

REQUEST FOR PROPOSALS
FOR
Eastern Shore Coastal Flood Line Mapping

Municipality of the District of St. Mary's



December 15, 2022

P.O. Box 296
Sherbrooke, NS
BOJ 3C0
Phone: 902-522-2049
Fax: 902-522-2309

www.saint-marys.ca

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Municipality of the District of St. Mary's - Request for Proposals

Eastern Shore Coastal Flood Line Mapping

INTRODUCTION

The Municipality of the District of St. Mary's is requesting proposals from qualified consultants to carry-out flood line mapping in on the Eastern Shore coast following the specifications of the Draft Nova Scotia Municipal Flood Line Mapping (MFLM) Document. The final decision on which consultant will be awarded the contract may also be subject to the review and approval of the Municipal Council and the availability of appropriated funds from which payment can be made.

Nova Scotia is one of the provinces most vulnerable to the impacts of flooding and climate change, notably through the combination of land subsidence, sea level rise, and increased precipitation. Most of the development in the province is located along the coastline or a major watercourse, meaning that the issue of flooding is a significant concern in Nova Scotia.

One of the tools available to Municipalities to protect public safety is the development of flood maps. Municipal Planning Strategies and Land Use By-laws can then be developed to control the type of development that may take place within flood-prone areas. In 1999, the Province of Nova Scotia enacted regulations under the Municipal Government Act (MGA), through the Statements of Provincial Interest (SPI), to set minimum criteria and planning standards within floodplain areas. The MGA is administered by the Department of Municipal Affairs and Housing (DMAH).

The MFLM Project endeavours to create a set of standards that will apply across the entire province, creating consistency in how flood line mapping is carried out. It is structured to provide guidance to municipalities as they engage consultants to carry out the work, while providing specific technical specification that consultants will follow. Its end goal is to ensure that all municipalities are applying the SPI on Flood Risk to areas in their jurisdiction that are likely to flood.

A MFLM Document began development in 2018 and went through several drafts and reviews. In November 2019, a draft of technical specifications was provided to three consultants for each to implement in a different test case watershed. The consultants provided feedback on the technical specifications and their experience implementing them in their respective test case. Those comments were received by DMAH and incorporated into the current version of the MFLM Document.

The current phase of the MFLM Project is an opportunity to apply the revised MFLM Document to more areas of the province and test the guidance components. Municipalities will use the MFLM Document to gather the necessary preliminary information and hire qualified consultants to carry out the mapping using the technical specifications.

The MFLM project is managed by a Project Team consisting of staff and/or elected officials from the municipalities in the study area with support from DMAH Staff.

SECTION ONE - TERMS AND CONDITIONS

SUBMISSIONS OF PROPOSALS

Mandatory Criteria

The following mandatory criteria are to be observed in the preparation of a Proposal for flood line mapping services to the Municipality of the District of St. Mary's.

- Completed Proposals and other correspondence should be submitted via email to:
Municipal Flood Line Mapping Project Committee
c/o Marissa Jordan, CAO
marissa.jordan@saint-marys.ca
- Proposals must be submitted via email as an attached PDF and clearly labeled with the subject line "***Eastern Shore Coastal Flood Line Mapping Proposal***"
- Proposals will not be accepted any later than **5:00 pm on December 29th, 2022**. Late proposals will not be accepted.
- Inquiries regarding this RFP can be directed via email to: Marissa Jordan, CAO
marissa.jordan@saint-marys.ca

Terms and Conditions

The terms and conditions of the Proposal are to remain firm and irrevocable from the proposed closing date of December 29th, 2022. It is anticipated that a decision will be made by **January 4th, 2023**.

PROPOSAL REGULATIONS

Rights of the Municipality of the District of St. Mary's

The following Rights apply in relation to this RFP:

- The Municipality of the District of St. Mary's reserves the right to reject any or all Proposals, or parts thereof, and the lowest fee will not necessarily be accepted.
- All Proposals shall be and remain irrevocable unless withdrawn prior to the designated closing time.
- Late or incomplete Proposals will be rejected.
- The submitter must be prepared to include in the contract for services any oral or written representations, undertakings or guarantees that are made prior to the final agreements, including the entire response to this RFP, or parts thereof.
- The Municipality of the District of St. Mary's shall pay no fee to any respondent for the preparation and delivery of its submission in response to the Municipality's request.
- The Municipality of the District of St. Mary's reserves the right to perform investigations as may be deemed necessary to insure competent persons will be utilized in the performance of the contract.

No Adjustments to Proposals

No adjustments to submitted Proposals will be allowed. However, Vendors may withdraw their Proposal prior to the selection date. To withdraw a proposal, the request must be made in writing via email to Marissa Jordan, CAO marissa.jordan@saint-marys.ca

Evaluation Criteria

Proponents will be evaluated based on the quality of the response to this RFP as described in ***Section 3 - Statement of Work***

No contract will be awarded except to responsible proponents capable of providing the services contemplated. Proponents should be primarily engaged in providing the services as outlined in this Request for Proposal. Proponents should have an extremely comprehensive understanding in the areas listed in this Request for Proposal. Understanding and previous experience in all aspects of similar projects is very essential criteria in the qualifying process. The proponent's personnel and management to be utilized in this service requirement should be knowledgeable in their areas of expertise.

SECTION TWO- GENERAL INFORMATION

REPORTING & PAYMENTS

Schedule & Reporting

If a contract is awarded, then the work is to commence as soon as possible after the contract has been awarded and signed. The successful respondent shall complete all work for all locations by March 24, 2023. The accepted Contractor is to follow the reporting process outlined in **Section 3-Statement of Work** of this RFP. Any circumstances that will result in changes to the agreed schedule shall be promptly brought to the attention of Marissa Jordan, CAO.

Information Collected

The successful proponent is advised that all information produced or collected during this contract is to be considered the property of the Municipality of the District of St. Mary's and shall be turned over upon conclusion of the project.

