD) Flood Zone (FZ)	Y	Y		
Climate Change And Current Development Condition (CLC-CD) FZ	Y	Y		
Comparison of CC-CD with CLC-CD FZ	Y	Y		

In producing the flood risk maps, identified in Tables 1 and 2, the following requirements must be met:

- Flood lines, or other lines digitized as geo-referenced polygons. All digital files are to be provided in provincial MTM projections (NAD83) in an Esri Geodatabase and as AutoCAD DWG Files.
- Overlaying the flood lines on 1:2,500 scale digital community maps. Where community mapping does not exist, the successful proponent must use the LiDAR data to produce contours with land features delineated from the ortho-photography.
- Overlaying the flood lines on 1:2,500 scale high resolution ortho-photography.
- Providing an overview map for each case of the 1:2,500 scale maps.
- Providing the area of the 1:20 and 1:100 AEP flood plains and where old flood risk mapping is available, comparing the change in area and percentage change. Where old flood risk mapping is not suitable for digital analysis a visual analysis is to be undertaken. The report must discuss how the old and new profiles compare.
- Providing the area of the climate change 1:20 and 1:100 AEP flood plains and comparing the change in area and percentage change with the base case 1:20 and 1:100 AEP flood profiles. The report must discuss how the base case and climate change flood profiles compare.
- Maps comparing the historical case and climate change flooded areas for the 1:20 and 1:100 AEP must also be provided. A summary of the comparison is to be provided in the report.

- All mapping is to be produced as per the feature codes provided by the Technical Committee.
- **The successful proponent must field verify (on the ground) all flood profiles before submission of the draft reports.**
- **On completion of the draft flood risk mapping, prior to submitting to WRMD for review, the successful proponent must have the flood risk maps reviewed by the communities to identify any obvious issues. Issues that can be rectified must be rectified prior to submitting to WRMD.**

Additional instructions for the Esri Geodatabase and the AutoCAD DWG Files are as follows:

- a) Esri Geodatabase:
  - i. All files must be compatible with the latest version of the software.
  - ii. Polygons on separate layers for each of the flood zones.
  - iii. Polygons on a separate layer for the contributing drainage area (watershed).
    - a) Cross section lines on separate layer with cross section number and the corresponding flood water levels as attribute information.
    - b) Historical map information is required as a separate layer.
    - c) Projection files to be included.
  - iv. All flood risk maps must also be provided in the geotiff format, this is a built in export option of Esri ArcGIS.
  
- b) AutoCAD DWG Files:
  - i. All files must be compatible with the latest version of the software.
  - ii. Polygons on separate layers for each of the flood zones.
  - iii. Cross section lines on separate layer with cross section number and the corresponding flood water levels as attribute information.
  - iv. Section lines on separate layer with the following attribute information – cross section number, 1:20 and 1:100 AEP elevations.
  - v. Historical map information is required as a separate layer.

## 11.1 Mapping Specifications

In the report, or technical appendices, the successful proponent must clearly outline the contour smoothing procedure used in preparation of the flood risk maps.

Where flood lines, or other lines, are coincident, the lines must be digitized as the same line and copied to the other appropriate layer(s). This is required as lines may need to be viewed in isolation from other features.

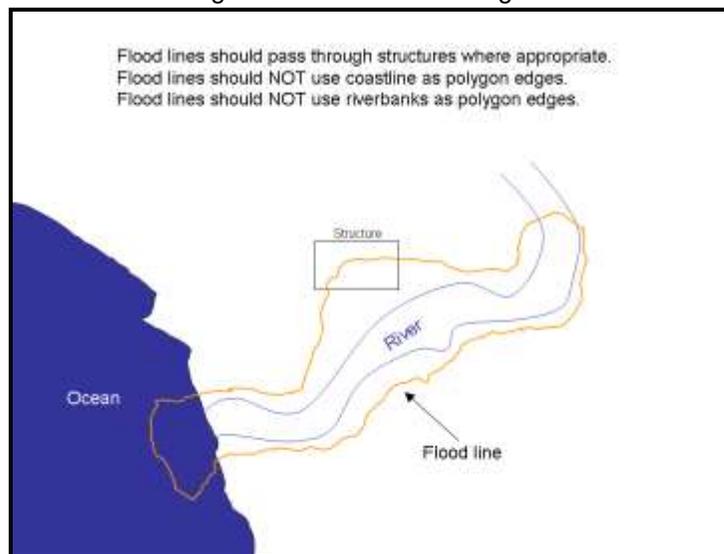
Flood zones along rivers must NOT use riverbanks as the edges of polygons. Riverbanks are prone to changes in morphology over time and updates to historical mapping can result in significant changes in water features. In such cases the extents / outer edges of flood lines must be digitized then closed across rivers as necessary.

Flood zones along shorelines of water bodies and/or coastlines must NOT use these features as the edges of polygons. Shorelines and coastlines are prone to erosion and / or deposition over time and updates to historical mapping can result in significant changes in water features. As well, flood zones are often required to be viewed at scales smaller (e.g. 1: 50,000) than the 1:2,500 scale mapping used to

produce flood risk mapping. Polygons which begin or end at shorelines and coastlines must extend past these features far enough to account for positional changes in features created by changes in the scale of historical mapping (i.e. 1:2,500 to 1:50,000) that may be used by end users.

The flood lines, or other lines, must not be edited to ensure they totally include or exclude buildings or other structures. The positions and shapes of buildings or other structures on digital mapping is not precise enough to make such determinations and is often outdated. In such cases, 1:20 year and 1:100 year flood lines must be drawn through these features until field visits can be made in order to determine the threat of flooding posed to these structures. Refer to Figure 3.

Figure 3: Flood Line Editing



## 12.0 Sensitivity Analysis

After completion of the hydrologic and hydraulic modelling, the successful proponent is to undertake a sensitivity analysis on the hydrologic and hydraulic model inputs. The successful proponent is to consider the effects of  $\pm 10\%$ ,  $\pm 20\%$  and  $\pm 30\%$  isolated changes in each parameter and determine their effects. In the event the change causes the parameter to fall outside the acceptable range of published values, the threshold value should be used. Factors to be considered for the sensitivity analysis must include:

1. In the hydrologic model, the SCS Curve Number and Manning's roughness coefficient are to be examined.
2. In the hydraulic model, Manning's roughness coefficient and the peak discharge are to be examined.
3. Assumptions made and any other factor that the successful proponent may consider appropriate after completion of field surveys.

Tables summarizing the effects at each cross section are to be included in the report. The successful proponent is to discuss the robustness of the model and provide insights based on the results.

## 13.0 Flood Forecasting

The successful proponent is to evaluate and implement a flood forecasting service for the Town of Happy Valley – Goose Bay and the community of Mud Lake for the study area using the hydrologic and hydraulic models implemented in this study. The flood forecasting service must factor in all meteorological, hydrological, and hydraulic factors that trigger flooding.

For the proposed flood forecasting service, develop an easy to use real time, custom river ice model or set up an existing non-proprietary river ice model to model flooding during ice generation and ice break up for the period of December to June. One possible non-proprietary river ice model is RIVICE.

- If RIVICE is selected then the RIVICE model implementation must be carried out in consultation with Dr. Karl-Erich Lindenschmidt, PhD, P.Eng, University of Saskatchewan, [karl-erich.lindenschmidt@usask.ca](mailto:karl-erich.lindenschmidt@usask.ca)
  1. Any anticipated costs for engaging Dr. Karl-Erich Lindenschmidt must be covered in the proposal.
  2. Further information on the RIVICE model and its application can be found here: Lindenschmidt, K.-E. (2017) RIVICE – a non-proprietary, open-source, one-dimensional river-ice and water-quality model. *Water* **9**, 314. <http://dx.doi.org/10.3390/w9050314>

## 14.0 Field Verification

Prior to submitting the final report, the successful proponent must review the entire flood plain, in the field, in order to ensure there are no anomalies or deviations in the mapping.

On completion of the draft flood risk mapping, prior to submitting to WRMD for review, the successful proponent must have the flood risk maps reviewed by the communities to identify any obvious issues. Issues that can be rectified must be rectified prior to submitting to WRMD.

## 15.0 Assumptions

All assumptions made in the study are to be based on good engineering judgement and discussed thoroughly in the report. The successful proponent is to clearly indicate, in a separate section of the final report, all assumptions made.

## **Appendix C: Hydrologic and Hydraulic Procedures for Flood Plain Delineation**

**Hydrologic and Hydraulic Procedures  
for  
Flood Plain Delineation**

Prepared by

WATER PLANNING AND MANAGEMENT BRANCH

INLAND WATERS DIRECTORATE

ENVIRONMENT CANADA

OTTAWA

MAY 1976

Updated by WRMD

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## INTRODUCTION

There has been a history of increasing development in Canada's flood plains leading to a greater potential for damages caused by flooding. This has been reflected by the vastly increased costs of flood damages over the past few years accompanied by growing public pressure on governments for additional protection. As protective works are costly to construct, do not provide absolute protection from flood damages and tend to invite additional development in the flood plain, an alternative approach is desirable in many cases. To this end, the governments of Canada and the provinces are embarking on a program of flood damage reduction centered on flood risk mapping which will eventually be of benefit to all Canadians.

The first step in the flood Damage Reduction Program is to identify the specific flood prone areas and delineate these areas on maps. Such maps delineate those areas of land that have been or could inundate by specified flood events and can be used for legislative and information purposes. The maps and background information must be produced in such a way as to serve the purposes of the potential users. Federal, provincial and municipal governments, river basin authorities, private companies and the general public are all potential users of these flood risk maps.

An important aspect in the production of useful flood risk maps is that all effort should be made to ensure that the information presented there on is as accurate as possible. Although the many intangibles involved in hydrologic and hydraulic investigations make it difficult to define rigid specifications, this document is intended to serve as a guide for such work and the procedures herein should be followed unless it can be clearly shown that they do not apply.

## **FLOOD TYPES**

The most important piece of information to be shown on any map will be the lines which define the area of land inundated by the designated flood. For federal and provincial purposes, all land within these lines will be the Designated Flood Risk Area. Specification of the flood event that defines the Designated Flood Risk Area will vary from province to province; it could be based on probability, a specified input or a large recorded flood. In all cases, however, the elevation of the water surface must be no less than that of the 100-year flood.

It is also quite likely that various other floods, smaller in magnitude than the designated flood, will be mapped or that the hydrologic and hydraulic analysis may be required even if the flood lines are not actually shown. It is possible, therefore, that any or all of the following three types of flood will be mapped at various locations in Canada, depending upon local conditions.

### **1. Floods Based on Probability**

A flood based on probability must be determined by a frequency analysis of recorded flood peaks and should be the best estimate for the required probability of occurrence. As was stated earlier, the designated flood will be the 100-year event or greater, but lesser events (20-year, 50-year, etc.) may also be required for information purposes.

### **2. Floods Produced by a Specified Input**

This type of flood is that produced by determining either the effects of a large regional storm over the basin or the runoff from a specified combination of snowmelt and precipitation. A specific probability is attached to such a flood; for example, the peak flow resulting from the 100-year storm is the 100-year flood.

### **3. Larger Recorded Flood**

It is unlikely that this type of event will be used as a designated flood unless, for example, the regional storm was centered over the basin in question. The main reason for mapping such a flood is for informational purposes. If residents of an area can remember such flood, it becomes easier for them to envisage the possible problems which would be caused by the designated flood.

## DATA REQUIRED

In order to determine the peak flows of the floods to be mapped with their corresponding water surface elevations, it is necessary to obtain a considerable amount of data from numerous sources. It will not be necessary to collect all of the following data for each specific case; the requirements will vary depending upon the types of flood to be mapped, the methodology to be used and the location. Much of the information, however, will be common to all cases.

### 1. Streamflow Records

The first and most obvious data required are any streamflow records that may exist for the stream in question and any tributaries involved. Also, if a regional flood frequency analysis is to be carried out, records must be collected for other streams in the same region. The main source of such data will be the Water Survey of Canada, but records may also be available from other organizations such as provincial agencies and power companies. In any event, data should be obtained from every available source and thoroughly reviewed for accuracy. To ensure that the most up-to-date records are obtained from the Water Survey of Canada, data should be retrieved directly from Water Survey of Canada. This would ensure that most of the data have been reviewed and adjusted to remove errors that may have appeared in publications.

For a flood frequency analysis, an annual maxima series will generally be required. Although a record of instantaneous peaks is desirable, in many cases mean daily flows will be the only available data. Should either partial duration series or combined probability analysis be required, it will then be necessary to obtain records of more than one peak flow in each year.

To enable routing of a flood from a gauging station to another control point, sufficient data must be obtained to define the complete flood hydrograph.

## **2. Historical Floods**

In this case, the term "historical flood" refers to an event that occurred prior to records being kept on a stream. There are many cases where reasonable estimates can be made of the magnitude of an historical flood from information on water surface elevations. Such information may be found in such places as newspaper files and public archives.

If the historical flood was unusually large and a good estimate of its magnitude can be made, the information can be used in a flood frequency analysis leading to increased confidence in the estimate of designated flood.

## **3. Specified Input**

If one of the floods to be considered is that produced by determining the effects of a regional storm, then documentation of that storm must be obtained. In most cases, information on the areal extent and distribution and precipitation rates with respect to time is readily available in meteorological publications.

If a flood is to be based on other specified input, relevant data on snowmelt and precipitation rates must also be collected.

## **4. Stage-Discharge Relationships**

Once the magnitude of a given flood is determined, the next step is to convert a discharge to a water surface elevation at a given point. If there is a stream gauge at the location, this is achieved by using the stage-discharge curve for the gauging station. Smaller floods usually fall within the range of discharge measurements plotted and so can be converted to stages with a fair amount of confidence. This of course is only true if measurements are taken at a stable section where the curve remains constant with respect to time. At unstable sections, the curve changes with physical changes in the stream channel and considerable judgment and experience of the site are necessary to use the curve. Judgment is also required in the extrapolation of stage-discharge curves

that will be necessary for floods of large magnitude. A small error in extending a curve can lead to sizeable errors in estimating the stage corresponding to a large discharge. Therefore such estimates are best made by personnel who are both experienced in this type of work and have a good knowledge of the location. This should preferably be done for gauging stations maintained by the federal government, by staff of the appropriate District Office of the Water Survey of Canada.

For control points where no gauging station exists, it will be necessary to develop a stage-discharge relation. This entails a considerable amount of field work to survey the cross-section and take discharge measurements over a range of streamflows. It is not adequate to measure discharge only at times of low flow, which is the optimum time for surveying cross-sections, but it is also essential to take measurements during medium and high flows.

In most parts of Canada, where flood flows normally occur in the spring, this would entail taking measurements over a period of several months to establish a reasonable range of the rating curve. Streamflow measurements should be as accurate as possible.

### 5. Hydraulic Coefficients

To determine the water surface profile along the reach of a stream corresponding to an elevation at a given point, it is usually necessary to undertake backwater computations. These computations normally work in a stepwise manner, determining the surface elevations at various points along the reach. The important variables to be considered are the hydraulic coefficients which affect the flow within each segment of the reach. Many of these coefficients are well established for all types of structures such as bridge piers and weirs and can be found in coefficient, Manning's 'n', which has considerable influence on hydraulic computations. Although there are guidelines available for estimating this coefficient, considerable experience is necessary

to determine realistic values. The coefficient must be estimated for the stream channel and the overbank area inundated by the various flood events. It should be noted that, in many backwater programs, the coefficient used also takes into account such things as bend and eddy losses. The combination of these is often referred to as Manning's 'n' for the sake of simplicity.

As Manning's 'n' is an important parameter in backwater calculations and is not a value that can be directly measured, it is worthwhile expending some effort in obtaining a good estimate. This can best be achieved using known water levels at various points along a reach for a past flood. As the effects of the roughness coefficient are not the same at high and low flows, it is not sufficient to obtain water levels when the flow is low.

#### **6. Elevations of High Water Marks**

Accurate readings of high water marks of past flood events are very useful for backwater calculations. However, obtaining reliable readings is often difficult due to the passage of time between the flood and the collecting of data.

The best way to obtain this data is by the use of crest-stage gauges at various locations along a reach. They are cheap, simple to install and maintain, and provide an accurate elevation of high water. The installation of crest-stage gauges would be worthwhile even if the passage of only one flood peak were recorded, but obviously more data would be an improvement. It is recommended, therefore, that crest-stage gauges should be installed at various points along a reach to be mapped if it is likely that a flood peak will pass during the course of the investigation.

There may be cases where such gauges have been installed and maintained by various agencies, such as the Water Survey of Canada and, if available, this information should be collected.

High water marks can also be collected by direct survey at the time of passage of a flood peak. This is usually achieved by pegging or otherwise marking the water level at various locations at or near peak discharge. If the stage is fairly constant and the distances to be travelled are small, a good indication of the true high water mark can be obtained. The levels of the pegs or marks can be determined at a later date, although they should be revisited soon after the flood to find indications of the actual high water mark. It is rarely known when the actual peak is occurring but, if pegs were placed close to the peak, they should serve as a good guide to locating marks of the maximum stage.

Other sources of information on past floods are newspaper files and public archives where documented examples of maximum water surface elevations can often be found.

### **7. Aerial Photographs**

In several cases where large floods have occurred in the last few years, a program of aerial photography was undertaken to delineate the inundated area. This information can be very valuable for mapping purposes as it gives a true indication of the flood line for a given event. If the stream is gauged and the discharges known at the time of photography, the information can serve as a check on water levels, roughness coefficients, etc. Also, if a large recorded flood that is to be mapped has been photographed, much of the work is eliminated.

### **8. Cross-Sections**

In order to determine the water surface profile of a given flood discharge, it is usually necessary to perform a backwater analysis along the reach of the stream or streams considered. For this purpose, it is necessary to obtain information on the geometry of the channel and its flood plain, which is accomplished by surveying cross-sections at various locations. Cross-sections are required at all representative locations throughout the channel reach. Such locations are where changes occur in slope, cross-

sectional area or channel roughness; locations where levees begin and end, at bridges and other channel restrictions. Where an abrupt change occurs, several cross-sections should be used to describe the change regardless of the distance between them.