Payments

Payments shall be based on Invoices submitted to the municipality at set points with specific reporting requirements:

- Invoice #1 – 80% of budget - Provided with Draft Report (March. 9, 2023)
- Invoice #2 – 20% of budget – Provided with Final Deliverables (Mar. 24, 2023)

Payments are typically made on a net thirty (30) days basis from receipt of invoice provided that the Municipality of the District of St. Mary's has approved the work that is being billed. Incomplete or unsatisfactory work will result in reduced compensation for the Contractor as deemed appropriate by the Municipality of the District of St. Mary's. No payment made by the Municipality of the District of St. Mary's under this contract shall constitute acceptance of work or products that are not in accordance with the requirements of the Contract.

COMPLIANCE & COVERAGE REQUIREMENTS

Included with the proposal shall be the Proponent's Proof of Insurance and Clearance Letter from the Workers Compensation Board of Nova Scotia, or equivalent.

Compliance With Laws & Regulations

The Contractor shall comply with all existing Federal, Provincial, and Municipal Regulations, guidelines and standards, and other authorities having jurisdiction. The Contractor will give all the notices and obtain all the licenses and permits, required to perform the work. The Contractor will comply with all laws applicable to the work or performance of the contract. This, however, does not remove the burden of due diligence from the successful proposer with regards to occupational health and safety regulation compliance.

Indemnity

If the contract is awarded, the successful proponent will be required to indemnify and hold the Municipality of the District of St. Mary's harmless and against all liability and expenses, including solicitor's fees, howsoever arising, or incurred, alleging damage to property or injury to, or death of, any person arising out or attributable to the proponent's performance of the contract awarded. Any property or work to be provided by the proponent under this contract will remain at the proponent's risk until written acceptance by the Municipality of the District of St. Mary's;

Municipality of the District of St. Mary's

and the proponent will replace, at the proponent's expense, all property or work damaged or destroyed by any cause whatsoever.

Workers Compensation

If the contract is awarded, the successful proponent shall supply the Municipality of the District of St. Mary's a valid Worker's Compensation letter of good standing or equivalent. The proponent shall also be responsible for obtaining and providing evidence that any Subcontractor is also covered and provide that information to the Municipality of the District of St. Mary's. No payments will be made without a valid clearance letter.

Insurance Requirements

If the contract is awarded, the successful proponent shall be required to provide proof of General Liability Insurance in a form acceptable to the Municipality of the District of St. Mary's, with the Municipality of the District of St. Mary's named as an additional insured on the policy. The amount of coverage will be \$1,000,000 per occurrence.

If the contract is awarded, the successful proponent shall provide proof of automobile liability insurance in respect to owned licensed vehicles subject to limits of not less than One Million Dollars (\$1,000,000) inclusive.

SECTION 3 - STATEMENT OF WORK (SoW)

PROJECT SCOPE

The work to be carried out by the proponent is laid out in detail in the Draft Municipal Flood Line Mapping (MFLM) Document (2022). The Draft MFLM Document has been included in the package with the RFP and should be thoroughly reviewed when developing your proposal.

The Document is comprised of four parts:

1. MFLM Overview
2. MFLM Guidance
3. MFLM Technical Specifications
4. MFLM Climate Change Standard

Project Area

Flood mapping for this MFLM Project is to be done for a coastal extent that will depend on time and data constraints along the eastern shore of Nova Scotia. This SoW asks consultants to propose a mapping extent that covers all the coastline of the Municipality of St. Mary's and extends along the coast of the Municipality of the District Guysborough.

Time Frame & Deliverables

The project team consisting of staff from both the Municipalities of St. Mary's and Guysborough with support from DMAH Staff. The team will manage the work and receive the deliverables. Consultants will be expected to engage with both municipalities adjacent to the project coast throughout the project. The date set for final deliverables reflects the need to receive, review, and approve the final reports as well as process outstanding invoices. More detail on deliverables is provided in the Project Tasks, Deliverables and Responsibilities sub-section below.

- Project Kick-Off Meeting: Jan 2023
- Stakeholder Engagement: Jan 2023
- Draft Report: March 9, 2023
- Stakeholder Presentation: March 2023
- Final Deliverables – March 24, 2023

Budget Considerations

Proponents should provide bids that are based on the requirements in the MFLM Document while remaining mindful of the specific attributes and complexity of the project area (size, topography, data availability, level of development, coastal characteristics, number of municipalities, etc.). It is expected that consultants will provide bids that are achievable and fully costed to enable them to produce the required deliverables, while being cognizant that their pricing will affect their score.

The project is funded through a provincial grant to the municipality of \$170,000. Contact and address information for the submission of invoices will be provided to consultants upon contract award. Invoices will be submitted to the municipality at set points with specific reporting requirements.

- Invoice #1 – 80% of budget - Provided with Draft Report (March. 9, 2023)
- Invoice #2 – 20% of budget – Provided with Final Deliverables (Mar. 24, 2023)

Project Tasks, Deliverables and Responsibilities *Project Kick-Off – Jan 2023*

Once the agreement has been signed, a date will be set for the Project Kick-off meeting. It will likely be a virtual meeting and include the Project Manager and other resources for the successful proponent. This ensures any questions about the process can be addressed immediately.

Stakeholder Engagement – Jan 2023

The Proponent should engage with stakeholders, specifically the municipalities and First Nations communities that are in or adjacent to the area being mapped, as early in the process as possible. The MFLM Guidance is written as a tool for municipalities to engage consultants to carry out flood mapping using the MFLM Technical Specifications. However, the MFLM Guidance contains valuable information the proponent should reflect on when engaging with stakeholders. The MFLM Guidance should be read inclusively with the entire MFLM Document.

Draft Report – March 9th, 2023

The Draft Report should comprise the completed results of the study (See Final Deliverables), listing any identified missing information/maps/data. The proponent should target to complete the project by the Draft Report date and leave the time before Final Deliverables are due to review, refine, and incorporate any reasonable changes that are requested by the Project Team. Any models or raw data will not be required with the Draft Report.

Stakeholder Presentation – March 2023

The results of the flood mapping and key components of the draft report should be presented to all municipalities in the study watershed; First Nations communities in the area should also be invited. The proponent should highlight key findings that would be most relevant to municipalities in the context of the Statement of Provincial Interest on Flood Risk. It is suggested that a virtual presentation would be the best option. A representative from the DMAH will be in attendance as well.