It is impossible to specify the interval at which cross-sections should be surveyed, but two points should be kept in mind. First, sufficient sections should be obtained to adequately define the river geometry and second, the interval between them should be such that the assumption of uniform flow within a section should be reasonably valid.

Surveyed cross-sections must include the entire flood plain of the main channel and any tributaries that are likely to experience backwater effects. Sufficient points should be established to accurately define the geometry of the cross-sections and they must be tied in horizontally to permanent structures and vertically to established benchmarks.

### **9. Streamflow Regulation**

If the stream under consideration is subject to artificial regulation by dams, diversions, etc., that has significant effects on peak flows, it is necessary to obtain data on the effect of such regulation to enable a conversion of streamflows to natural conditions prior to undertaking a flood frequency analysis.

For reservoirs, records of outflows, stage and stage-storage curves are required, and for diversions the quantity diverted into or out of the system. Rule curves or operating procedures must also be obtained to enable a reversion of a natural flood estimate to regulated conditions. It may be necessary, if an installation was made within a period of record to collect data on the times of installation, cut-off, reservoir filling, etc.

## **10. Meteorological and Physiographic Data**

These types of data will be necessary for two areas of study, regional flood frequency analysis and hydrologic modelling. The actual variables required depend upon their relative significance or the information necessary to calibrate a hydrologic model.

For regional flood frequency analysis, the following are commonly considered but may not all be significant: drainage area, area of lakes and swamps, basin slope, channel slope and channel length as well as mean annual runoff, precipitation and snowfall. Other variables may also be of significance depending upon the region, its topography and climate.

For hydrologic modelling purposes, many of the above are involved as well as information on soil types, forest cover, groundwater, infiltration rates and soil moisture conditions. To operate a model, a great deal of meteorological data is required including rainfall, temperature and snowfall records, radiation data, snowmelt coefficients and lapse rates. The data required vary widely depending on the model used and the best test of their validity is in the reconstitution of recorded flows.

## **11. Lake and Sea Levels**

A problem arises when a stream discharges into a large lake with a backwater effect or into the ocean with its tidal effect. For a given designated flood flow in the stream, there is a wide range of possible lake or sea levels that would be coincident. It is necessary to obtain lake or sea level data in such cases to enable a reasonable judgment or assumption to be made. Decisions on the backwater or tidal effect must be based on the variability of water levels and the probable timing of the designated flood.

## FLOOD MAGNITUDES

The two main steps in the mapping of a flood plain are (1) determine the desired flood magnitude, and (2) delineate the area inundated by that flood. Whether the flood be based on frequency analysis or the resultant runoff of a specified input, there is considerable investigation necessary to develop a reasonable estimate. This is the main part of the hydrologic investigation required and should be carried out using the best techniques available. For many water resources projects in the past, very little attention was paid to hydrologic investigations and many rule-of-thumb methods were used. It is now realized, however, that improved work in this area is essential to good overall design, and this particularly applies to a program of flood risk mapping as it affects a large part of the population. Thus, for this program, a high standard of analysis along with good engineering judgment will be required.

### 1. Flood Frequency Analysis

In most cases, it is visualized that the floods to be mapped will be determined by frequency analysis. In the past there has been much use and abuse of frequency analysis in hydrology, but it is hoped that adherence to the procedures described herein will ensure the validity of the analysis. While it may be difficult to specify some of the aspects of flood frequency analysis, there are some rules that must be followed.

#### a) Conversion of Regulated Flows to Natural Conditions

In flood frequency analysis of peak flows, the initial assumption is made that floods are natural events that can be described by a particular probability distribution. If man has imposed his will upon a stream in such a way as to affect peak flows, then they are no longer natural events and no distribution is applicable. Thus, the first step in undertaking a frequency analysis is the conversion of regulated streamflows to natural conditions. This is achieved by removing the effect of regulatory installations, such as dams and diversions, if they have a significant influence on the flood peak. If their

influence is small, however, conversion is not required, but is always necessary to estimate their effect prior to judging the significance thereof.

Given adequate data on, such as diversion flows, reservoir stages, outflows and stage-storage curves, it is a simple if tedious task to convert flows to natural conditions. If such data are not available, however, the problem becomes more difficult. Records are generally available for major installations, which are the most likely to affect peak flows, but there may not be data available for smaller projects. It may be necessary, therefore, to estimate their effect by various techniques depending on the type of installation.

#### **b) Non-Stationary Record**

When records of historical peak flows are used for a frequency analysis, it is assumed that all the data are samples from a single population. This implies, therefore, that conditions in the watershed have remained unchanged during the period of record. In some cases, considerable change in a basin over the years has affected the flood regime. Forestry operations, urbanization, agricultural drainage and irrigation can have a considerable effect on streamflows. If this effect is significant, it is necessary to assess the changes that have occurred with time in order to develop a stationary record for analysis.

#### **c) Extension of Streamflow Records**

It has been the practice in the past, particularly when undertaking a regional flood frequency analysis, to extend the records of flood flows at short-term sites by correlation with adjacent streams. Generally, this has been used to determine a more accurate assessment of the plotting positions of the recorded floods when graphical techniques are used to define a frequency curve. Such a procedure is not used, however, with statistical techniques and therefore should normally be avoided.

The only case where extending a streamflow record can be justified is where the stream has a short period of record and there is not enough data available to carry out a regional analysis. Then, the record can be extended based on a larger sample at an adjacent stream or on metrological data in order to estimate the desired flood event

#### d) Single Site Flood Frequency Analysis

A single site flood frequency analysis for the stream in question will be adequate only if the record is long and reliable. If the record is not of sufficient length (say 30 to 40 years) or there is some doubt of its reliability, a regional flood frequency analysis should be carried out, in which case several single site analyses are combined.

The first step in a frequency analysis is to obtain the available data and assess its reliability. Whenever possible, instantaneous peak flows should be analyzed rather than mean daily values, but in practice this may not be feasible. The record should be checked for the possibility of ice or log jams causing an increase in stage which would lead to an erroneous discharge value.

Once the record has been assessed and is judged to be reliable, a frequency analysis of annual peak flows must be carried out. There are various theoretical probability distributions that can be used for this purpose; those commonly in use include, 1) Extreme Value Distribution (Gumbel I), 2) Lognormal Distribution, 3) Three-Parameter Lognormal Distribution, and 4) Log Pearson Type 3 Distribution.

The preferred method of estimating distribution parameters is that of maximum likelihood, since minimum variance estimates are obtained. If no maximum likelihood solution can be found, the method of moments should be used while computed or graphical estimates based on empirical plotting positions should be avoided.

It is often difficult to determine which distribution best describes a given data sample. There are various significance tests available, but with the small sample sizes

usually found in hydrology, they are virtually meaningless. Although graphical estimates should not be used, it is always worthwhile to plot the data and computed frequency curve to give a visual indication of goodness of fit. This can be used in conjunction with other factors such as a comparison of sample and distribution statistics, the variances of the estimates and, where applicable, the boundary limits of the distribution.

As was stated earlier, it is usually good practice to plot the observed peaks at empirical plotting positions and the computed frequency curve on the relevant probability paper to gain a visual impression of the frequency curve. In some cases, a broken line effect is indicated which is not described by any theoretical distribution. If this occurs, the data must be thoroughly examined to establish the cause of the non-homogeneity of the sample. There are several possible reasons for this such as moving of a gauging station, change in regulation patterns, urbanization or other changes in watershed characteristics which should be considered prior to analysis. It is also possible that the sample may be biased by the inclusion of several rare events within a short time period. It is most likely, however, that the explanation for the broken line effect will be that peak flows were caused by two or more flood generating mechanisms. In this case, the flood series contains samples from more than one population and should be treated as such.

It is quite common in parts of Canada for floods to occur in both spring and summer and fall. The spring flood is usually caused mainly by snowmelt, while rainfall may generate a second peak flow. The annual maximum flow may be generated by either of these causes, therefore a series of annual peak flows contains two data samples. In this case, a combined probability analysis should be carried out where each sample is treated independently. A combined frequency curve is then computed, which would adequately follow the plotted data.

### e) Regional Flood Frequency Analysis

A flood frequency regime based on the analysis of data from a single site may not accurately represent the regional characteristics. A regional flood frequency analysis tends to overcome this problem by including data samples from several sites within a hydrologically homogeneous region.

This type of analysis should be used when the record on the stream in question is short or unreliable and in cases where there is some doubt of the validity of the single site frequency curve. In cases where there is little or no data for the stream, the only solution is a regional analysis and it should also be used when a stream is gauged at some distance from the reach to be mapped.

The first problem in carrying out a regional analysis is to determine the extent of the homogeneous region. This must be based initially on knowledge of meteorological and physiographic conditions so that all streams used would appear to have similar runoff characteristics. For each stream in the region with sufficient length of record (at least 10 years), a single site frequency analysis is carried out taking into account all the factors described earlier. Obviously the same probability distribution must be used in all cases, so one must be chosen that is applicable to the region. It is common to use a two parameter distribution for regional analysis as the necessity for estimating a regional coefficient of skew is avoided, however a three-parameter distribution should be used if indicated by the single site analyses.

At this point a technique must be chosen to develop regional characteristics from the single site frequency curves. There are three methods or variations thereof that are commonly used.

#### *i) Index Flood Method:*

For each of the sites used in the analysis, a dimensionless frequency curve is developed by plotting floods of various return periods as ratios of the mean annual

flood. The mean used should be that of the distribution rather than the sample mean. A check on the homogeneity of the region can be made using a test.

Once it is established that all streams are within a homogeneous region, a dimensionless regional flood frequency curve is developed. For each of several return periods, the median of the individual ratios to the mean annual flood is determined. These median values, when plotted on the appropriate probability paper, define the dimensionless regional flood frequency curve.

The final step entails developing an equation to estimate the mean annual flood for any stream within the region. Multiple regression analysis is used to develop a relation between the mean annual flood and various physiographic and climatic parameters. Variables such as drainage area mean annual runoff, channel slope, basin slope, areas of lakes and swamps and soil characteristics would be considered, but others may also be significant.

***ii) Estimating Floods at Various Return Periods:***

A second technique is to estimate floods specified return periods directly by multiple regression analysis. The independent variables chosen are similar to those used to estimate the mean annual flood, but a series of relationships is developed, one for each of selected return periods. The dependent variables used in the analysis are floods of the selected return periods.

***iii) Estimating Distribution Parameters:***

Multiple regression techniques can also be used to estimate regional values of the parameters of a probability distribution. The relevant parameters are first derived for each of the individual sites in the region, then regression equations are developed to estimate them for ungauged streams.

#### **f) Transfer of Location**

It is likely that in many cases there will be no gauge on a stream at the location where mapping of the flood plain is required. If there is no gauge on the stream at all, or a gauge is far from the desired location, regional techniques must be used to estimate flood magnitudes. If however, a stream is gauged sufficiently close to the required point, a transfer of flows by streamflow routing or simpler techniques can be achieved.

Streamflow routing should be used if there is significant storage between the gauging station and the required control point. Routing can be carried out either prior to or after the frequency analysis. In the first case, recorded flood hydrographs are routed to the desired location, then a frequency analysis is carried out on the routed peak discharges. In the latter case, a frequency analysis is first carried out, then the estimated flood is routed through the system. It becomes necessary, however, to develop a complete flood hydrograph for this purpose rather than only estimating a peak discharge.

#### **g) Conversion to Regulated Conditions**

Streamflows that included the effect of artificial regulation were converted to natural conditions prior to undertaking a frequency analysis. Once an estimate has been made of the natural flood magnitude, therefore, it is necessary to reconvert that flow to regulated conditions. As well as the data used for the original conversion, it will be necessary to determine and document probable operating procedures of the installations under conditions of the design flood.

## **2. Runoff from a Specified Input**

In the event that the designated flood is to be based on a specified input rather than on frequency analysis, it becomes necessary to convert the input data into discharge values. The two likely inputs are an historical regional storm and a combination of snowmelt and precipitation.

In the first case, the storm must be transposed from the location of its actual occurrence to the basin in question and its orientation changed, within limits, so as to maximize the effects on the watershed. The limits of storm transposition are not easy to define, but it should only be attempted within a meteorologically similar region. No major orographic barriers should be crossed and the extent of the transposition should be such that the storm mechanisms remain valid. To change the orientation, the conditions must be studied to ensure that the change is consistent with the atmospheric conditions that produced the storm. As a guide, it has been suggested that the orientation of a storm should not be changed by more than 20 degrees. In the final analysis, decisions made on storm transposition should be based on the synoptic meteorological experience of the region. It is recommended that this type of exercise be carried out by experienced meteorologists.

If the specified input is to be a combination of snowmelt and precipitation, it is necessary to document the rates and areal extent of each and to justify the specified values. It should be shown that such a combination on the basin concerned is realistic by comparison with recorded meteorological data in the region.

The second and major part of the process is the conversion of the input to runoff, and runoff to discharge at the location required. This involves the use of a hydrologic model of the watershed, of which there are many types currently available. Most of these models are adequate for the region in which they were developed and for the size of the watershed they were designed to handle. Applying them to different regions and larger or smaller watersheds is not always successful, however, so great care should be taken when choosing a model. Watershed models can vary from those based on a simplified triangular unit hydrograph to those that attempt to describe every aspect of the hydrologic cycle. In general, it is preferable to use the simplest model that is adequate to simulate observed discharges. In many of the more complex systems,

enormous amounts of data are required apart from the basic physiographic and meteorological characteristics. Data on evaporation, soil moisture, infiltration rates, groundwater storage, etc., are not available in many cases and so the model parameters must be estimated. Thus it is common that the majority of the parameters are estimated rather than measured which leads to a low level of confidence in the results.

Any model applied to a particular watershed should take into account the factors which have a major influence on the runoff characteristics. It should have the capacity to adequately describe the main physiographic aspects of a watershed as well as the effects of channel and lake storage and groundwater influence. Furthermore, the model should have the ability to incorporate those types of artificial regulation that may exist in the basin under study.

As the major meteorological input to a model in this case may be a particular documented storm, it should be able to operate on a time scale that will both analyze the precipitation data and synthesize discharges at such intervals as are relevant for the watershed. For large basins, computations on a daily basis will generally suffice; for small basins, however, the time interval may be very small. Also of concern is the type of input to be analyzed. If it is a regional storm that can only occur in summer or fall, no provision for snowmelt is required. If, however, the input is a specified combination of snowmelt and precipitation, a model must be chosen that can take both into account.

It is not reasonable to specify which hydrologic models should be used in this program as any such decision would only be subjective. The best test of a watershed model lies in its ability to adequately reproduce recorded flows. It is not adequate for the purposes of the flood risk mapping program to blindly apply any model to a watershed without adequate testing for both calibration and verification of the model parameters. Generally, hydrologic models are calibrated for a basin by successive attempts at reproducing recorded data whilst varying those parameters that are not

fixed until an adequate reconstitution is developed. This procedure is followed for several historical events so that model calibration is not based on a single sample. If sufficient records exist on the stream, several reconstitutions of recorded discharges should be run, independent of the calibration runs, to verify the model. If there are no records on the stream in question, the model must be calibrated and tested on a similar adjacent watershed where the variable parameters can be assumed to match those of the basin under study.

It is known that the runoff characteristics of a watershed can vary widely depending upon the quantity and intensity of precipitation and the antecedent conditions. If the synthesis of streamflows in this case is to be based on the largest storm of record in a particular region, the calibration of model parameters should be attempted using other large storms rather than lesser events. Also, the antecedent conditions assumed should match those in effect prior to the occurrence of the historical storm.

If a combination of snowmelt and precipitation is specified, model parameters relevant to snowmelt should initially be estimated from rainfall-free events. Similarly, estimates of precipitation-runoff parameters should be based on events free from snowmelt. Calibration and verification of the model should then be finalized using recorded discharges caused by both elements.

When attempting to match synthesized streamflows to the recorded data, it should be remembered that the important value for flood plain mapping is the peak flow. Therefore, more attention should be paid to adequately reproducing the peak flow than to matching the shape of the entire flood hydrograph.

## HYDRAULIC ANALYSIS

At this stage of an investigation, the magnitude of a flood to be mapped has been determined by one of the methods previously described. The next step involves converting the streamflow to a water surface elevation at a given location, generally downstream of the reach to be mapped, and computing the water surface profile for the reach.

Computation of water surface profiles from a given downstream starting point usually involves the use of backwater analysis. Such analysis is very tedious for manual calculation and therefore is generally achieved by using a computer program. There are several reliable backwater programs available and the choice of a particular system can depend on many factors. One should be used that has been well tested and applied successfully to many different conditions. It should have the capability to incorporate those conditions that will be met in the reach under study. As a guide, the following points should be taken into consideration when selecting a program to compute water surface profiles.

### 1. Type of Flow

Most programs available are for steady, gradually varying flow only using the standard step method of computation. Programs were generally developed for subcritical flow, although some can handle supercritical conditions. When possible the mixed flow regime should be selected unless there are explicit reasons for not doing so.

### 2. Cross-Sections

A program should be able to incorporate cross-sections of any shape and should have the capability to subdivide the sections to enable separate analysis of the channel and overbank regions. The number of subdivisions should be adequate to reflect the varying hydraulic characteristics of the entire cross-section up to the limits of the flood

plain. It may also be advantageous to have the ability to interpolate between specified cross-sections where velocity changes are rapid.

The program should also be able to account for skewed cross-sections which become necessary where bridge crossings are not perpendicular to the channel.

### **3. Critical Depth**

Critical depth should be computed at each cross-section to ensure that the water surface stays on the correct side of critical. This is necessary as some programs continue calculations assuming subcritical flow regardless of the critical depth. Minimum specific energy should be used to calculate critical depth rather than a simplified approach.

If the depth crosses critical, some programs simply assume critical depth is reached at the next section whereas others interpolate between cross-sections to obtain a more accurate location.