Final Deliverables – March 24, 2023

Final deliverables include a report and associated maps, data, and digital models. The specifics of what the final deliverables must contain are listed in **Chapter 9 of the MFLM Document – Appendix B - Technical Specifications**.

All project deliverables are to be provided to the Project Team for review, approval, and acceptance. All deliverables are to be submitted in electronic format. All work products are the property of the municipalities and will be shared with the Province for use and storage.

Project Team Responsibilities

The Project Team is prepared to assist and support the successful proponent in accessing existing data, coordinating initial contact with stakeholders in the watershed, and understanding the process and intent of the MFLM Document. The main contact for the Project Team is:

Marissa Jordan, CAO marissa.jordan@saint-marys.ca

EVALUATION CRITERIA

The Project Team will evaluate each proposal based on the rated criteria as set out below.

Rated Criteria Category	Weighting	Minimum Threshold
Proposed Resources	20	
Relevant Experience	10	
Project Plan	40	
Map of Project Extent	20	
Price	10	
Total Weighting	100	70

Proposed Resources

Project managers are expected to play a central role in the completion of the project. Project managers are expected to have:

- a) Minimum 10 years of experience related to flood mapping and experience managing multidisciplinary teams.
- b) Experience designing systems which produce useable results for a variety of situations and data availability.
- c) Experience clearly communicating the results of past projects to clients, stakeholders, and the public both in written reports and presentations.
- d) Demonstrated recognition as an industry leader through the provision of presentations at conferences and articles in peer reviewed journals is considered a strong asset.

The respondent's firms are also required to indicate proposed resources that have experience working on flood line studies. Resources may include, but are not limited to:

- a) engineers,
- b) planners,
- c) scientists,
- d) climatologists,
- e) technologists, and
- f) technicians.

A single resource can fulfill multiple requirements (excluding the Project Manager). The Project Team must be able to validate the resource's experience by the details in the resume (e.g., dates, titles, etc.). The following required experience must clearly be detailed for the proposed resources:

- a) One non-manager resource with ten (10) years of experience in the creation of flood line mapping.
- b) One (1) resource experienced in completing coastal flood line mapping projects.
- c) One (1) resource experienced in completing fluvial flood line mapping projects.

Identify the Project Manager and any other proposed resources that will be engaged in any manner in the project in a table structured as provided here. In an appendix include resumes for each person showing similar work they have done.

Name	Title	Proposed Role	Related Experience (# months or years)	Status E=Employer C=Contractor P=Partner

The Municipality will not be obligated in any manner to accept additional services and reserves the right to solicit proposals from other consultants, if a proposal is considered unacceptable for any reason.

Relevant Experience

The proposal should include examples of two projects that are relevant to the creation of flood lines for municipalities. The experience will be enhanced if the project manager proposed for this project was involved. Any experience with the MFLM Document will be deemed an asset. Experience should include the following information:

- Project Name
- Client
- Project Manager
- Project Dates
- Brief description of work completed
- Brief discussion of how the previous work is relevant

Project Plan

The project plan should include a project timeline or Gantt Chart that contains tasks that will fulfill the requirements of the MFLM Technical Specifications. The project plan should reflect the requirements of the MFLM Technical Specifications and detail how:

- consultation with the Municipalities and other stakeholders (i.e., First Nations communities) will be carried out
- the proponent will meet the minimum technical specifications
- additional flood mechanisms will be determined
- necessary topographic and bathymetric data will be gathered
- the proponent will deal with minimal data availability
- the proponent will ensure hydraulic structure requirements are met
- stormwater system information will be considered
- hydrologic and hydraulic modelling requirements will be met
- model calibration events will be chosen
- the proponent will ensure mapping will meet the requirements
- the proponent will ensure that the reporting and mapping deliverables are provided by the deadlines set out in this SoW.

Project Map

Each proponent is to submit a map of the proposed project area that will have flood lines mapped. This should include the entire coastline of the Municipality of the District of St. Mary's as well as the proposed extent of the Municipality of the District of Guysborough. The maps from each proposal will be compared and greater extents will receive more points. The proposal with the largest extent will receive 15 points, and all other proposals will be ranked on a linear relationship such that a proposal at half the extent would receive half the points. Further points may be awarded for consideration of additional flooding mechanisms and more advanced analysis of estuarine flooding.

Price

Each proponent is to submit an estimate of costs to complete flood line mapping using the MFLM Document for a specific and defined project watershed as listed in Section 2.1 of this SoW. The project budget cap is **\$170,000**. The proposal with the lowest cost will receive 10 points, and all other proposals will be ranked on a linear relationship such that a proposal at twice the cost would receive half the points.

Vendors may submit invoices at a per diem rates lower than that identified in the vendor's initial bid submission but not higher. The vendor's estimate of costs must clearly show the number of days estimated to perform the services as well as their per diem rate proposed for the project. Travel and living expenses are the sole responsibility of the Selected Respondents and must be included in lump sum fee for each project bid submitted.

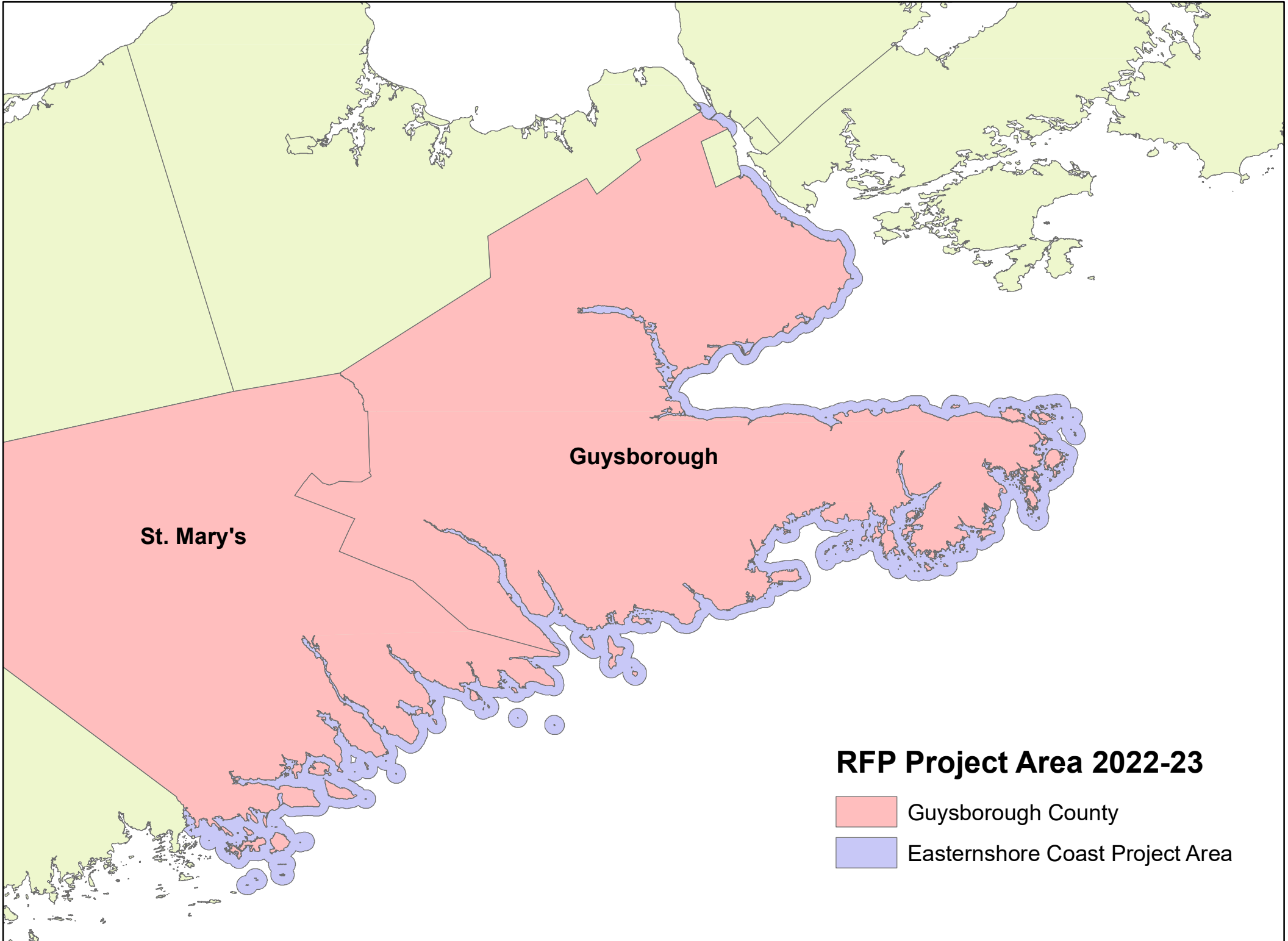
Municipality of the District of St. Mary's

VENDOR INFORMATION

Please provide your Vendor Contact Information.

Vendor Name	
Contact Name	
Contact Phone	
Contact Fax	
Contact e-Mail	



Easternshore Coastal Flood Line Mapping Project



St. Mary's

Guysborough

RFP Project Area 2022-23

-  Guysborough County
-  Easternshore Coast Project Area

DRAFT Nova Scotia Municipal Flood Line Mapping

OVERVIEW

DEPARTMENT OF MUNICIPAL AFFAIRS AND HOUSING

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Appendix A: Guidance Document

Appendix B: Technical Specifications

1.0 INTRODUCTION

1.1 Background

Nova Scotia is one of the provinces most vulnerable to the impacts of flooding and climate change, (Climate Change Nova Scotia, 2005), notably through the combination of land subsidence, sea level rise, and increased precipitation. Most of the development in the province is located along the coastline or a major watercourse, meaning that the issue of flooding is a significant concern in Nova Scotia.

One of the tools available to Municipalities to protect public safety is the development of flood maps. Municipal Planning Strategies and Land Use By-laws can then be developed to control the type of development that may take place within flood-prone areas. This can prevent vulnerable development from being established in flood risk areas.

In 1999, the Province of Nova Scotia enacted regulations under the Municipal Government Act, through the Statements of Provincial Interest (SPI), to set minimum criteria and planning standards within floodplain areas. The regulations originally applied to five main watercourses recognized as experiencing flooding risks, but they are also intended to apply to any newly mapped floodplain area. Section 3 of this document reproduces the SPI to ensure the contents are understood by all parties and provides further information on interpretation. These regulations need to be adhered to throughout the process of developing flood maps and planning regulations.

To build on this SPI, and continue to manage this growing risk, the Province of Nova Scotia has undertaken the development of a **Municipal Flood Line Mapping Document** to support the development of flood maps throughout the Province. This document follows the Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation, 2019 document, which can be reviewed for further information on the value of flood mapping and steps involved.

1.2 Purpose

The **Municipal Flood Line Mapping Document** is composed of the **Overview** document and two Appendices. The Overview document (this document) outlines the need for flood mapping in the province, discusses how the Statement of Provincial Interest on Flood Risk Areas applies, and provides an overview of how the Municipal Flood Line Mapping Document was developed. It also defines the roles of the municipality, consultant, and client engineer and provides a glossary of technical terms that are used throughout the Overview and appendices.

The **Appendix A: Guidance Document** (Guidance) has been prepared to facilitate the tendering of flood mapping studies; enabling municipalities who may not have technical flood expertise to tender, review and adopt technically robust flood studies and mapping products. The guidance document provides information on the typical contents of a flood mapping study, explains minimum specified standards in plain language, and describes additional flood factors that should be considered if they are present in

the study area. The guidance document will allow municipalities to select flood factors, or flood mechanisms, that are relevant to the specific area being studied and include a stakeholder and community-based input. Tendering authorities are expected to be mainly municipal governments but may also be planning commissions or the Provincial Government. The tendering authority is referred to as the municipality in all these documents for simplicity.