### **4. Velocity Distribution**

The velocity of flow is not uniform for a cross-section necessitating the subdivision of the section into, as far as possible, elements of equal velocity. From these elements, a weighted velocity head can be computed for the section, the accuracy of which increases with the number of elements.

### **5. Roughness**

It is very important in a backwater analysis that the friction losses be computed as accurately as possible. The program should enable specification of several values of Manning's 'n' for each cross-section as well as for different reach lengths between cross-sections if required. The ability to change roughness coefficients by a given ratio is useful for testing the sensitivity of the water surface profile to the roughness values.

## **6. Use of High Water Marks**

It is an advantage for a program to have the ability to use known high water marks to calculate the roughness coefficients. In this case, only preliminary estimates are needed to initialize the program rather than specifying inflexible roughness coefficients which can lead to considerable errors in the water surface profile.

## **7. Bridge Losses**

Any program used must normally include provisions for computing bridge losses under three possible conditions. The first is a low flow condition when the water surface is below the bottom chord of the bridge. Secondly a pressure flow condition exists when the surface is above the bottom chord, and finally a combination of weir and pressure flow when the bridge is overtopped.

## **8. Culvert losses**

If backwater analysis is carried out on a small stream that flows through culverts, the capability to compute culvert losses is required in the program. In most cases, where the flood is considerably larger than the design discharge for a culvert, the conditions would be similar to that of a bridge under a combination of weir and pressure flow.

## **9. Split Channel Flow**

This type of flow occurs when the discharge is separated into two or more channels by the presence of islands in the stream. It is then necessary to determine the proper division of flow in each of the channels with the corresponding water surface elevations.

## **10. Other Factors**

There are several other factors that should be considered in the selection of a program for computing water surface profiles. It should be fully documented so that the methodology and logic can be followed, assumptions verified and changes made where necessary. It is essential that the user fully understand the program rather than treating

it as a "black box". It may be necessary to add routines for special circumstances that may exist in a particular reach but are not provided for in the original package.

In addition to the points mentioned above, most of which will be common to all streams investigated, there are two other important items that may have to be considered in some parts of Canada. The first of these is the delineation of a floodway on the flood risk maps. The floodway is defined as the stream channel and that part of the flood plain required to convey the design flood. For the floodway to be smaller in the area than the flood risk zone, therefore, there must be an increase in water surface elevation. It is thought that a maximum increase will be specified when defining a floodway. At first glance this concept appears to offer no advantages as it increases the area of the flood risk zone. However, in cases where a floodway is designated, some development will be permitted within the Designated Flood Risk Area provided it is not also within the floodway. This can lead to improved use of the land within the flood plain and may provide an incentive for the further development of flood proofing techniques.

Should it be necessary, therefore, to delineate a floodway, a program must be selected that has the capacity to carry out the necessary computations. Normally, trial limits of the floodway would be specified, based on the geometry of the channel and its flood plain, and a trial and error technique used to adjust the width thereof until the increase in water surface elevation is maintained within the specified maximum.

The second problem that is encountered in some parts of the country is an increase in water levels caused by ice or log jams. Such an increase can be considerable, leading to more widespread flooding than would be experienced with a flood of much larger magnitude without the jam occurring. Ice and log jams generally occur at a specific location, where there is a constriction in the channel, either natural or artificial. It would be normal, therefore, to survey a cross-section at that point, which would

enable a backwater program to take account of such an event. Should flooding in the entire reach to be mapped be the result of an ice or log jam, the backwater computations are started at the location of the jam. If the jam occurs within the reach, however, the procedure must be split into two parts. Downstream of the jam, the normal procedure will be followed for the specified flood. At the location of the jam, a new initial water surface elevation must be specified to compute the profile for the upstream reach. Thus, it is a fairly simple matter to account for ice and log jams in the hydraulic analysis, if the stage resulting from the jam can be determined.

Estimating the effects of such jams on a flood of given magnitude, however, is not a simple problem. There seems to have been little research carried out in this field, so new techniques may have to be developed. Estimates should be based on the past history of jams at the particular location, taking any relevant factors into account. It may be possible to develop estimates for the resulting water level directly on a probability basis or by adding the stage effect of a jam to that resulting from a flood of given probability. It is probable that this type of decision will be made prior to the commencement of an investigation.

## **11. Dykes**

A special problem arises where dykes have been constructed in the flood plain for protective purposes. If the dykes would be overtopped by the designated flood, the land behind them would fall within the Designated Flood Risk Area. If they are of sufficient height, the dykes would normally delineate the extent of inundation. This does not apply, however, if the dykes are not structurally adequate and would fail under conditions of a large flood.

A structural assessment of dykes will not normally be considered as part of the investigation but will probably be specified prior to the commencement of any hydraulic analysis.

## **TECHNICAL REPORT**

Upon completion of the hydrologic and hydraulic investigations and prior to the compilation of the flood risk maps, a draft technical report will be submitted to the Technical Committee. The report should present the studies in sufficient detail that specialists in this field can determine the adequacy of the work and its conformance to the procedures outlined in this document. A review of the draft report will be undertaken at this stage and then, subject to the acceptance of the work described therein, the flood risk maps will be compiled. While it is not intended to specify a format for the report, the following points should be included.

### **1. Location Description**

A section of the report should describe the area to be mapped, the stream and its tributaries, watershed characteristics, climatic conditions and flood generating mechanisms. Small-scale maps should be used to illustrate the text.

### **2. Flood Types**

The floods to be mapped including the designated flood, those of lower probability and a large recorded flood, if required, should be described. If a floodway is to be delineated, the necessary constraints such as a limitation on the increase in water levels should be explained.

### **3. Data**

All the data used in the investigation, whether measured or estimated, should be fully described. The source of the data should be given and background information must be provided for any assumed values to enable an assessment of their validity. Tables, maps and graphs should be used to illustrate data such as streamflow records, historical storms, stage-discharge relationships, cross-sections and surveyed profiles. Reproductions of relevant aerial photographs should also be presented.

## **4. Flood Magnitudes**

### **a) Flood Frequency Analysis**

Information relevant to the conversion of regulated streamflows to natural conditions and the stationarity of the data series should be fully described. If the effects are not sufficiently large to warrant adjustments to the data, this should be explained with quantitative estimates of their significance at the point in question.

For a single site frequency analysis, the data used should be shown and the choice of probability distribution and method of parameter estimation explained. Frequency curves with plotted data points and computed confidence limits are essential. If an historical flood is included in the analysis, the techniques used must be explained and the effects of its inclusion on the frequency curve and the variance of the estimate should be shown. Should a joint probability analysis be required, all relevant information including basic assumptions must be described.

For a regional flood frequency analysis, the extent of the region and streams included must be described along with the records used at each site. The single site analyses should be covered as above and, depending on the method of regionalization used, homogeneity tests, variables used in multiple regression analyses and their statistical significance, regression equations, correlation coefficients and standard errors of estimate must be described.

Should a transfer of location of the estimated flood be required, the method and underlying assumptions must be explained. Reconversion of natural flood estimates to regulated conditions should be described when appropriate along with an explanation of the operating procedures assumed and the basis for the assumptions.

### **b) Runoff from a Specified Input**

The input in this case must be fully documented and any storm transposition and change in orientation explained. A brief description of the hydrologic model employed

must be included outlining the basic methodology and assumptions and the history of its previous use. The data required to operate the model, both measured and estimated, should be shown with background explanation for the estimated values.

It is important that the verification of the model be adequately described by illustrating several reconstitutions of recorded events independent of those used for calibration purposes. Finally, the derivation of the floods to be mapped should be explained.

### **5. Hydraulic Analysis**

Extrapolation of stage-discharge curves should be shown with an explanation of the methods employed. A description of the backwater program should include a brief explanation of each aspect of its operation that is significant to the particular stream. It should be clear which coefficients were estimated and which were obtained by direct or indirect measurement. Plots of all cross-sections must be shown as well as water surface profiles for the entire reach for each of the flood events considered. If a floodway is delineated, the specified increase in water level should be explained and the limits of the floodway shown on cross-section plots. The water surface profile computed for the floodway condition must also be included. In cases where ice or log jams are taken into account, a complete description of the techniques used should be given.

### **6. Other Procedures**

Should special cases arise that necessitate the use of procedures outside the scope of this document, a complete description of the techniques used must be given. It should not be necessary for a reviewer to search through a list of references to fully understand the investigation; the report should stand as a self-explanatory document.

## **Appendix D: Feature Codes**

Dept	Data Type	Status	Feature	Description	FCODE	Feature Type	Fill Colour	Fill Type	Border Colour	Border Type
EN	FR	DS - Designated	FF - Floodway Fringe	Designated Floodway Fringe - 1:100 year return interval flood zone. Some types of development are permitted with flood proofing.	ENFRDSFF	Area	Yellow	Trans 50%	Black	Solid
			CS - Cross Section	Surveyed cross section used in hydraulic model to develop flood lines - attributes: 1:20 year flood elevation, 1:100 year elevation and cross section number to be included	ENFRDSCS	Line	Magenta	Solid	Magenta	Solid
			FW - Floodway	Designated Floodway - 1:20 year return interval flood zone. Most types of development, particularly residential, are not permitted.	ENFRDSFW	Area	Orange	Trans 50%	Black	Solid
			SP - Special Policy	Special Policy Area Floodway - Some development may be permitted with an approved comprehensive development plan for the area.	ENFRDSSP	Area	Pink	Trans 50%	Black	Solid
			HS - Historical	Historical Flood Extent - Delineation of recorded extreme flood event	ENFRDSHS	Area	Light Green	Trans 50%	Black	Solid
			IB - Ice or Debris Flood	Ice or Debris Flood - Delineation of recorded or estimated flood event with ice or debris blockages	ENFRDSIB	Area	Light Green	Trans 50%	Black	Dashed
			SE - Study Extents	Flood Study Extents - Delineation of flood risk mapping study limits	ENFRDSSE	Line	Gray	Solid	Gray	Solid
		UD - Undesignated	FF - Floodway Fringe	Designated Floodway Fringe - 1:100 year return interval flood zone. Some types of development are permitted with flood proofing	ENFRUDFF	Area	Yellow	Trans 25%	Black	Solid
			FW - Floodway	Interim (Under Review) Designated Floodway - 1:20 year return interval flood zone. Most types of development, particularly residential, may not be permitted.	ENFRUDFW	Area	Orange	Trans 25%	Black	Solid
			HS - Historical	Historical Flood Extent - Delineation of recorded extreme flood event	ENFRUDHS	Area	Pink	Trans 25%	Black	Solid
			IB - Ice or Debris Flood	Ice or Debris Flood - Delineation of recorded or estimated flood event with ice or debris blockages	ENFRUDIB	Area	Light Green	Trans 25%	Black	Solid

Dept	Data Type	Status	Feature	Description	FCODE	Feature Type	Fill Colour	Fill Type	Border Colour	Border Type
		FC - Flood Control	FC - Flood Control Area	Flood Control Area - Development may be restricted to ensure that the use of these areas is compatible with the flood hazard.	ENFRFCFC	Area	Red	Trans 50%	Black	Solid
			DT - Total Drainage Area	Total Drainage area at downstream limit of flood risk area	ENFRFDDT	Area	Cyan	Solid	Cyan	Solid
		FD - Flood Drainage	DS - Sub basin drainage area	DS - Sub basin drainage area, generally multiple areas as defined in the hydrotechnical study	ENFRFDDS	Area	Cyan	Trans 50%	Cyan	Solid
				Climate Change Floodway Fringe - 1:100 year return interval flood zone based on climate change projections		Area	Dark Green	Trans 50%	Black	Solid
				Climate Change Floodway - 1:20 year return interval flood zone based on climate change projections		Area	Light Green	Trans 50%	Black	Solid
				Depth Inundation Zones - Greater than 2.0 metres of water within floodway		Area	Dark Blue (R = 9, G = 9, B = 145)	Trans 50%	Black	Solid
				Depth Inundation Zones - 1.5 to 2.0 metres of water within floodway		Area	Medium Dark Blue (R = 29, G = 68, B = 184)	Trans 50%	Black	Solid
				Depth Inundation Zones - 1.0 to 1.5 metres of water within floodway		Area	Medium Blue (R = 31, G = 131, B = 224)	Trans 50%	Black	Solid
				Depth Inundation Zones - 0.5 to 1. metres of water within floodway		Area	Medium Light Blue (R = 116, G = 180, B = 232)	Trans 50%	Black	Solid
				Depth Inundation Zones - 0.0 to 0.5 metres of water within floodway		Area	Light Blue (R = 182, G = 237, B = 240)	Trans 50%	Black	Solid
				Depth Inundation Zones - normal water surface		Area	Light Blue Grey R = 224, G = 236, B = 235)	Trans 50%	Black	Solid

**Appendix E: Additional Terms and Conditions of Final Contract**

## **APPENDIX E: Additional Terms and Conditions**

### ***Acceptance of the Proposal***

The Department of Municipal Affairs and Environment (MAE) reserves the right not to accept any proposal. The RFP should not be construed as a contract to purchase services. The MAE shall not be obligated in any manner until a written agreement relating to an approved proposal has been duly executed.

### ***Proposal Revisions***

Proposal revisions must be received prior to the RFP submission/closing date and time.

### ***Financing of Proposals***

The cost associated with preparing and submitting proposals will not be paid by the MAE.

### ***Acceptance of RFP Conditions***

Receipt of proposal offer will be considered acceptance of the RFP terms and conditions by the Consultant, and will be incorporated in the Consultant's proposal.

### ***Subcontracting***

The use of subcontracted services is permitted but must be identified in the written proposal and is subject to the prior written approval of MAE. MAE reserves the right to include contract terms regarding the replacement of subcontractors.

### ***Negotiation Delay***

If a written contract cannot be concluded within (15) fifteen days of notification to the designated Consultant, the MAE may, at its sole discretion, terminate negotiations with that Consultant and either negotiate a contract with another Consultant in accordance with the established criteria under this RFP or choose to terminate the RFP process and not enter into a contract with any of the Consultants.

### ***Proposals as Part of Contract***

Proposals may be negotiated with Consultants and, if accepted, may form part of any contract awarded.

### ***Media Interviews***

Under no circumstances will any employee or representative of the Consultant consent to or provide any media interviews respecting or touching the Agreement of Service without specific written permission of the Review Committee.

### ***Indemnification***

Consultant hereby indemnifies and holds the MAE harmless of, from and against all claims, losses, damages, costs, expenses, and other actions made, sustained, brought, threatened to be brought or prosecuted, in any manner based upon, occasioned by or attributable to any:

- communication or action by Consultant in the performance or purported performance of this Agreement by Consultant;
- injury or death of a person, or loss or damage to property caused or alleged to be caused by Consultant in carrying out this project;
- claims relating to the infringement of copyright, trade marks, confidential information or any other intellectual property rights or the use of any other content of the research for which Consultant was required by this Agreement to obtain permission(s).

### ***Default***

The following events constitute Events of Default:

- Consultant becomes bankrupt or insolvent or is placed in receivership or takes the benefit of any statute relating to bankrupt or insolvent debtors;
- An order is made or resolution is passed for the winding up of Consultant, or Consultant is dissolved;
- Consultant is in breach of the performance of, or compliance with, any term, condition, or obligation on Consultant's part to be observed or performed, MAE had notified Consultant in writing of such breach, and Consultant has not remedied such breach within a reasonable time subsequent to the written notification;
- Consultant has submitted false or misleading information to the MAE;
- In the opinion of MAE acting reasonably, Consultant has failed to make satisfactory progress in carrying out the project.

In an Event of Default occurs, the MAE may avail itself of the following remedy:

(a) immediate termination of this Agreement. Upon termination, MAE shall cease to have any obligation to make any further payment of the eligible costs of the Project, with the exception of amounts owing on project deliverables or activities completed.

### ***Non-Waiver***

It is understood and agreed that either party may waive any provision of this Agreement intended for such party's sole benefit, but it is further agreed that any waiver of the performance of any condition by the other party shall not constitute a continuing waiver of any other or subsequent default, but shall include only the particular breach or default so waived.

### ***Disclaimers/Limitations of Liability***

Neither acceptance of a proposal nor execution of an Agreement shall constitute approval of any activity or development contemplated in any proposal that requires any approval, permit or license pursuant to any federal, provincial, regional district or municipal statute, regulation or by-law. It is the responsibility of the consultant to obtain such prior to commencement of the services under the proposed contract.

### ***Other Purpose***

This document or any portion thereof may not be used for any purpose other than the submission of proposals.

***Disclosure***

All documents submitted by Consultants shall become the property of the MAE, and as such will be subject to the disclosure provisions of the *Access to Information and Protection of Privacy Act*. Information pertaining to the MAE obtained by the Consultant as a result of participation in this project is confidential and must not be disclosed

The MAE reserves the right to modify the conditions of the RFP, at any time up to the closing time.

**THE MAE, ITS EMPLOYEES, AGENTS AND CONSULTANTS EXPRESSLY DISCLAIM ANY AND ALL LIABILITY FOR REPRESENTATIONS, WARRANTIES EXPRESSED OR IMPLIED OR CONTAINED IN, OR FOR OMISSIONS FROM THIS RFP PACKAGE OR ANY WRITTEN OR ORAL INFORMATION TRANSMITTED OR MADE AVAILABLE AT ANY TIME TO A CONSULTANT BY OR ON BEHALF OF THE STEERING COMMITTEE. NOTHING IN THIS RFP IS INTENDED TO RELIEVE A CONSULTANT FROM FORMING THEIR OWN OPINIONS AND CONCLUSIONS IN RESPECT TO THIS RFP.**

## **Appendix F: Map To Map Implementation Workflow**



## REPORT

# MAP TO MAP IMPLEMENTATION WORKFLOW

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# Map To Map Implementation Workflow

Author	Dean Djokic
Date	March, 2012
ArcGIS / Arc Hydro version	10 sp3 / 2.1.0.42
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# Map To Map Implementation Workflow

## Introduction

This document presents description of the Map To Map (M2M) implementation workflows developed for the Hydrologic Modelling Section, Water Resources Management Division, Department of Environment and Conservation, Government of Newfoundland and Labrador, Canada, (WRMD) in the context of modeling of impacts of global climate change (GCC) on flooding.