The **Appendix B: Technical Specifications** (Technical Specifications) provides flood mapping criteria to establish an acceptable level of quality for the analysis and deliverables, as well as provide consistency between studies. The specification document is intended to become part of the Request for Proposals tender documents, to which the selected consultant must adhere. It is intended to allow a clearer and simpler scope definition, procurement process, consultant selection, review of the study, and delivery of product. This is expected to be a benefit to municipalities and the Province, as well as to consultants, who will have a more consistent set of standards with which to work.

In addition to the appendices that make up the Municipal Flood Line Mapping Document there is a **Climate Change Standard** (Standard) which is referenced but remains separate from this document. The Standard is comprised of the *Standard for the incorporation of climate change into riverine and coastal flood mapping in Nova Scotia* and the associated supporting documents. This Standard was developed prior to the Municipal Flood Line Mapping Document and was key in its development.

The Technical Specifications directly references the Standard, but the specific numbers and rates of change are not provided. This is to ensure consultants are reviewing the climate change documents and have a full understanding of the context and complexity. It also allows each document to be updated independently as climate science is continually evolving and new data and better modeling is available.

To create the **Climate Change Standard**, the Government of Nova Scotia consulted with multiple academic institutions in recognition of the need to obtain expert input. An interdisciplinary working group comprised of researchers in various fields was formed. These fields included: municipal planning, water resources engineering, coastal hydraulics, and climatology.

Upon formation of the expert working group, members were allocated the task of conducting literature reviews on topics within their expertise areas and relevant to the climate change standard. Four primary topic areas were identified:

- Planning Horizons and Considerations
- Global Climate Models and Downscaling Approaches
- Sea Level Rise and Storm Surge Projections
- Future Climate Intensity-Duration-Frequency Relationships

From these four topic areas a climate change standard was developed. The objective of the standard is to develop a consistent framework for the incorporation of future climate changes into riverine and coastal flood mapping in Nova Scotia. The framework was developed with the intention of providing a scientifically defensible, consensus-based approach that is practical to implement.

1.3 Application and Limitations

The **Appendix A: Guidance Document** explains a recommended approach to engaging stakeholders and tendering a flood mapping study and provides municipalities various options to include in their study. An important component of the Guidance is to present and describe the various potential flood mechanisms that may exist and propose a step-by-step approach to identifying the flood mechanisms to include in the study. The Guidance does not contain details of the technical elements. If a municipality would like to have a deeper understanding of what is expected from consultants, they should refer to the Technical Specifications.

The **Appendix B: Technical Specifications** sets out descriptions of the methods to be followed and proposes reference documents to use to effectively apply those methods. It is intended to create a minimum acceptable level of quality, as well as impart some consistency in the approaches taken across the Province. This document also presents the rationale for the methods selected and the approaches specified. The specifications themselves may not account for every foreseeable flood type, however, the process allows for flexibility to account for local flood mechanisms and specific requirements of a municipality, as well as the ability for consultants to use their best professional judgement when carrying out the flood mapping.

The **Climate Change Standard** is meant to be applied to the planning horizons set out in the document and within the context of land use planning. Though it has potential application to other contexts, these would not be the intended purpose. The Standard also is limited by the scientific knowledge and tools available at the time of its formation. Due to the rapidly evolving nature of climate science the Standard needs to be periodically updated with new information and tools as they become available. Currently, there are significant uncertainties in climate change projections. Throughout the Standard, the precautionary principle was applied to address these uncertainties.

1.4 Development and Testing of the Technical Specifications

The Technical Specifications began development in the Summer of 2019 and went through several drafts and reviews. In November 2019, a draft of the Technical Specifications was provided to three consultants for each to implement in a different test case watershed of the province. The consultants provided feedback on the Technical Specifications and their experience implementing in their respective test case. Those comments were then received by the Province and incorporated into the current version of the Municipal Flood Line Mapping Document.

1.5 Municipal Flood Line Mapping Input Criteria and Outputs

Nova Scotia is a province with wide ranging topographic, hydrologic, soil, and coastal characteristics, and the Municipal Flood Line Mapping Document presents an adaptable approach that allows municipalities to customize the analysis to include the more relevant factors influencing flooding risks in their study area. This allows a more effective approach in terms of both quality and level of effort.

While many of the criteria are set as specifications, the selection of the flood processes component is typically based on professional judgement. Some of this judgement will be made by the municipality, supported by information obtained from stakeholders and the community, but the much of the judgement

will remain with the consultant carrying out the flood mapping. For example, more complex mechanisms may exist in the study area, such as tidal amplification, which can not be easily discerned by the municipality. Similarly, it may not be necessary to include an analysis of dam operation if it is confirmed that the operational procedure for the dam is to allow storms to flow through uncontrolled.

The outputs from the flood line mapping exercise will be a series of maps that portray flood risk today and into the future as accurately as possible given the data available. This type of information is considered a valuable tool to protect public safety and the maps will provide a clear visual tool for the municipality to use as a guide as they develop and implement planning policy or other measures. The maps produced will note the potential flood extents and depths and include hazard mapping, which is a measure of hazard (in this case, depth of water multiplied by the velocity) and can be categorized into 3 different classes (Table 1).

Table 1 Hazard classification according to depth and velocity

Class	Values in Depth (m) x Velocity (m/s)	Level of danger
Class 1	0.5 to 1.5	Danger to some
Class 2	1.5 to 2.5	Danger to most
Class 3	Above 2.5	Danger to all

2.0 GENERAL PROCESS

2.1 Overall Procedure

A general flow chart of steps, roles and responsibilities is presented below. The objective is to simplify and clarify the process to allow:

- Consistency in the development of flood studies across the province while providing flexibility for each study to include only the relevant causes of flooding (flood mechanisms).
- Enable municipalities to have better access to expertise in flood studies and obtain a study that is scientifically robust and can support land use planning.

2.2 Role of Municipalities

2.2.1 *Summary of process followed by municipalities*

For the study scope to be meaningful and representative of the actual flood mechanisms that exist in the watercourse, the municipality will have undertaken a number of steps to try to identify the main causes of flooding, as well as the key vulnerabilities in the system. Early identification of the sources of flooding risks allows the study to focus on the key representative aspects. The data and information listed below can be collected directly by the municipality or contracted out as one or more separate studies. If this information has not been collected prior to writing the RFP, it can also be included in the scope of work for the flood mapping study.

To support the study, the municipality should have:

- Gathered information on the local experience of flooding from municipal staff, Emergency Management Office, First Nations communities, provincial departments, business associations, and local associations (e.g., salmon association, watercourse protection group, etc.), as well as the public and any other interested group.
- Identified vulnerabilities along the watercourse and filled out the “Additional Mechanisms Checklist” for inclusion in the scope of work¹.
- Collected water level and rainfall data to help identify flood mechanisms and support model calibration.

In addition to the above data and information, the municipality should gather any applicable plans, bylaws, policy, regulations, and reports that would be relevant to flood mapping. This will provide the consultant with the planning context for the study area. Maps and GIS data, especially relating to current and future land use in the municipality will be instrumental in defining the level of granularity needed in the flood line maps and in the development of the hazard maps.

¹ Note: The checklist for municipalities is provided in Appendix A: Guidance Document.

2.2.2 Water Level and Rainfall data collected by the Client

Any water level and rainfall data collected prior to developing the RFP for the flood mapping study will help the municipality identify some of the additional flood mechanisms. This data will also be useful in the flood line mapping study by providing calibration data for the models.

Local, anecdotal knowledge collected by the Municipality may produce an understanding of the presence of the most common flooding mechanisms (floods associated with snowmelt or ice jams for example), but may not shed light on some more complex mechanisms, such as tidal amplification or seicheing. Such mechanisms can typically be detected by analysing water level measurements at the site or by the coast and comparing them with expected peak tide levels from the closest harbour with tidal information available from the Canadian Hydrographic Service. If the municipality has the capacity to do this it is encouraged, but it is likely that these complex mechanisms will need to be identified by professionals familiar with the related processes.

Official sources of data on rainfall and water levels do not adequately cover the entire province for the purposes of flood line mapping. It is entirely possible that only sparse rainfall data may be available for the area of interest. Additionally, water level data may not be available from the Environment Canada flow gauging stations as these often only collect flow data. To supplement existing sources of data, municipalities should endeavour to collect rainfall and water level measurements upstream of the tidal influence prior to the outset of the flood mapping study. As suggested previously, this may require a separate study.

To provide consistent data to support model calibration, measurements should adhere to the following parameters:

1. Measurements should be taken for a duration of 1 month minimum, in the period between the months of October to May (to avoid the summer dry and calm conditions).
2. Rainfall measurements collected with a rain gauge capable of obtaining 5-minute interval rainfall measurements. The rain gauge will be placed in the watershed of the watercourse studied.
3. Collect water level measurements related to the CGVD2013 geodetic vertical datum upstream of the tidal influence, close to the study area.
4. Water level measurements close to the study area but within the tidal influence at CGVD2013 geodetic vertical datum.

A municipality may want to engage an independent client engineer who can manage data collection and stakeholder engagement, as well as review the final flood mapping report.

2.3 Role of Consultant

The consultant's responsibility is to carry out the flood study following the Technical Specifications. This includes any mechanisms identified in the "Additional Mechanisms Checklist". The methodology the consultant must follow is laid out explicitly in the Technical Specifications, but there is room for the consultant to use their professional judgement. The goal should be to provide the municipality with the

best result considering budget, data availability, and timeline constraints. However, to provide consistency in flood mapping across the province it is important to follow the methods as closely as possible, and to provide justification, if not followed. This will help not only the municipality, but also the Province and the client engineer reviewer to understand the results of the study.

Once the consultant has been selected, they will work with the municipality to confirm that the additional mechanisms identified in the Statement of Work are applicable and identify any data gaps that will need to be filled before or concurrent with the flood mapping study.

2.3.1 Identification of tidal amplification and seiching

The municipality may have already identified tidal amplification and/or seiching within the study area and included it in the Statement of Work. Regardless, the consultant will need to take any required water level measurements within the tidal influence, graph, and compare them to the tidal predictions from Fisheries and Oceans Canada (DFO) for the closest site. The DFO data needs to be converted from Chart Datum to CGVD2013 to compare to the measurements. If the peak water levels are different, this indicates the presence of tidal amplification or seiching. Tidal amplification consists of increased tidal height peaks, while seiching consists of oscillations that continue to occur outside of the tidal peaks (several peaks between high tide times). If any of those mechanisms have been detected and were not originally included in the Statement of work, they should be incorporated through an amendment.

2.4 Review Process

Review Process	Municipal Review
	Client Engineer Review
	Approval

For the process of producing scientifically defensible flood lines to be effective, a review of the analysis and results is necessary. It is suggested that a multi-stage process be conducted:

1. The municipality will review the report and provide comments on any apparent differences between the Technical Specifications and the draft report. It may be that some of the differences are justified, however the consultant would need to have provided a rationale for the changes.
2. A third, independent party will be contracted as a client engineer. Their responsibility will be to compare the analysis with the Technical Specifications to ensure consistency in approach and in methods used, as well as possibly identify any potential issues or concerns. Note that this client engineer could also have other responsibilities such as managing data collection and stakeholder engagement.
3. The consultant will address any of the concerns raised by the municipality and the client engineer. This may require further justification for any deviation from the Technical Specifications or additional work to correct errors or oversights.
4. The municipality will conduct a final review before accepting the flood line mapping study. Since the study will ultimately belong to the municipality and will be used to inform future planning efforts it is important that they have a complete understanding of what they will be receiving.

The objective of the review process is to ensure consistency between the Technical Specifications and the flood mapping study analysis, report, and maps. The Technical Specifications and the “Additional Mechanisms Checklist” will be the basis for review of the deliverables.

2.4.1 Municipal Review

The municipality will review the deliverables to ensure:

- The various items requested are included in the deliverables.
- The analysis appears to include the various mechanisms requested.
- The report is clear and well written.
- The maps are readable, and the GIS files can be opened and are in the correct format.
- The report generally meets the expectations of the municipality.