Map To Map is a concept initially developed and implemented in 2003 as a demonstration project of Model Builder capabilities. It was developed at the University of Texas at Austin by Oscar Robayo under guidance of David Maidment and support from Esri Inc. and US Army Corps of Engineers, Hydrologic Engineering Center (HEC) (<http://www.crrw.utexas.edu/gis/gishydro05/Modeling/Map2Map.htm>). The basic concept is to take a “map of rainfall” and transform it to the “map of flooding”, thus Map To Map.

Original implementation of M2M used HEC-HMS hydrologic model to transform the NEXRAD rainfall precipitation into discharges and HEC-RAS hydraulic model to calculate water surface elevations along cross-sections. Floodplain delineation was performed using ArcGIS processing capabilities and Model Builder for process automation. As a demonstration project, original M2M implementation was successful as it proved that such a concept can be successfully implemented within GIS environment. The original M2M implementation though had many custom parts that were “hand-crafted” for each model run and made it difficult to implement in a generic way. Also, they were not maintained as the components used for their initial implementation evolved.

With transition to ArcGIS 10, Arc Hydro tools implemented several of M2M original components and simplified the overall process. Arc Hydro infrastructure now allows M2M implementation that is simpler and more sustainable. Proper M2M implementation though requires careful considerations when developing both HMS and RAS models. WRMD’s focus on impacts of GCC adds additional requirements on the M2M process. The original M2M process did not consider potential changes in the models (e.g. model parameters) and boundary conditions, just changes in precipitation over a fixed H&H environment and mapping of that change into floodplain. With GCC concerns, fixed H&H environments cannot be assumed.

The scope of this document is to present the M2M implementation workflows using existing ArcGIS and Arc Hydro infrastructure, focusing on specific WRMD requirements for GCC modeling. Tools that would make that process easier but do not currently exist are identified. The workflows are described by presenting a specific use case for a flood study performed for the Shearstown area, by Hatch in 2012. The intent is that this document can be used as a blueprint for future studies of similar type and facilitate efficient integrated H&H model development with respect to M2M implementation.

Documentation and evaluation of the results of hydrologic and hydraulic models run to support GCC impact assessment can be complex and is out of scope of this document. GIS technology can be used for such documentation and evaluation and further study can be undertaken to identify effective GIS role and products that could be produced to support GCC evaluation.

### **GIS data and H&H models**

GIS data and hydrologic (HEC-HMS) and hydraulic (HEC-RAS) models for the Shearstown area used in this document were provided by the WRMD. They were used as is without any changes, except in few places to facilitate M2M process. These changes will be highlighted in the latter text as they are critical for successful M2M implementation.

### **Software environment**

All processing was performed using Arc Hydro version 2.1.0.42 (March 2012) operating on ArcGIS V10 sp3.

### **Organization of the document**

Document has two main sections. The first section describes the organization of the key M2M components. The second section then presents explicit example using sample data and “design” M2M workflow scenario.

## Map To Map Methodology for GCC

### Introduction

The basic M2M concept is to take a “map of rainfall” and transform it to the “map of flooding”, by first applying a hydrologic model to transform rainfall into discharge and then use the discharge in the hydraulic model to get water surface elevations (WSE) at cross-sections. These WSE are then mapped into floodplain using GIS processing. The original M2M implementation had the following steps:

- 1) Transform spatially distributed rainfall (time series) obtained from NEXRAD polygons to HMS subbasin polygons (GIS operation).
- 2) Convert GIS time series into DSS (custom code).
- 3) Run HMS model using DSS input (generates DSS output).
- 4) Convert HMS DSS to RAS DSS (custom code).
- 5) Run RAS using DSS as input.
- 6) Post process RAS results to floodplain (GIS operation).

In this workflow, neither HMS and RAS models, nor RAS boundary conditions change. The only thing that changes is the rainfall input. This is the “operational” scenario.

In the context of global climate change analyses, M2M consists of running hydrologic (HEC-HMS) and hydraulic (HEC-RAS) models in a sequence with different initial and boundary conditions. Normally these operations are performed for steady-state design conditions and not in real-time operational conditions as the original M2M. This is the “design” scenario. There are several conditions that can be investigated:

- Change in landscape affecting hydrologic model (e.g. land use change, impervious area change, etc.). These changes would generate changes to the hydrologic model (basin model in HMS).
- Changes in landscape affecting hydraulic model (e.g. change in hydraulic properties such as roughness coefficients, or changes in channel morphology that would affect channel geometry). These changes would generate changes to the hydraulic model (geometry model in RAS).
- Changes in (design) rainfall pattern. In HMS, these changes would generate a different time series for the design gage (a different gage) used in the model if uniform rainfall distribution is used (typical implementation), or change in the whole met model if change in spatial distribution of rainfall is investigated.
- Change in hydraulic boundary conditions to the hydraulic model (flow model in RAS).

For NL GCC implementation, focus was on changes to design rainfall and hydraulic boundary conditions. The organization of the data and models for M2M process presented in this document will support all four types of changes that can be investigated. The examples though will focus on design rainfall and boundary change implementation.

The intent of M2M process is to minimize necessary manual interaction between the end user and the process of model and initial/boundary condition selection, and the model execution. This requires very specific organization of the models and the data, sometimes against the standard industry practices. The following sections describe individual components of the M2M process and identify how each component needs to be configured to enable effective incorporation within the M2M infrastructure.

## HMS model setup requirements

In order to run “Run HMS” AH function (that runs HMS in “silent mode” in the background) names of the hms project, basin, gage, and met files **MUST** have the same name. This requirement dictates the naming used for model components and significantly limits any naming flexibility.

One HMS model should have only one basin, one met, one gage, and one control component (while a single HMS model used in M2M can have multiple components, they cannot be used since only the component that has the same name as the model itself can be executed in automated way).

For design conditions modeling, the precipitation time series does not vary in space. Thus, a single “design” gage can be developed for each design condition (e.g. 100-year, 24-hour, current condition) and applied uniformly to each subbasin in HMS.

In HMS model setup, time series data associated with the input precipitation must be separate and completely independent from the spatial “paired data” (e.g. storage-discharge or cross-section data). The precipitation data will be stored in a dss file that is directly tied into the “design” gage data and does not depend on the geometry of the model but only on the precipitation event being used for the modeling. The name of the dss storing the temporal data will be the same as the name of the HMS model. Any “paired data” must be stored in a dss file that is directly associated with the geometry of the model and has a different name than the HMS model name.

## GeoHMS model setup requirements

There are a few restrictions on GeoHMS model development. GeoHMS is not used dynamically in the M2M process, that is, it is not called directly to update any of the parameters. GeoHMS is used only in HMS model development. In design conditions discussed here, that is even more pronounced as the distribution of precipitation is applied uniformly and does not depend on the spatial characteristics of the HMS subbasins.

Once GeoHMS model is defined in spatial context, the only significant consideration is definition of “design gage”. In the GeoHMS subbasin file, there is “PrecipGage” field that needs to contain the name of the design gage to be used for precipitation model. That name must **exactly** match the name of the design gage that has the dss file with the precipitation time series to be used in the model and is referenced in the “.gage” HMS file. That name will then be exported into the “.met” file generated by GeoHMS that will link the subbasin name to that gage name.

If several precipitation models will be analyzed, a “.met” file needs to be generated for each precipitation model (design gage).

In order to be consistent and enable potential use for GeoHMS/HMS models in a broader M2M context (operational mode), the following best practices should be followed:

- 1) GeoHMS and HMS subbasins should match in spatial context. Basically the GeoHMS derived subbasins should not be manually modified within HMS (their spatial extent and shape). Instead, if any discrepancies are observed, GeoHMS model should be updated and new HMS basin file generated. This will ensure that GeoHMS subbasins can then be used for calculation of spatially varying rainfall in operational conditions.

## RAS model setup requirements

In order to run “Run RAS” AH function (that runs RAS in “silent mode” in the background) definition of the RAS run MUST be specified by fully defined RAS “.prj” file. The geometry, flow, and plan file extensions should be named consistently (e.g. g01, f01, and p01 respectively) and referenced as such in the “.prj” file. RAS project should reference only one geometry, one flow, and one plan.

Flow exchange points where the flows will be passed on from HMS to RAS have to be explicitly defined in RAS. This is done by specifying the “Node Name” of the cross-section that will be receiving the flow from HMS to be the name of the HMS element (normally that will be a HMS junction element) that will be the source of the flow. Normally, that will be assigned to the cross-section in GeoRAS and brought into the RAS through GIS data import option.

## GeoRAS model setup requirements

There are a few restrictions on GeoRAS model development. GeoRAS is not used dynamically in the M2M process, neither in pre- or post-processing. GeoRAS is used only in RAS model development. For post-processing of RAS results, only AH and standard ArcGIS geoprocessing functions are used.

When developing GeoRAS model, cross-sections that serve as flow exchange points need to be linked to the HMS elements that provide the flow to that cross-section. This is done by populating the “NodeName” attribute in the GeoRAS cross-section cut line feature class with the name of the HMS element providing the flow (e.g. “J28” if junction with name J28 is the one providing the flow). This is done by hand. Once the GeoRAS generates the RAS .sdf file, node name will be passed on to RAS and will not have to be populated in RAS explicitly.

## M2M component automation

HMS and RAS input file structures and tool operations define the approach that has to be taken in defining the variation of the M2M runs. There are three key components in M2M process definition:

- 1) Organization of viable model alternatives (HMS/RAS).
- 2) Selection of model components to represent a single M2M run (which precipitation event is to be combined with what hydrologic and hydraulic environment and boundary conditions).
- 3) Running of the M2M model alternative.

In addition, the results need to be archived for later analysis and documentation. M2M component automation can take many forms depending on the organizational and project needs. In this document, individual M2M workflow steps are presented and then a specific set of automated processes are presented as an example of what can be accomplished.

## M2M data organization

To enable effective management of M2M model components, a simple directory and model naming structure is recommended to keep models independent and easily accessible. The structure is based on keeping the model component names fixed (all models have the same component names) and utilizing names of folders to differentiate between the alternatives. This is driven by the complex structure of HMS and RAS control files. If model components are allowed to have flexible names, each time a M2M run was constructed, HMS and RAS control file would have to be created/modified on the fly. While possible, that is risky as these structures can change with new HMS/RAS releases making the maintenance of the system difficult and less sustainable.

The following general directory structure is recommended (only key files are highlighted in each directory). The actual names of directories and files are not important and can be changed as desired. It is suggested though, that once the names are fixed, they are not changed to facilitate documentation and implementation.

```

MapToMap\
  Maptomap.gdb          geodatabase with reference layers
  HMS\
    Dss\
      Rmodel1\HMSM2M.dss
      Rmodel2\HMSM2M.dss
      Rmodel3\HMSM2M.dss
    Basin\
      Smodel1\HMSM2M.basin, HMSM2M.met
      Smodel2\HMSM2M.basin, HMSM2M.met
      Smodel3\HMSM2M.basin, HMSM2M.met
    Fix\HMSM2M.gage, HMSM2M.hms
    CurrentRun\         (for selected Rmodel# and Smodel*)
      HMSM2M.dss        from "Rmodel#" directory
      HMSM2M.basin      from "Smodel*" directory
      HMSM2M.met        from "Smodel*" directory
      HMSM2M.gage       from "Fix" directory
      HMSM2M.hms        from "Fix" directory
  GeoHMS\
    Smodel1\ all GeoHMS data for support of HMS spatial model 1
    Smodel2\ all GeoHMS data for support of HMS spatial model 2
    Smodel3\ all GeoHMS data for support of HMS spatial model 3
  RAS\
    BoundaryConditions\
      BC1\RASM2M.f01, RASM2M.p01
      BC2\RASM2M.f01, RASM2M.p01
      BC3\RASM2M.f01, RASM2M.p01
    Geometry\
      Smodel1\RASM2M.prj, RASM2M.g01
      Smodel2\RASM2M.prj, RASM2M.g01
      Smodel3\RASM2M.prj, RASM2M.g01
    CurrentRun\         (for selected BC# and Smodel*)
      RASM2M.f01        from "BC#" directory
      RASM2M.g01        from "BC#" directory
      RASM2M.f01        from "Smodel*" directory
      RASM2M.prj        from "Smodel*" directory
  GeoRAS\
    Smodel1\ all GeoRAS data for support of RAS spatial model 1
      \Layers\demfp     DEM to be used for floodplain delineation
    Smodel2\ all GeoRAS data for support of RAS spatial model 2
      \Layers\demfp     DEM to be used for floodplain delineation
    Smodel3\ all GeoRAS data for support of RAS spatial model 3
      \Layers\demfp     DEM to be used for floodplain delineation
  ResultArchive\
    Run_ID%%%\ (single combination of HMS (Rmodel# and Smodel*) and RAS (BC# and
      Smodel*). There needs to be a control table/file with the list of all the HMS
      and RAS components that went into that run and description of why that run
      was done. %%% is the unique identifier of the run.
    HMS\all HMS files for that run
    RAS\all RAS files for that run
    GeoRAS\ all postprocessed spatial data

```

Figure 1. M2M directory structure.

Directory structure explanation:

- 1) In order to automate component processing in the M2M, specific naming of M2M processing elements is recommended:
  - a. All HMS components should be named “HMSM2M”.
    - i. Exception is naming of design gaging stations that can have any name.
  - b. All RAS components should be named “RASM2M”.
- 2) All M2M related files are organized under single parent directory called “MapToMap”.
- 3) Maptomap.gdb contains all “global” spatial layers that are used to support the M2M implementation. At least this includes the M2MRUN table (described later in the text). It can also include any background spatial layers that can be used to support M2M implementation (e.g. RAS/HMS model footprints, political/natural reference layers to be used in M2M starting map, etc.).
- 4) “HMS” directory contains all files related to HMS models.
  - a. “Dss” directory contains design precipitation time series data. The name of the dss file is the same for all possible precipitation scenarios – “hmsm2m.dss”. Every precipitation scenario has its own unique directory name (denoted as “Rmodel1”, “Rmodel2”, etc.). This directory name can be user specified and can reflect specific scenario for easy identification (e.g. “D\_100\_24” for “design, 100-year, 24-hour storm”).
  - b. “Basin” directory contains specific basin and met models. These are specific combinations of HMS spatial elements (basin file) and precipitation scenarios applied to them (met file). Each subdirectory (denoted as “Smodel1”, “Smodel2”, etc.) presents one unique combination of basin and met models. This directory name can be user specified and can reflect specific scenario for easy identification (e.g. “Shearstown\_D\_100\_24” for “Shearstown area, design storm, 100-year, 24-hour storm”).
    - i. Example 1. If the same basin model is modeled with two different precipitation scenarios, there will be two “S\*” directories, in which the basin files will be the same and met models will be different (pointing to a different design gage).
    - ii. Example 2. If the same precipitation is used with two HMS models for the same area (e.g. change in subbasin layout or model parameter to accommodate fully developed conditions), there would be two “S\*” directories, in which the basin files will be different and met models will be the same.
  - c. “Fix” directory contains two files that are the same for all combinations. This is the “HMSM2M.gage” file that has reference to all the design gages, and “HMSM2M.hms” that always references the same basin and met components.
  - d. “Currentrun” directory contains the complete HMS model that is currently being analyzed.
- 5) “GeoHMS” directory contains all the spatial data used in GeoHMS for HMS model development. Each “S\*” subdirectory matches the names in the “HMS\Basin\S\*” directory and contains all the spatial data for development of HMS basin and met model contained in the “HMS\S\*” directory.
- 6) “RAS” directory contains all files related to RAS models.



- a. “BoundaryConditions” directory contains specific flow (“RASM2M.f01”) and plan (“RASM2M.p01”) files that define the boundary conditions and flow exchange points for a particular scenario for a particular location. Each subdirectory (denoted as “BC1”, “BC2”, etc.) presents one unique combination of geometry and boundary conditions. This directory name can be user specified and can reflect specific scenario for easy identification (e.g. “Shearstown\_Current\_100” for “Shearstown area, current conditions, 100-year design storm”).
  - b. “Geometry” directory contains specific RAS geometry and project files. These are specific combinations of RAS spatial elements (geometry file) and project elements. Each subdirectory (denoted as “Smodell1”, “Smodell2”, etc.) presents one unique geometry model. This directory name can be user specified and can reflect specific scenario for easy identification (e.g. “Shearstown\_D\_100\_24” for “Shearstown area, design storm, 100-year, 24-hour storm”). Although this name does not need to match the HMS “Basin\S\*” name, it is good practice to do so for RAS model that matches the HMS model (points to the same flow exchange points).
  - c. “Currentrun” directory contains the complete RAS model that is currently being analyzed.
- 7) “GeoRAS” directory contains all the spatial data used in GeoRAS for RAS model development (preprocessing). Each “S\*” subdirectory matches the names in the “RAS\Geometry\S\*” directory and contains all the spatial data for development of RAS geometry and flow files.
- a. The subdirectory \Layers contains Esri grid “demfp” that is the DEM to be used in post-processing. This grid needs to have the appropriate spatial extent and resolution (cell size).
- 8) “ResultArchive” directory contains archive of all the results of M2M runs. Each subdirectory contains one combined HMS-RAS run. Subdirectories are referenced by the run ID. The ID is maintained in the M2MRUN table and uniquely identifies the combination of HMS and RAS modeling alternatives used for that particular M2M run.
- a. “HMS” directory contains all the HMS files for the run.
  - b. “RAS” directory contains all the RAS files for the run.
  - c. “GeoRAS” directory contains all the postprocessed spatial layers (floodplain polygon and depth grid) for the run.

It is not recommended that input spatial data be archived for each run. While it is anticipated that HMS and RAS models might be calibrated in RAS and HMS and thus a particular run might be slightly different from the “raw” input data and need to be explicitly archived to preserve those “tweaks”, for spatial data if changes are being made, they should be done on the core data level and that spatial model needs to be stored as an explicit new model. Thus archiving of spatial (GIS) component is not needed as they are available in their respective model folder as is. Postprocessed spatial data (at least flood depth and extent) are archived.

## Selection of model components to represent a single M2M alternative run

A single M2M run consists of one chained execution of HMS and RAS models and RAS model result mapping (flood depth and extent definition). Definition of the HMS and RAS models has the following elements:

- 1) Selection of precipitation model (\*.dss).
- 2) Selection of HMS spatial model (\*.basin).
- 3) Selection of RAS spatial model (\*.g01).
- 4) Selection of RAS boundary conditions (\*.f01).

In addition, a name and some description of the model run should be provided. These data are stored in the M2MRUN table stored in the “Maptomap.gdb” geodatabase. The M2MRUN table has the following structure:

Field Name	Field Type	Description
ID	Long	Unique internal identifier for the run
M2MRUNNAME	Char 30	Short name of the run
PMODEL	Char 30	Name of the relative directory containing the precipitation model to use
HMSMODEL	Char 30	Name of the relative directory containing the HMS spatial model to use
RASMODEL	Char 30	Name of the relative directory containing the RAS spatial model to use
BCMODEL	Char 30	Name of the relative directory containing the RAS boundary conditions to use
DESCRIPTION	Char 100	Model run description
ISRUN	Long	Field indicating whether the model has been run or not. 0 – not run, 1 – already run and the result directory exists

Table 1. M2MRUN table structure.

NOTE: At this point, there is not an Arc Hydro tool to populate this table. It needs to be populated manually.

Once the M2M alternative is executed, the “ISRUN” field is set to 1. The results are stored in the ResultArchive\Run\_ID%%%\ directory where %%% is the values of the ID field for that alternative.

## Map2Map example run

### Data organization

To demonstrate the basic principles of M2M implementation, Shearstown data that were provided were organized in the proposed structure and a sample M2M run was performed.

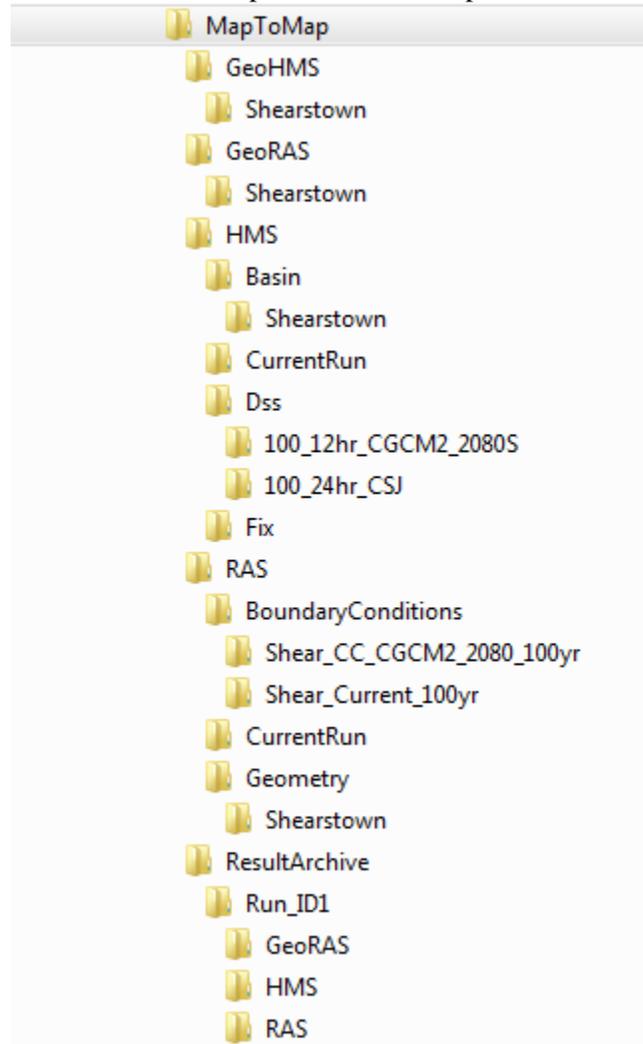


Figure 2. M2M directory structure for the example.

The following scenarios are presented:

- 1) Rainfall model. There are two models:
  - a. Current conditions – 100 year, 24-hour.
  - b. CC precipitation distribution – 100 year, 12-hour, CGCM2 model for 2080.
- 2) Spatial HMS model. There is one HMS basin model.
  - a. Shearstown.
- 3) Spatial RAS model. There is one RAS geometry model.
  - a. Shearstown.

- 4) RAS Boundary conditions. There are two boundary conditions:
  - a. Current conditions – 100 year event.
  - b. CC conditions – CGCM2, 2080 – 100 year event.
- 5) GeoHMS. There is one GeoHMS model.
- 6) GeoRAS. There is one GeoRAS model.

## **M2M model component modification**

Minor changes to the original models and GIS data were necessary to enable their inclusion in the M2M workflow.

- 1) HMS model was simplified to contain only one basin, one met, one gage, and one control component.
- 2) All components of the HMS model were renamed according to proposed structure and placed in proper directory structure.
- 3) Temporal and spatial paired data were placed in separate dss files (HM2M.dss for temporal data and HM2M\_PairedData.dss for spatial data).
- 4) RAS model was simplified to contain only one geometry, one flow profile, one flow file, and one steady plan file.
- 5) All components of the RAS model were renamed according to proposed structure and placed in proper directory structure.
- 6) In RAS, for all RAS cross-sections receiving flows from HMS, their NodeName was populated with appropriate junction label matching HMS junction providing the flows.
- 7) In the GeoRAS cross-section (cut line) feature class, for all cross-sections receiving flows from HMS, their NodeName was populated with appropriate junction label matching HMS junction providing the flows.

## **M2M workflow execution**

### **M2M HMS model component run**

This section presents individual tool runs for the part of M2M workflow that runs HMS and generates flows that need to be “moved” to RAS. It is envisioned that this will be one of the M2M sub-models. The starting point for the analysis is an ArcMap project with the DEM and GeoRAS cross-sections loaded. The project needs to be saved before running any of the tools.

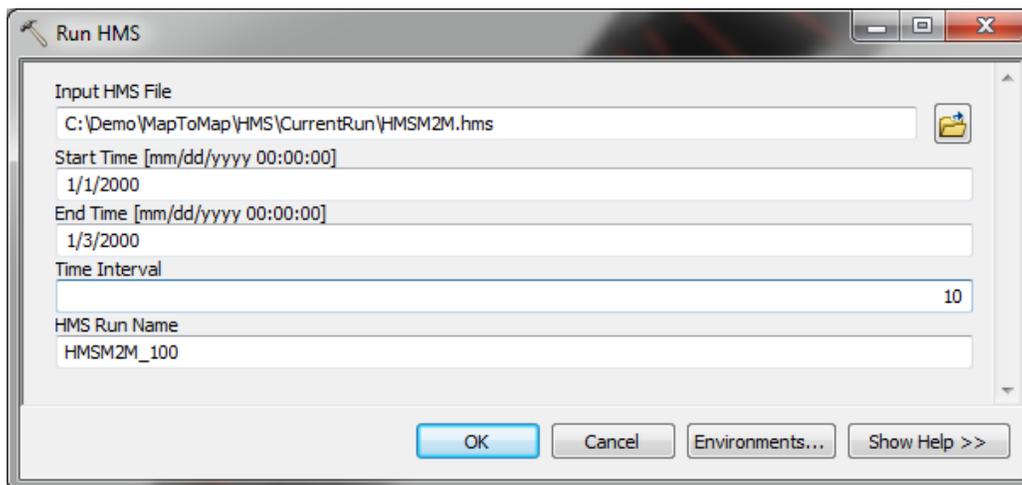
RAS \*.f01 file (this is a flow file that has boundary conditions for the RAS run) before running the HMS M2M operations has the following content (“RASM2M.f01”):

```

1 Flow Title=FloodM2MP_100
2 Program Version=4.10
3 Number of Profiles= 1
4 Profile Names=1:100
5 River Rch & RM=Shearstown_Brook,Main          , 6544.472
6     38
7 River Rch & RM=Shearstown_Brook,Main          , 4527.462
8     42
9 River Rch & RM=Shearstown_Brook,Main          , 2846.736
10    53
11 River Rch & RM=Shearstown_Brook,Main          , 1960.358
12    57
13 Boundary for River Rch & Prof#=Shearstown_Brook,Main          , 1
14 Up Type= 3
15 Up Slope=0.0001
16 Dn Type= 1
17 Dn Known WS=1.7
18 DSS Import StartDate=
19 DSS Import StartTime=
20 DSS Import EndDate=
21 DSS Import EndTime=
22 DSS Import GetInterval= 0
23 DSS Import Interval=
24 DSS Import GetPeak= 0
25 DSS Import FillOption= 0
26

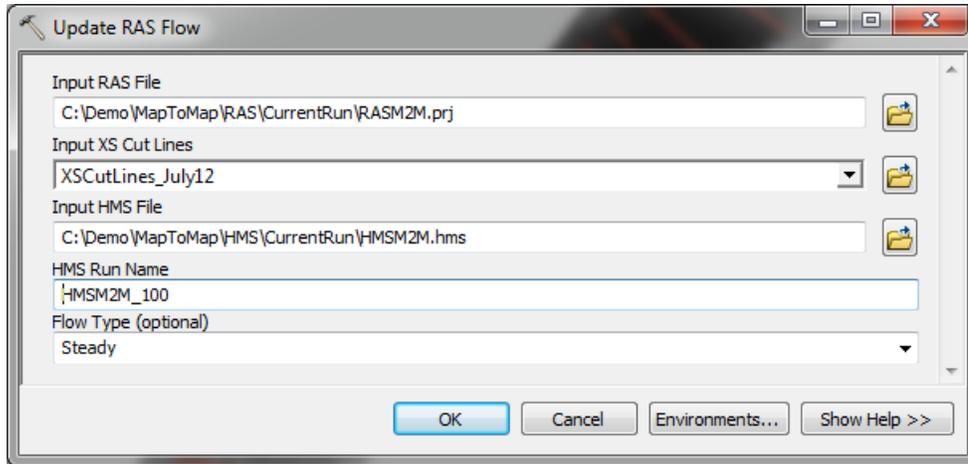
```

- 1) Run “Run HMS” from “Arc Hydro -> H & H Modeling -> Map to Map” toolbox. Input elements match manually run HMS model. A new “.control” and “.script” files are created based on provided “HMS Run Name”. “.run” file is updated. The result of the tool is a HMS run whose results are stored in the model “.dss” file. All files will be in the same directory as specified “.hms” file.



```
Executing: RunHMS C:\Demo\MapToMap\HMS\CurrentRun\HMSM2M.hms 1/1/2000
1/3/2000 10 HMSM2M_100
Start Time: Wed Mar 28 03:14:36 2012
Succeeded at Wed Mar 28 03:14:46 2012 (Elapsed Time: 10.00 seconds)
```

- Run "Update RAS Flow" from "Arc Hydro -> H & H Modeling -> Map to Map" toolbox. The result of the tool is modified "\*.prj" file for the specified RAS model .xml file version of the input .sdf file. File will be in the same directory as RAS input files.



```
Executing: UpdateRASFlow C:\Demo\MapToMap\RAS\CurrentRun\RASM2M.prj
XSCutLines_July12 C:\Demo\MapToMap\HMS\CurrentRun\HMSM2M.hms HMSM2M_100
Steady
Start Time: Wed Mar 28 03:18:56 2012
Reading DSS path and updating RAS flow..
Flow values updated for 4 features from DSS File
C:\Demo\MapToMap\HMS\CurrentRun\HMSM2M.dss!
Succeeded at Wed Mar 28 03:18:58 2012 (Elapsed Time: 2.00 seconds)
```

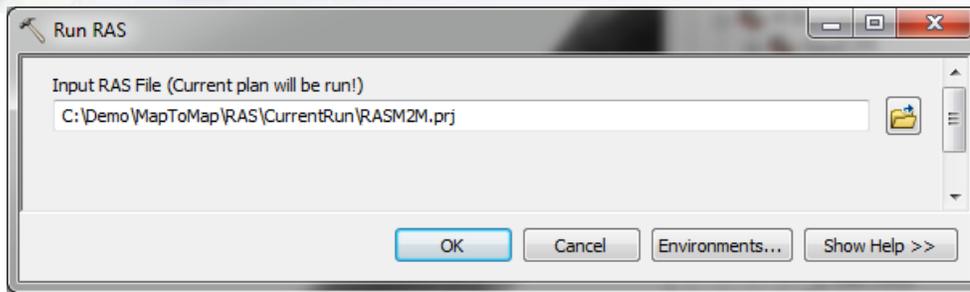
### M2M RAS model component run

This section presents individual tool runs for the part of M2M workflow that runs RAS and generates output geodatabase with results. It is envisioned that this will be one of the M2M sub-models. Generated geodatabase will contain at least:

- Stream centerline (2D)
- Cross-sections (2D) with water surface elevation field populated
- Bounding polygon

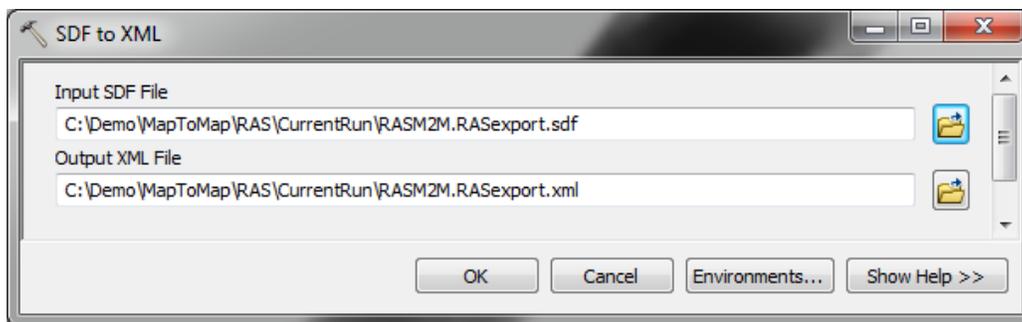
The starting point for the analysis is an ArcMap project with the DEM loaded. The project needs to be saved before running any of the tools.

- Run "Run RAS" from "Arc Hydro -> H & H Modeling -> Map to Map" toolbox. The result of the tool is a RAS run with export of results into .sdf file. File will be in the same directory as RAS input files.



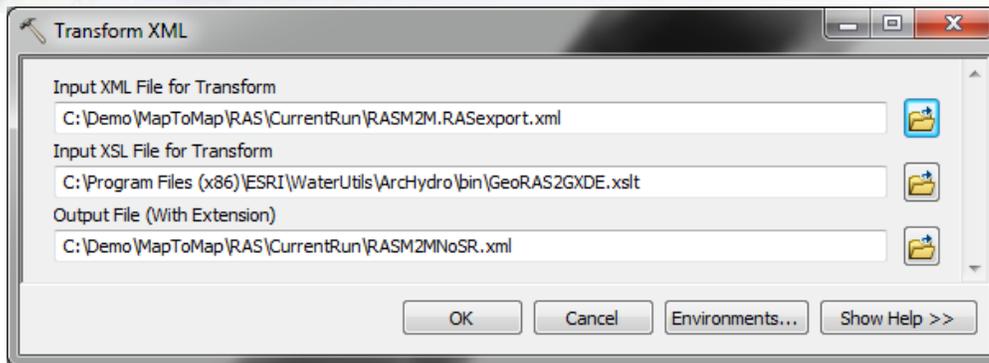
```
Executing: RunRAS C:\Demo\MapToMap\RAS\CurrentRun\RASM2M.prj
Start Time: Wed Mar 28 03:23:57 2012
RAS run results exported to
C:\Demo\MapToMap\RAS\CurrentRun\RASM2M.RASexport.sdf.
Succeeded at Wed Mar 28 03:24:00 2012 (Elapsed Time: 3.00 seconds)
```

- 2) Run "SDF to XML" from "Arc Hydro -> H & H Modeling -> Map to Map" toolbox. The result of the tool is .xml file version of the input .sdf file. File will be in the same directory as RAS input files.