2.4.2 Client Engineer Review

The client engineer review shall check the deliverable for consistency with the Technical Specifications document and the Checklist. It is understood that the review is not expected to check every detail of the modelling nor validate the actual flood lines, but rather review the process, model general parameters, and results. If the consultant proposed alternative modeling methods and provided rationale, the client engineer should have the capacity to understand if these changes meet the intent of the Technical Specifications.

The review will include the report, maps, GIS files, and the model files or a set of tables with the main model parameters. More specifically, the review shall include comments on:

- Overall quality of reporting.
- The approach to the various analyses of the minimum requirements.
- The approach to the various analyses of the different flood mechanisms.
- The main model parameters (runoff, losses, overflows, roughness, geometry).
- Calibration of the model(s).
- Whether the results fall within expected values (runoff coefficients for example).
- Whether the reporting and mapping meet the specifications for deliverables, and any outstanding element(s).
- If it is recommended that further detail be provided, or further analysis be carried out.

It is recommended that the review by the client engineer be conducted during the study period, and not once the study is completed. In this manner, any issue that arises can be discussed and resolved before the study is resumed. This will greatly simplify and accelerate the review process. The onus is therefore on both the study consultant (to let the consultant engineer review when any issue arises) and the consultant engineer reviewer (to keep track of the study progress and ask relevant questions), to ensure the process can be effective.

2.4.3 Approval

The formal acceptance of the report and flood maps by both the municipality and the consultant engineer, will be required before the final report is approved.

3.0 STATEMENT OF PROVINCIAL INTEREST

This chapter presents the Statement of Provincial Interest (SPI) on Flooding Risk Areas, to provide the supporting regulations for the development of municipal flood mapping. This chapter provides information on how municipalities should apply the provisions of the SPI on Flood Risk Areas and discusses how planning regulations are to be implemented as a minimum within the floodplains. The primary goal of the regulations is to protect public safety.

Statements of Provincial Interest outline the province's vision for protecting Nova Scotia's land and water resources. They also address issues related to the growth of our communities. Statements of provincial interest are adopted as regulations under the Municipal Government Act.

Statements of Provincial Interest regarding Flood Risks Areas were made under Section 193 and subsections 194(2) and (5) of the Municipal Government Act, S.N.S. 1998, c. 18. N.S. Reg. 101/2001 (April 1, 1999). They can be found through the following link:

<https://novascotia.ca/just/regulations/regs/mgstmt.htm#text>

The text below is current as of May 2022.

3.1 Definitions

These definitions apply to the Statements of Provincial Interest.

Floodplain means the low-lying area adjoining a watercourse.

Floodproofed means a measure or combination of structural and non-structural measures incorporated into the design of a structure which reduces or eliminates the risk of flood damage, usually to a defined elevation.

Floodway means the inner portion of a flood risk area where the risk of flooding is greatest, on average once in twenty years, and where flood depths and velocities are greatest.

Floodway Fringe means the outer portion of a flood risk area, between the floodway and the outer boundary of the flood risk area, where the risk of flooding is lower, on average once in one hundred years, and floodwaters are shallower and slower flowing.

FLOOD RISK AREAS

GOAL: To protect public safety and property and to reduce the requirement for flood control works and flood damage restoration in floodplains.

BASIS

1. Floodplains are nature's storage area for flood waters.
2. New development in a floodplain can increase flood levels and flows thereby increasing the threat to existing upstream and downstream development.
3. Five floodplains have been identified as Flood Risk Areas under the Canada-Nova Scotia Flood Damage Reduction Program.

APPLICATION: This statement applies to all Flood Risk Areas that are designated under the Canada-Nova Scotia Flood Damage Reduction Program. These are:

- (1) **East River**, Pictou County,
- (2) **Little Sackville River**, Halifax County,
- (3) **Sackville River**, Halifax County,
- (4) **Salmon and North Rivers**, Colchester County, and
- (5) **West and Rights Rivers and Brierly Brook**, Antigonish County.

There are other areas in the Province that are subject to flooding which have not been mapped under the Canada-Nova Scotia Flood Damage Reduction Program. In these areas, the limits of potential flooding have not been scientifically determined. However, where local knowledge or information concerning these floodplains is available, planning documents should reflect this information and this statement.

3.2 FLOOD RISK AREAS

APPLICATION

Under the Canada–Nova Scotia Flood Damage Reduction Program (FDRP), five rivers in the province were designated and mapped during the 1980s. These rivers were considered at that time the most significant in the province in terms of flood risk as it related to the amount of existing development and the likelihood for flooding. Hence, they posed a high potential for flood damage. An important condition in the federal-provincial FDRP agreement was that any new development in a designated flood risk area was not eligible for government flood damage assistance. An integral part of this program was the mapping of the flood risk areas on these five rivers.

Numerous other areas in the province are known to be subject to flooding, including many watercourses and coastal floodplains. “Watercourses,” as defined in legislation refers to “a lake, river, stream, ocean or other body of water” (MGA s.191(r) [Charter s.209(s)]).

Documentation of flooding events in these areas varies in type and extent. In areas without flood mapping, documentation can take the form of historical records, such as narrative descriptions, photographs, and recorded flood marks on buildings or structures. If such or some other documentation is available, a municipality should attempt to develop models or scenarios regarding the flooding. For example, historical documentation, such as photos and recorded flood levels, could be used to develop elevation maps to help define flood areas.

Municipalities are also encouraged to undertake scientific studies to more precisely document flood risk in areas not covered by the FDRP mapping. If a municipality identifies in its *planning documents* locally known *floodplains* (non-FDRP flood risk areas), and establishes land-use controls for these areas, care should be taken to ensure that these controls can be justified. The rationale for these land-use controls should be set out in policy in the *planning documents*.



FLOOD RISK AREAS PROVISIONS

1) Planning documents must identify Flood Risk Areas consistent with the Canada-Nova Scotia Flood Damage Reduction Program mapping and any locally known floodplain.