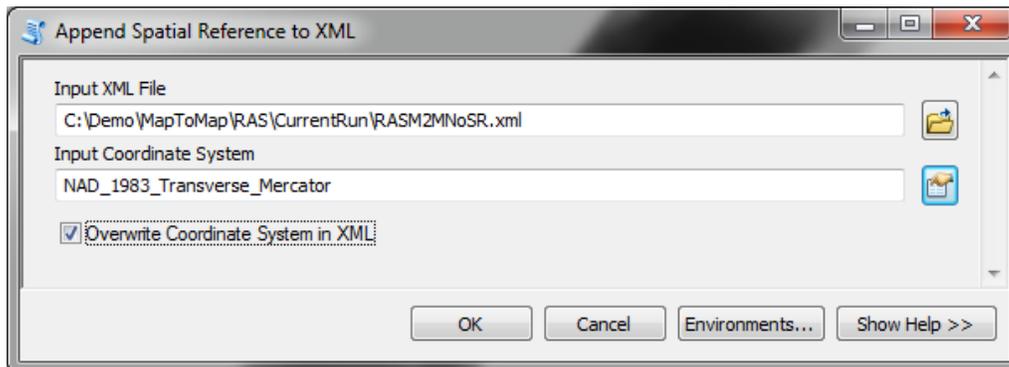
```
Executing: SDFToXML C:\Demo\MapToMap\RAS\CurrentRun\RASM2M.RASexport.sdf
C:\Demo\MapToMap\RAS\CurrentRun\RASM2M.RASexport.xml
Start Time: Wed Mar 28 03:26:18 2012
Converting SDF to XML...
SDF successfully converted
C:\Demo\MapToMap\RAS\CurrentRun\RASM2M.RASexport.xml
Succeeded at Wed Mar 28 03:26:18 2012 (Elapsed Time: 0.00 seconds)
```

- 3) Run "Transform XML" from "Arc Hydro -> GIS Data Exchange -> XML Exchange" toolbox. The result of the tool is transformed .xml file version (AH generic) of the input .xml file (model specific). File will be in the same directory as RAS input files. Proper XSLT needs to be specified for RAS->AH xml format conversion ("GeoRAS2GXDE.xslt" from Arc Hydro bin directory – usually C:\Program Files (x86)\ESRI\WaterUtils\ArcHydro\bin).



```
Executing: TransformXML C:\Demo\MapToMap\RAS\CurrentRun\RASM2M.RASexport.xml
"C:\Program Files (x86)\ESRI\WaterUtils\ArcHydro\bin\GeoRAS2GXDE.xslt"
C:\Demo\MapToMap\RAS\CurrentRun\RASM2MNoSR.xml
Start Time: Wed Mar 28 03:30:10 2012
Succeeded at Wed Mar 28 03:30:11 2012 (Elapsed Time: 1.00 seconds)
```

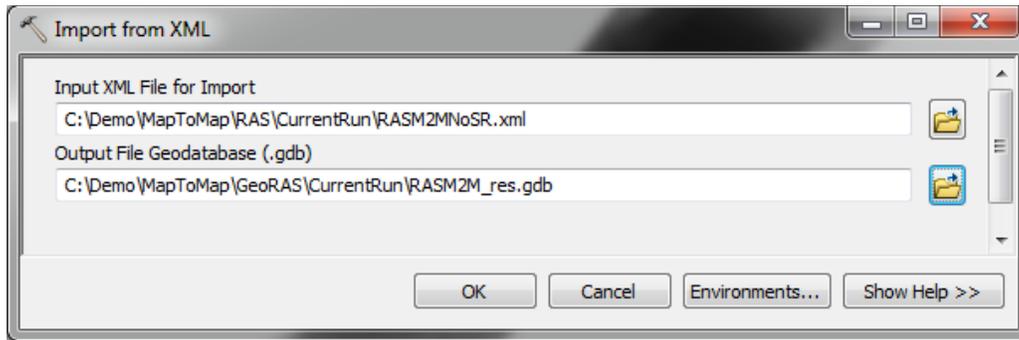
- 4) Since the original sdf file generated by RAS does not contain information about spatial reference that is needed to construct the result's geodatabase, the XML generated in the previous step needs to be updated with the spatial reference information. Run "Append Spatial Reference to XML" from "Arc Hydro -> GIS Data Exchange -> XML Exchange" toolbox. The result of the tool is updated .xml file with <WKT> element properly populated (no new file is created – the input file is updated). When asked for "Input Coordinate System", click on  next to it to open the spatial reference "picker", select "Import ..." option and navigate to the DEM.



```
Executing: AppendSpatialReferencetoXML
C:\Demo\MapToMap\RAS\CurrentRun\RASM2MNoSR.xml
PROJCS['NAD_1983_Transverse_Mercator',GEOGCS['GCS_North_American_1983',DATUM
['D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],PRIME
M['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['Transverse
_Mercator'],PARAMETER['False_Easting',304800.0],PARAMETER['False_Northing',0
.0],PARAMETER['Central_Meridian',-
53.0],PARAMETER['Scale_Factor',0.9999],PARAMETER['Latitude_Of_Origin',0.0],U
NIT['Meter',1.0]] true
Start Time: Wed Mar 28 03:32:23 2012
Running script AppendSpatialReferencetoXML...
Replacing coordinate system...
```

Completed script AppendSpatialReferencetoXML...  
Succeeded at Wed Mar 28 03:32:25 2012 (Elapsed Time: 2.00 seconds)

- 5) Now the generic import XML is ready and can be used to generate the results geodatabase. Run “Import from XML” from “Arc Hydro -> GIS Data Exchange -> XML Exchange” toolbox. The result of the tool is geodatabase according to GeoRAS import specifications.



```
Executing: ImportFromXML C:\Demo\MapToMap\RAS\CurrentRun\RASM2MNoSR.xml
C:\Demo\MapToMap\GeoRAS\CurrentRun\RASM2M_res.gdb
Start Time: Wed Mar 28 03:37:59 2012
Succeeded at Wed Mar 28 03:38:06 2012 (Elapsed Time: 7.00 seconds)
```

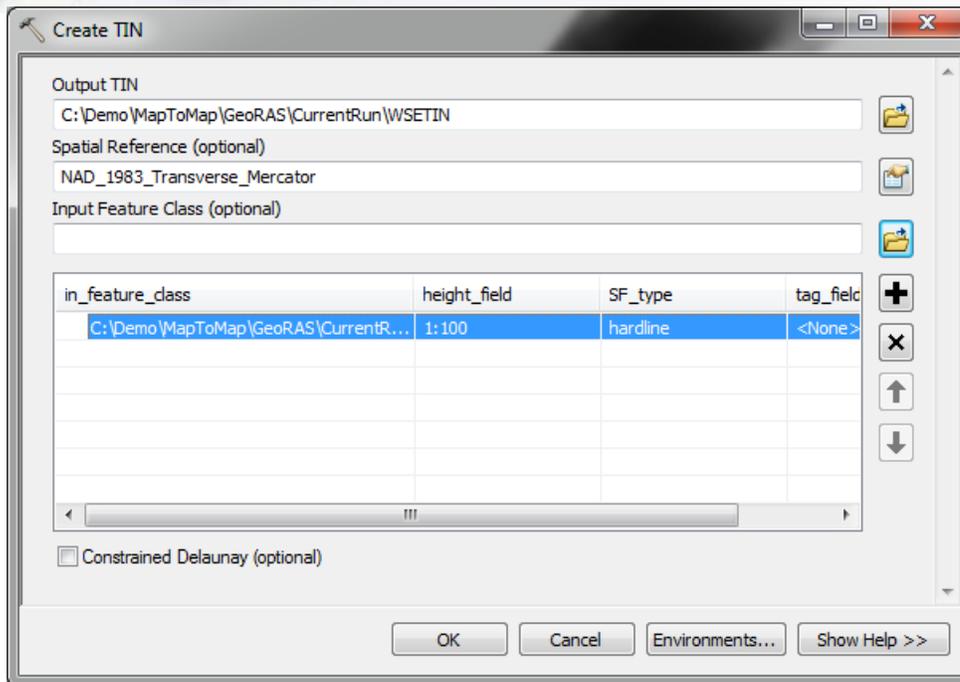
The features in the resulting geodatabase are not added to the map.

### M2M RAS results mapping component run

This section presents individual tool runs for the part of M2M workflow that generates floodplain extent polygon and flood depth based on RAS result geodatabase created in the previous sub-model. It is envisioned that this will be one of the M2M sub-models.

The starting point for the sub-model is an ArcMap project with the DEM loaded and RAS results geodatabase generated by the previous sub-model. The project needs to be saved before running any of the tools. This can be the same project from the previous step.

- 1) Run “Create TIN” from “3D Analyst -> TIN Management” toolbox. Define the spatial reference to be the same as for the DEM. Select as “in\_feature\_class” XSCutLine feature class from the RAS results geodatabase created in the previous step. Specify “1:100” as the height\_field from which to extract water surface elevations. The result of the tool is water surface elevation TIN surface whose extent is defined by the extent of cross-sections.

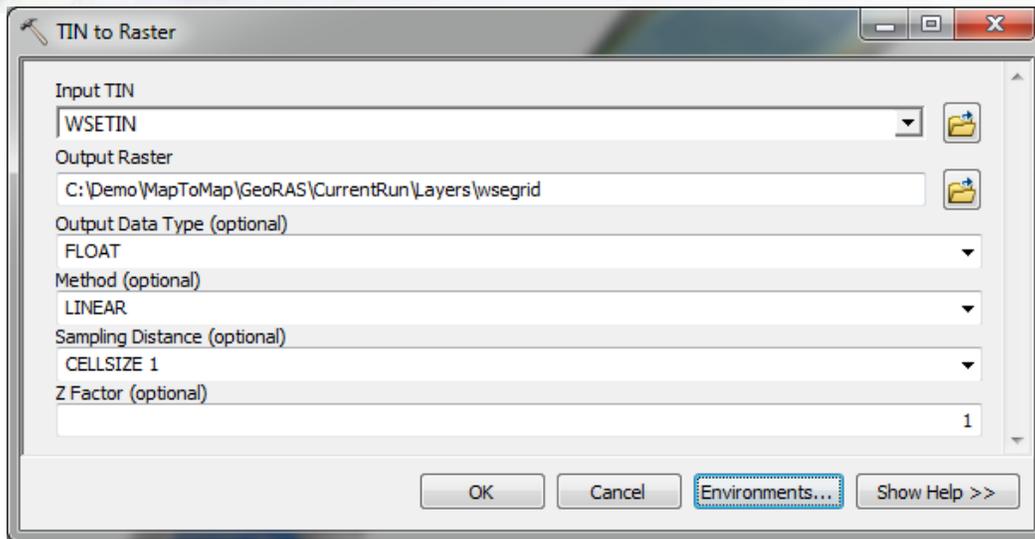


```

Executing: CreateTin C:\Demo\MapToMap\GeoRAS\CurrentRun\WSETIN
PROJCS['NAD_1983_Transverse_Mercator',GEOGCS['GCS_North_American_1983',DATUM
['D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],PRIME
M['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['Transverse
_Mercator'],PARAMETER['False_Easting',304800.0],PARAMETER['False_Northing',0
.0],PARAMETER['Central_Meridian',-
53.0],PARAMETER['Scale_Factor',0.9999],PARAMETER['Latitude_Of_Origin',0.0],U
NIT['Meter',1.0]]
"C:\Demo\MapToMap\GeoRAS\CurrentRun\RASM2M_res.gdb\RasResults\XSCutlines
1:100 hardline <None>" DELAUNAY
Start Time: Wed Mar 28 03:48:34 2012
Succeeded at Wed Mar 28 03:48:34 2012 (Elapsed Time: 0.00 seconds)

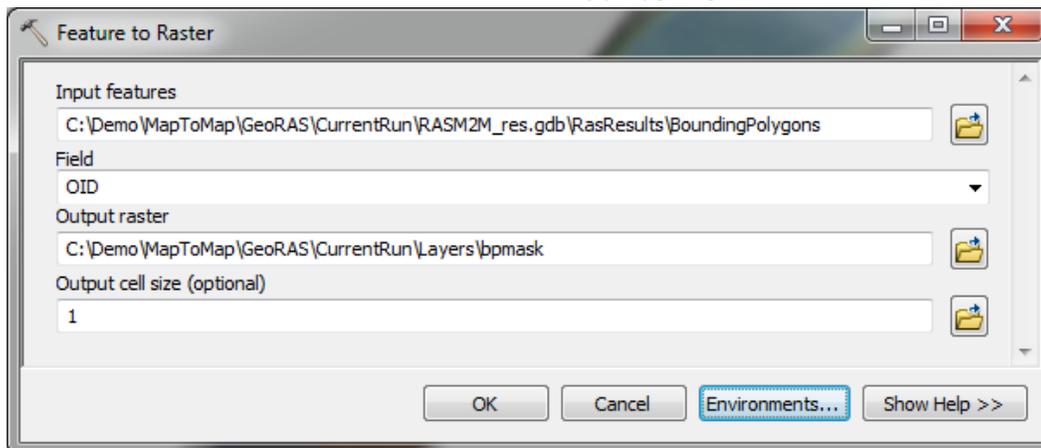
```

- Convert WSE TIN to a WSE grid. Run "TIN to Raster" from "3D Analyst -> Conversion -> From TIN" toolbox. Define environments: snap raster = DEM. Set the Sampling Distance as "CELLSIZE 1" for example, where 1 is the cell size of the DEM. The result of the tool is water surface elevation grid.



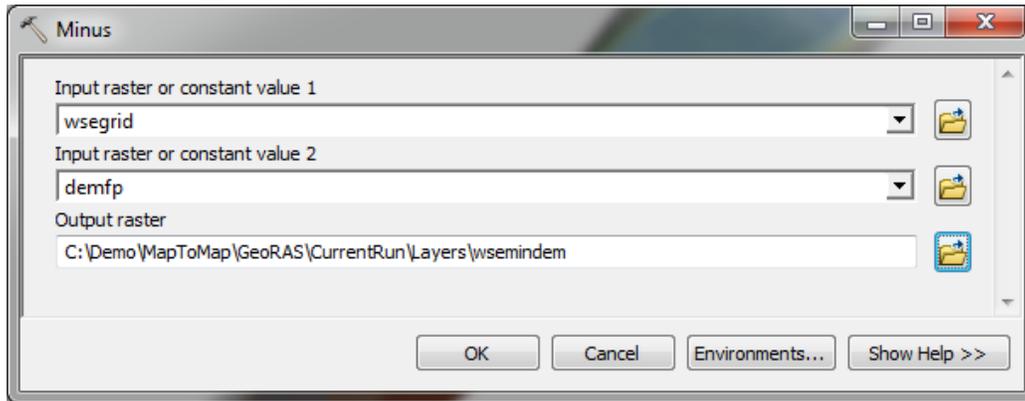
```
Executing: TinRaster WSETIN
C:\Demo\MapToMap\GeoRAS\CurrentRun\Layers\wsegrid FLOAT LINEAR "CELLSIZE 1"
1
Start Time: Wed Mar 28 03:52:10 2012
Succeeded at Wed Mar 28 03:52:17 2012 (Elapsed Time: 7.00 seconds)
```

- 3) Generate bounding polygon raster mask. It will be used to mask out the results of the depth calculations since flooding must be confined within the model bounding polygon. Run “Feature to Raster” from “Conversion -> To Raster” toolbox. Define environments: snap raster = DEM, cell size = DEM. The result of the tool is bounding polygon grid.



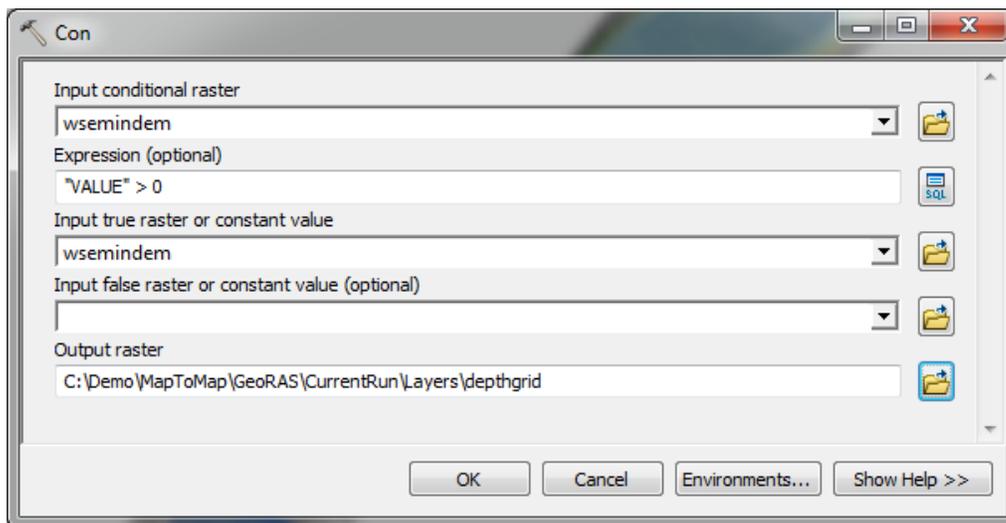
```
Executing: FeatureToRaster
C:\Demo\MapToMap\GeoRAS\CurrentRun\RASM2M_res.gdb\RasResults\BoundingPolygon
s OID C:\Demo\MapToMap\GeoRAS\CurrentRun\Layers\bpmask 1
Start Time: Wed Mar 28 03:55:37 2012
Succeeded at Wed Mar 28 03:55:39 2012 (Elapsed Time: 2.00 seconds)
```

- 4) Calculate difference between WSE and DEM (positive values are inundated areas). Run “Minus” from “Spatial Analyst -> Math” toolbox. Define environments: snap raster = DEM, cell size = DEM, mask = bpmask. Negative values need to be removed as they do not make sense in the context of inundation depth.



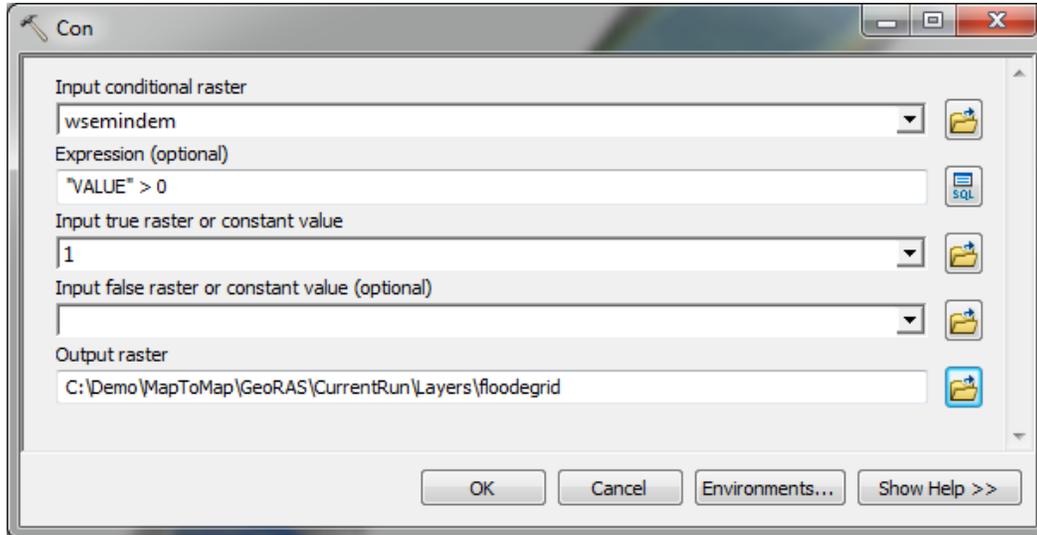
```
Executing: Minus wsegrid demfp
C:\Demo\MapToMap\GeoRAS\CurrentRun\Layers\wsemindem
Start Time: Wed Mar 28 03:59:47 2012
Succeeded at Wed Mar 28 03:59:51 2012 (Elapsed Time: 4.00 seconds)
```

- 5) Limit the depth grid only to positive values. Run “Con” from “Spatial Analyst -> Conditional” toolbox. Define environments: snap raster = DEM, cell size = DEM, mask = bpmask. The result of the tool is inundation depth grid contained within the bounding polygon.



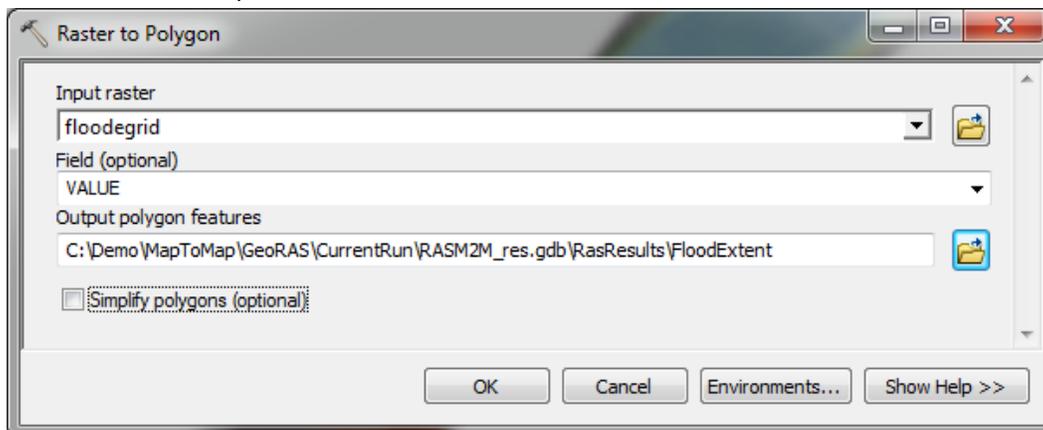
```
Executing: Con wsemindem wsemindem
C:\Demo\MapToMap\GeoRAS\CurrentRun\Layers\depthgrid # ""VALUE" > 0"
Start Time: Wed Mar 28 04:02:54 2012
Succeeded at Wed Mar 28 04:02:58 2012 (Elapsed Time: 4.00 seconds)
```

- 6) Create a flood extent grid of 1 where there is inundation and no data elsewhere. Run “Con” from “Spatial Analyst -> Conditional” toolbox. Define environments: snap raster = DEM, cell size = DEM, mask = bpmask.



```
Executing: Con wsemindem 1
C:\Demo\MapToMap\GeoRAS\CurrentRun\Layers\floodegrid # ""VALUE" > 0"
Start Time: Wed Mar 28 04:05:24 2012
Succeeded at Wed Mar 28 04:05:28 2012 (Elapsed Time: 4.00 seconds)
```

- 7) Generate floodplain polygon by converting the floodplain extent grid to a polygon. Run “Raster to Polygon” from “Conversion -> From Raster” toolbox. Save the result in the geodatabase (but not feature dataset).



```
Executing: RasterToPolygon floodegrid
C:\Demo\MapToMap\GeoRAS\CurrentRun\RASM2M_res.gdb\RasResults\FloodExtent
NO_SIMPLIFY VALUE
Start Time: Wed Mar 28 04:07:54 2012
Succeeded at Wed Mar 28 04:07:58 2012 (Elapsed Time: 4.00 seconds)
```

Perform optional floodplain “cleaning” (e.g. remove disconnected flood polygons). This is not recommended before thorough quality control of the results is performed and is not presented here. Also, there are no “standards” for doing this. It is recommended that NL develops their “standard” and encapsulates it into a sub-model that would be run after the basic floodplain information is derived in previous steps.

## M2M process automation

Two model builder models have been developed to demonstrate how the individual steps presented above can be automated. The first model builder is called “HMS to GeoRAS” and it takes process from running HMS to running RAS to generating results GeoRAS geodatabase. The user interface is presented in the following figure.

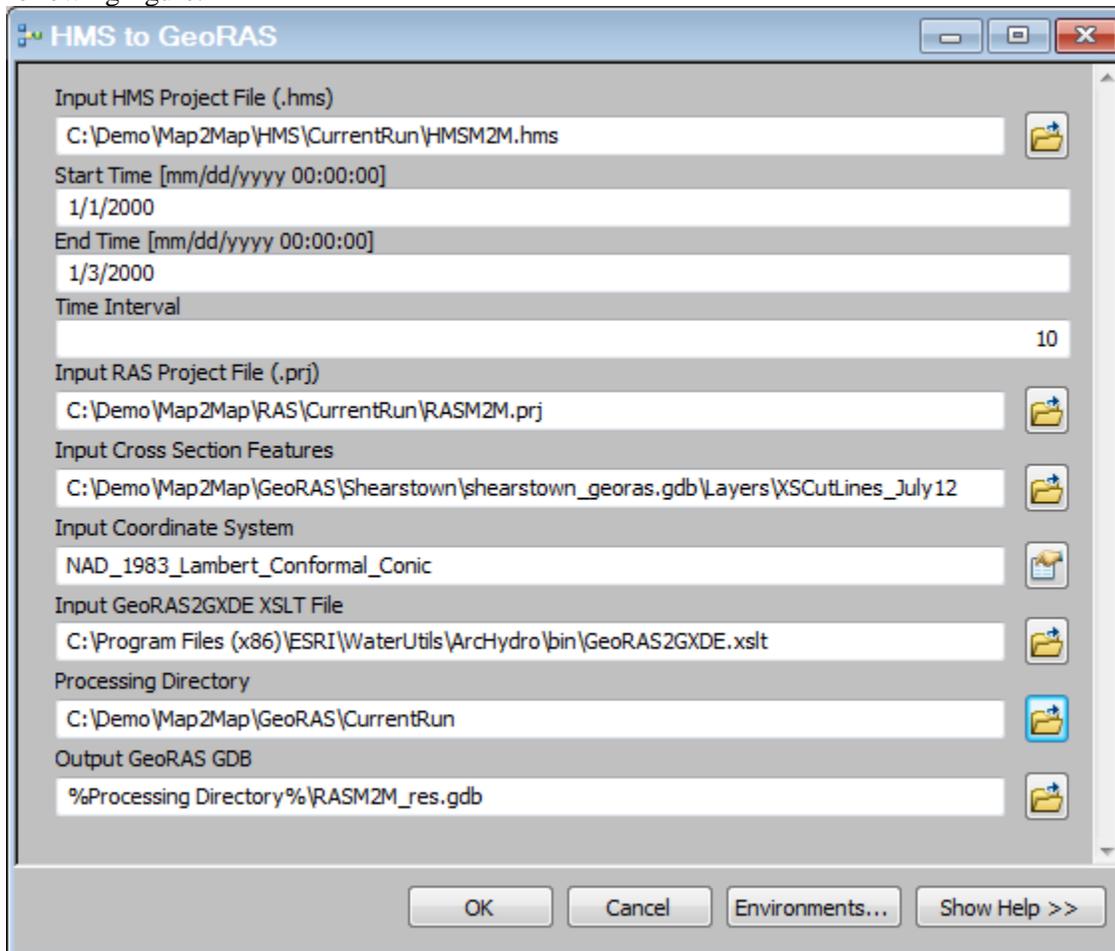


Figure 3. Run time interface for “HMS to GeoRAS” model.

```
Executing: HMStoGeoRAS C:\Demo\Map2Map\HMS\CurrentRun\HMSM2M.hms 1/1/2000
1/3/2000 10 C:\Demo\Map2Map\RAS\CurrentRun\RASM2M.prj
C:\Demo\Map2Map\GeoRAS\Shearstown\shearstown_georas.gdb\Layers\XSCutLines_Ju
ly12
PROJCS['NAD_1983_Lambert_Conformal_Conic',GEOGCS['GCS_North_American_1983',D
```



```
ATUM['D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],P
RIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['Lamber
t_Conformal_Conic'],PARAMETER['False_Easting',1968500.0],PARAMETER['False_No
rthing',13123333.3333333],PARAMETER['Central_Meridian',-
99.0],PARAMETER['Standard_Parallel_1',28.3833333333333],PARAMETER['Standard
_Parallel_2',30.2833333333333],PARAMETER['Latitude_Of_Origin',27.8333333333
333],UNIT['Foot_US',0.3048006096012192]] "C:\Program Files
(x86)\ESRI\WaterUtils\ArcHydro\bin\GeoRAS2GXDE.xslt"
C:\Demo\Map2Map\GeoRAS\CurrentRun "%Processing Directory%\RASM2M_res.gdb"
Start Time: Thu Mar 29 15:02:54 2012
Executing (Run HMS): RunHMS C:\Demo\Map2Map\HMS\CurrentRun\HMSM2M.hms
1/1/2000 1/3/2000 10 "Run 1"
Start Time: Thu Mar 29 15:02:57 2012
Succeeded at Thu Mar 29 15:03:14 2012 (Elapsed Time: 17.00 seconds)
Executing (Update RAS Flow): UpdateRASFlow
C:\Demo\Map2Map\RAS\CurrentRun\RASM2M.prj
C:\Demo\Map2Map\GeoRAS\Shearstown\shearstown_georas.gdb\Layers\XSCutLines_J
uly12 C:\Demo\Map2Map\HMS\CurrentRun\HMSM2M.hms "Run 1" Steady
Start Time: Thu Mar 29 15:03:14 2012
Reading DSS path and updating RAS flow..
Flow values updated for 4 features from DSS File
C:\Demo\Map2Map\HMS\CurrentRun\HMSM2M.dss!
Succeeded at Thu Mar 29 15:03:57 2012 (Elapsed Time: 43.00 seconds)
Executing (Run RAS): RunRAS C:\Demo\Map2Map\RAS\CurrentRun\RASM2M.prj
Start Time: Thu Mar 29 15:03:57 2012
RAS run results exported to
C:\Demo\Map2Map\RAS\CurrentRun\RASM2M.RASexport.sdf.
Succeeded at Thu Mar 29 15:04:00 2012 (Elapsed Time: 3.00 seconds)
Executing (Parse Path): ParsePath C:\Demo\Map2Map\HMS\CurrentRun\HMSM2M.hms
NAME
Start Time: Thu Mar 29 15:04:00 2012
Succeeded at Thu Mar 29 15:04:00 2012 (Elapsed Time: 0.00 seconds)
Executing (SDF to XML): SDFToXML
C:\Demo\Map2Map\RAS\CurrentRun\RASM2M.RASexport.sdf
C:\Demo\Map2Map\GeoRAS\CurrentRun\HMSM2M.RASexport.xml
Start Time: Thu Mar 29 15:04:00 2012
Converting SDF to XML...
SDF successfully converted
C:\Demo\Map2Map\GeoRAS\CurrentRun\HMSM2M.RASexport.xml
Succeeded at Thu Mar 29 15:04:00 2012 (Elapsed Time: 0.00 seconds)
Executing (Transform XML): TransformXML
C:\Demo\Map2Map\GeoRAS\CurrentRun\HMSM2M.RASexport.xml "C:\Program Files
(x86)\ESRI\WaterUtils\ArcHydro\bin\GeoRAS2GXDE.xslt"
C:\Demo\Map2Map\GeoRAS\CurrentRun\HMSM2M_GenericXML.xml
Start Time: Thu Mar 29 15:04:00 2012
Succeeded at Thu Mar 29 15:04:01 2012 (Elapsed Time: 1.00 seconds)
Executing (Append Spatial Reference to XML): AppendSpatialReferencetoXML
C:\Demo\Map2Map\GeoRAS\CurrentRun\HMSM2M_GenericXML.xml
PROJCS['NAD_1983_Lambert_Conformal_Conic',GEOGCS['GCS_North_American_1983',
DATUM['D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]]
,PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['Lam
bert_Conformal_Conic'],PARAMETER['False_Easting',1968500.0],PARAMETER['Fals
e_Northing',13123333.3333333],PARAMETER['Central_Meridian',-
99.0],PARAMETER['Standard_Parallel_1',28.3833333333333],PARAMETER['Standar
```

```

d Parallel 2',30.283333333333334],PARAMETER['Latitude_Of_Origin',27.83333333
333333],UNIT['Foot_US',0.3048006096012192]] true
Start Time: Thu Mar 29 15:04:01 2012
Running script AppendSpatialReferencetoXML...
Replacing coordinate system...
Completed script AppendSpatialReferencetoXML...
Succeeded at Thu Mar 29 15:04:03 2012 (Elapsed Time: 2.00 seconds)
Executing (Import from XML): ImportFromXML
C:\Demo\Map2Map\GeoRAS\CurrentRun\HMSM2M_GenericXML.xml
C:\Demo\Map2Map\GeoRAS\CurrentRun\RASM2M_res.gdb
Start Time: Thu Mar 29 15:04:03 2012
Succeeded at Thu Mar 29 15:04:07 2012 (Elapsed Time: 4.00 seconds)
Succeeded at Thu Mar 29 15:04:08 2012 (Elapsed Time: 1 minutes 14 seconds)
    
```

The following figure presents the “HMS to GeoRAS” model overview and zoomed-in details.

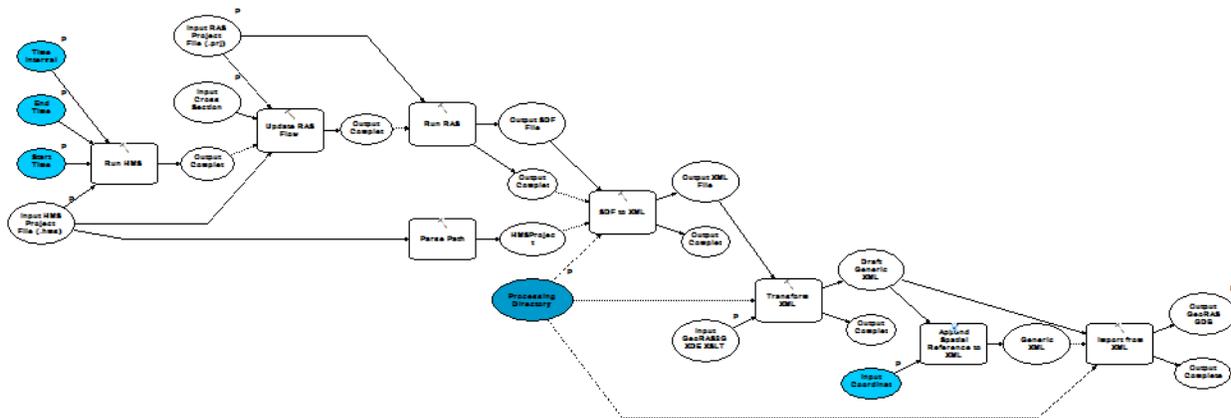


Figure 4. “HMS to GeoRAS” model.

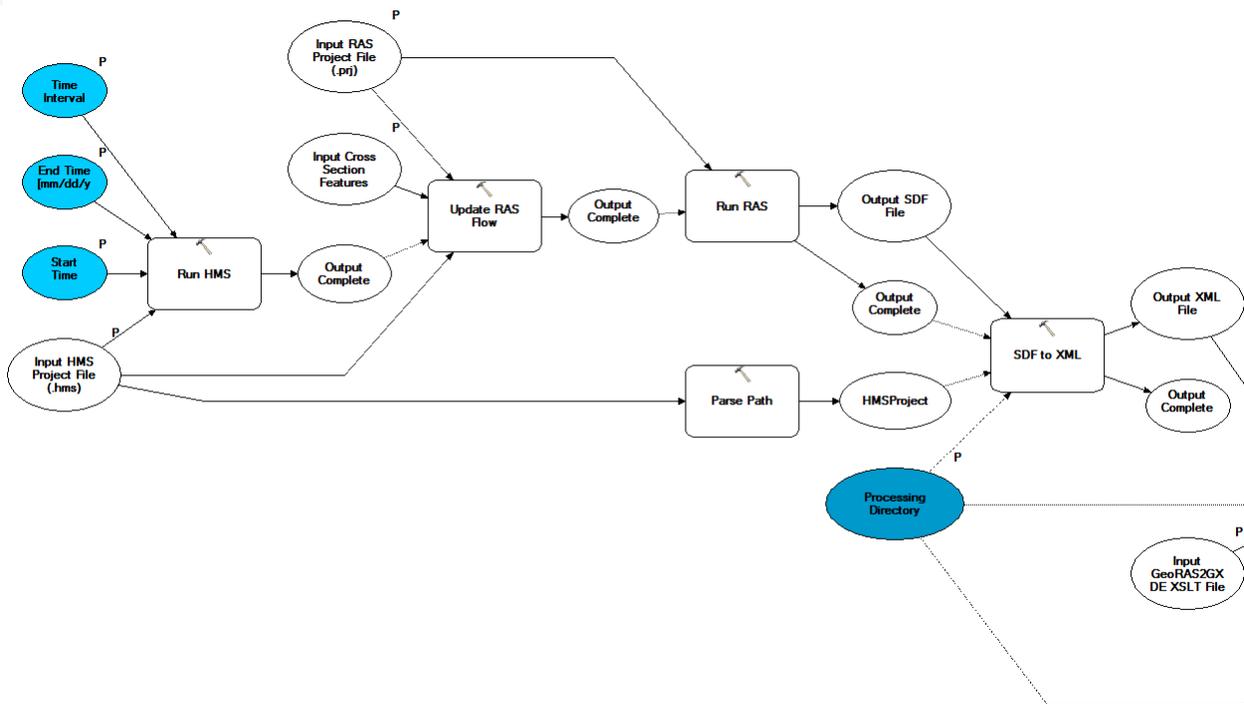


Figure 5. "HMS to GeoRAS" model details (1/2).

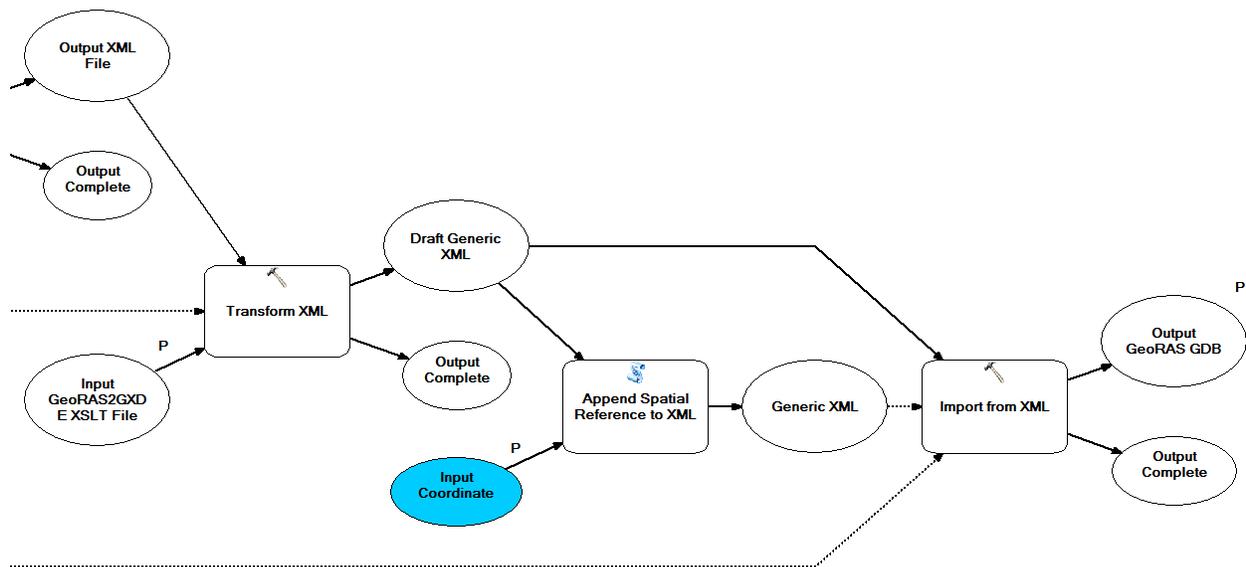


Figure 6. "HMS to GeoRAS" model details (2/2).

The second model builder is called “GeoRAS to Flood” and it takes results GeoRAS geodatabase and DEM and generates flood depth and flood extent polygon. The user interface is presented in the following figure.

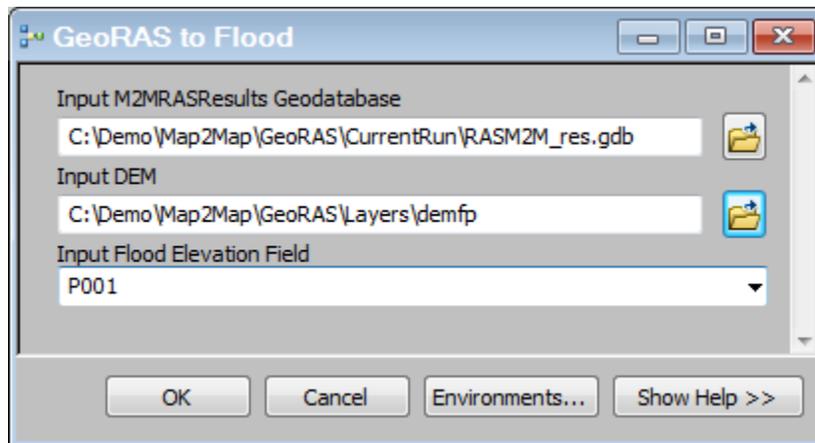


Figure 7. Run time interface for "GeoRAS to Flood" model.

```

Executing: GeoRASToFlood C:\Demo\Map2Map\GeoRAS\CurrentRun\RASM2M_res.gdb
C:\Demo\Map2Map\GeoRAS\Layers\demfp P001
Start Time: Thu Mar 29 14:37:38 2012
  Executing (Spatial Reference From Raster): SpatialReferenceFromRaster
  C:\Demo\Map2Map\GeoRAS\Layers\demfp
  Start Time: Thu Mar 29 14:37:40 2012
  Running script SpatialReferenceFromRaster...
    Projection type = Projected
    Projection name = NAD_1983_Transverse_Mercator
  Completed script SpatialReferenceFromRaster...
  Succeeded at Thu Mar 29 14:37:40 2012 (Elapsed Time: 0.00 seconds)
  Executing (Select Data): SelectData
  C:\Demo\Map2Map\GeoRAS\CurrentRun\RASM2M_res.gdb RasResults
  Start Time: Thu Mar 29 14:37:40 2012
  Succeeded at Thu Mar 29 14:37:40 2012 (Elapsed Time: 0.00 seconds)
  Executing (Select Data (2)): SelectData
  C:\Demo\Map2Map\GeoRAS\CurrentRun\RASM2M_res.gdb\RasResults XSCutlines
  Start Time: Thu Mar 29 14:37:40 2012
  Succeeded at Thu Mar 29 14:37:40 2012 (Elapsed Time: 0.00 seconds)
  Executing (Get Field Alias): GetFieldAlias
  C:\Demo\Map2Map\GeoRAS\CurrentRun\RASM2M_res.gdb\RasResults\XSCutlines P001
  Start Time: Thu Mar 29 14:37:40 2012
  Running script GetFieldAlias...
  Alias: 1:100
  Completed script GetFieldAlias...
  Succeeded at Thu Mar 29 14:37:40 2012 (Elapsed Time: 0.00 seconds)
  Executing (Parse Path): ParsePath
  C:\Demo\Map2Map\GeoRAS\CurrentRun\RASM2M_res.gdb PATH
  Start Time: Thu Mar 29 14:37:40 2012
  Succeeded at Thu Mar 29 14:37:40 2012 (Elapsed Time: 0.00 seconds)

```

```

Executing (Create Directory): CreateDirectory
C:\Demo\Map2Map\GeoRAS\CurrentRun\Layers
Start Time: Thu Mar 29 14:37:40 2012
Running script CreateDirectory...
Completed script CreateDirectory...
Succeeded at Thu Mar 29 14:37:41 2012 (Elapsed Time: 1.00 seconds)
Executing (Create TIN): CreateTIN
C:\Demo\Map2Map\GeoRAS\CurrentRun\Layers\wsetin
"PROJCS['NAD_1983_Transverse_Mercator',GEOGCS['GCS_North_American_1983',DAT
UM['D_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],PR
IMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['Transv
erse_Mercator'],PARAMETER['False_Easting',304800.0],PARAMETER['False_Northi
ng',0.0],PARAMETER['Central_Meridian',-
53.0],PARAMETER['Scale_Factor',0.9999],PARAMETER['Latitude_Of_Origin',0.0],
UNIT['Meter',1.0]];-5317800 -10001100 450310428.589905;-100000 10000;-
100000 10000;0.001;0.001;0.001;IsHighPrecision"
"C:\Demo\Map2Map\GeoRAS\CurrentRun\RASM2M_res.gdb\RasResults\XSCutlines
1:100 hardline <None>" #
Start Time: Thu Mar 29 14:37:41 2012
Running script CreateTIN...
Completed script CreateTIN...
Succeeded at Thu Mar 29 14:37:42 2012 (Elapsed Time: 1.00 seconds)
Executing (Get Raster Properties): GetRasterProperties
C:\Demo\Map2Map\GeoRAS\Layers\demfp CELLSIZE
Start Time: Thu Mar 29 14:37:42 2012
Cellsize in x direction = 1.000000
Succeeded at Thu Mar 29 14:37:42 2012 (Elapsed Time: 0.00 seconds)
Executing (TIN to Raster): TINtoRaster
C:\Demo\Map2Map\GeoRAS\CurrentRun\Layers\wsetin
C:\Demo\Map2Map\GeoRAS\CurrentRun\Layers\wsegrid # # "CELLSIZE 1" #
Start Time: Thu Mar 29 14:37:42 2012
Running script TINtoRaster...
Completed script TINtoRaster...
Succeeded at Thu Mar 29 14:37:48 2012 (Elapsed Time: 6.00 seconds)
Executing (Select Data (3)): SelectData
C:\Demo\Map2Map\GeoRAS\CurrentRun\RASM2M_res.gdb\RasResults
BoundingPolygons
Start Time: Thu Mar 29 14:37:48 2012
Succeeded at Thu Mar 29 14:37:48 2012 (Elapsed Time: 0.00 seconds)
Executing (Feature to Raster): FeatureToRaster
C:\Demo\Map2Map\GeoRAS\CurrentRun\RASM2M_res.gdb\RasResults\BoundingPolygon
s OID C:\Demo\Map2Map\GeoRAS\CurrentRun\Layers\bpmask 1
Start Time: Thu Mar 29 14:37:48 2012
Succeeded at Thu Mar 29 14:37:49 2012 (Elapsed Time: 1.00 seconds)
Executing (Minus): Minus C:\Demo\Map2Map\GeoRAS\CurrentRun\Layers\wsegrid
C:\Demo\Map2Map\GeoRAS\Layers\demfp
C:\Demo\Map2Map\GeoRAS\CurrentRun\Layers\wsemindem
Start Time: Thu Mar 29 14:37:49 2012
Succeeded at Thu Mar 29 14:37:52 2012 (Elapsed Time: 3.00 seconds)
Executing (Con): Con C:\Demo\Map2Map\GeoRAS\CurrentRun\Layers\wsemindem
C:\Demo\Map2Map\GeoRAS\CurrentRun\Layers\depthgrid # ""VALUE" > 0"
Start Time: Thu Mar 29 14:37:52 2012
Succeeded at Thu Mar 29 14:37:56 2012 (Elapsed Time: 4.00 seconds)

```

```

Executing (Con (2)): Con C:\Demo\Map2Map\GeoRAS\CurrentRun\Layers\wsemindem
1 C:\Demo\Map2Map\GeoRAS\CurrentRun\Layers\floodgrid # ""VALUE" > 0"
Start Time: Thu Mar 29 14:37:56 2012
Succeeded at Thu Mar 29 14:38:00 2012 (Elapsed Time: 4.00 seconds)
Executing (Raster to Polygon): RasterToPolygon
C:\Demo\Map2Map\GeoRAS\CurrentRun\Layers\floodgrid
C:\Demo\Map2Map\GeoRAS\CurrentRun\RASM2M_res.gdb\FloodExtent NO_SIMPLIFY
VALUE
Start Time: Thu Mar 29 14:38:00 2012
Succeeded at Thu Mar 29 14:38:04 2012 (Elapsed Time: 4.00 seconds)
Succeeded at Thu Mar 29 14:38:04 2012 (Elapsed Time: 26.00 seconds)
    
```

The following figure presents the “GeoRAS to Flood” model overview and zoomed-in details.

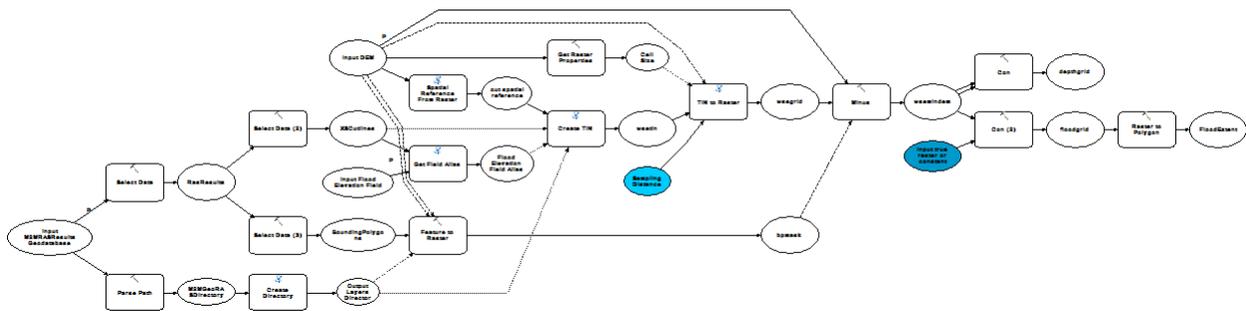


Figure 8. “GeoRAS to Flood” model.

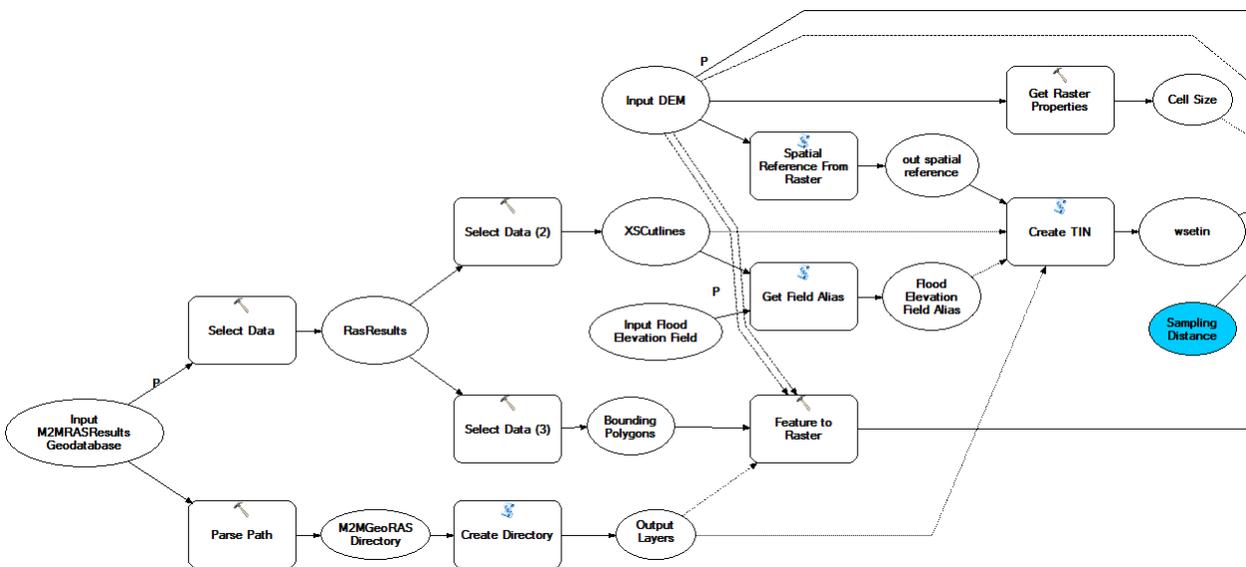


Figure 9. “GeoRAS to Flood” model details (1/2).

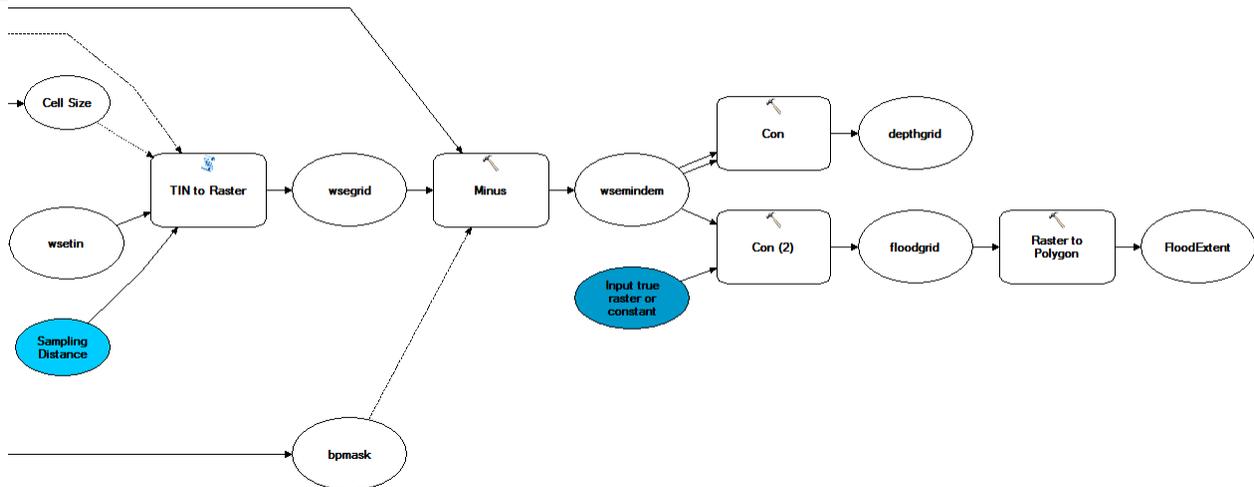


Figure 10. “GeoRAS to Flood” model details (2/2).

Variations to these two models can be made based on specific processing requirements.

## Summary

This document describes the Map To Map (M2M) implementation workflows developed for the Hydrologic Modelling Section, Water Resources Management Division, Department of Environment and Conservation, Government of Newfoundland and Labrador, Canada, (WRMD) in the context of modeling of impacts of global climate change (GCC) on flooding. The presented workflows are based on ArcGIS and Arc Hydro existing capabilities. Special considerations needed for GCC M2M implementation are explicitly addressed and an example is presented using the existing Shearstown HMS and RAS models.

Existing Arc Hydro tools for M2M implementation are identified and incorporated into two example Model Builder models that can be used to automate the M2M workflow. Two additional tools are identified that could further simplify/streamline M2M implementation in GCC context and could be developed in next step of M2M implementation at WRMD (currently their functionality is implemented using out of the box ArcGIS capabilities):

- 1) “Populate M2MRUN Table”. This tool would enable the analyst to organize M2M run scenarios (selection of HMS and RAS models, and their initial and boundary conditions) using a simple user interface and store those definitions in the M2MRUN table.
- 2) “Execute M2M Run”. This tool would loop through the selected records in the M2MRUN table and execute the M2M workflow for those selected records for which “IsRun” field = 0.

Current ArcGIS and Arc Hydro capabilities, together with systematic organization and development of HMS and RAS models to be used in GCC impact evaluation provide viable infrastructure for automation of GCC modeling.