2) For Flood Risk Areas that have been mapped under the Canada-Nova Scotia Flood Damage Reduction Program planning documents must be reasonably consistent with the following:

a) within the Floodway,
(i) development must be restricted to uses such as roads, open space uses, utility and service corridors, parking lots and temporary uses, and
(ii) the placement of off-site fill must be prohibited;

(b) within the Floodway Fringe,

(i) development, provided it is flood proofed, may be permitted, except for

PROVISIONS

1) The first step is to identify any FDRP and other flood risk areas within the municipality and delineate them on maps in the **planning documents**. These maps should identify the areas in terms of both the floodway and floodway fringe. FDRP areas should be dealt with separately from other flood risk areas since the federal-provincial agreement specifies there will be no government flood damage assistance for new developments in FDRP flood risk areas.

2) a) (i) This provision applies only to the flood risk areas for the five rivers that were designated under the FDRP. Each flood risk area is divided into two sub-areas: **floodway** and **floodway fringe**. The **floodway** is the area where flooding will be the deepest, with the fastest flow and greatest potential for damage. The **floodway** has a 5 per cent chance of being flooded in any given year. More stringent restrictions should be placed on development in the **floodway**, including prohibiting permanent structures and restricting land uses to activities that would create minimal impact. Permitted uses could include those involving the following:

- cropland
- recreation and open spaces (athletic fields, golf courses, parks)
- utility or service corridors (underground piped infrastructure)
- mobile enterprises (those easily moved in case of flooding, such as a mobile canteen or flea market)
- seasonal activities (permitted only when the potential for flooding is low)
- minimal impact activities (will not alter flood patterns and rates, or the capacity of the floodplain)

2) a) (ii) Placing fill in a flood risk area can alter the flow patterns and rates of floodwaters, as well as the storage capacity of the floodplain itself. Adding new fill reduces the storage capacity and increases the likelihood that lands previously not subject to flooding will be flooded. Hence, a municipality's **planning documents** must prohibit the placing of **off-site fill** in the **floodway**.

b) (i) Flooding is less likely to occur in the **floodway fringe** than in the **floodway**, and when floods do occur the depth and speed of the floodwaters is also less. The **floodway fringe** has a 1 per cent chance of being flooded in any given year. Buildings and structures for certain uses may be permitted, provided they are built in a way that minimizes the impact. Since ice floes are often associated with flooding in Nova Scotia, the design of structures should take this into account.

**FLOOD RISK AREAS
PROVISIONS**

2) b) (i) (cont.)

(1) residential institutions such as hospitals, senior citizen homes, homes for special care and similar facilities where flooding could pose a significant threat to the safety of residents if evacuation became necessary, and

(2) any use associated with the warehousing or the production of hazardous materials,

(ii) the placement of off-site fill must be limited to that required for flood proofing or flood risk management.

3) Expansion of existing uses must be balanced against risks to human safety, property and increased upstream and downstream flooding. Any expansion in the Floodway must not increase the area of the structure at or below the required flood proof elevation.

4) For known floodplains that have not been mapped under the Canada-Nova Scotia Flood Damage Reduction Program, planning documents should be, at a minimum, reasonably consistent with the provisions applicable to the Floodway Fringe.

5) Development contrary to this statement may be permitted provided a hydrotechnical study, carried out by a qualified person, shows that the proposed development will not contribute to upstream or downstream flooding or result in a change to flood water flow patterns.

2) b) (i)

(1) Concern about the possible damage or destruction of buildings and property is one of the reasons for the statement on Flood Risk Areas. Some uses, such as for emergency services or care facilities, should not be permitted in the **floodway fringe**, since access is always essential.

(2) Additionally, allowing **hazardous materials** to be stored or produced in a **floodway fringe** could pose serious health and environmental risks. Uses associated with these materials, including petrochemical storage, must be prohibited in the **floodway fringe**.

2) b) (ii) Since floodwaters are shallower and slower-moving in the **floodway fringe**, the placement of **off-site fill** when raising the elevation of the ground under and around a building to provide **floodproofing** is acceptable. **Off-site fill** can also be used for dyke construction, flood control, or improving the flow of floodwaters.

3) This applies to FDRP mapped areas but can be applied to other known **floodplains**. The objective of this provision is to maintain the storage capacity of the **floodplain** and prevent alteration of floodwater flow. This can be achieved by limiting building and structure expansions to vertical additions through development agreements or site-plan control.

4) This pertains to flood risk areas that have not been designated under the FDRP. At a minimum, the requirements of a **flood fringe** area should be used for these flood risk areas. However, using flood fringe requirements does not preclude a municipality from establishing more stringent requirements if more detailed information (such as flood risk mapping) or local conditions warrant doing so.

5) This applies to both FDRP and other flood risk areas. It enables a municipality to permit development if a hydrotechnical study demonstrates that doing so will not increase flooding or change flow patterns. A hydrotechnical study is a specialized scientific investigation of water flows and factors contributing to floods (e.g., tides, ice, storm surges, etc.).

Municipalities with flood risk areas mapped under the FDRP should not assume that the approved FDRP mapping or the conditions that apply under that program to those lands will change because of the hydrotechnical study. Additional matters, related to factors such as climate change and development that has occurred in the last 30 years or more since the creation of the mapping, might cause the areas of concern to expand.

4.0 GLOSSARY

Flood mechanisms: These are specific causes of flooding, identified by the processes that take place, and lead to flooding. For example, intense rainfall is a flood mechanism. Other, less obvious causes may also exist, such as jamming of a drainage gate by sediment or debris.

Vulnerabilities: Vulnerabilities as discussed in these documents include land use, infrastructure, or services that would be negatively impacted by flooding.

Tidal amplification: Tidal amplification consists of the increase in tidal peak water levels, caused by the funnelling effect of a cone-shaped inlet.

Seiching: Seiching consists of oscillations, sometimes very large, that continue to occur outside of the tidal peaks (several peaks between high tide times). The Bay of Fundy is an example of very large scale seiching, where the oscillation time matches the time between tides.

Return period: The return period of an event is the average number of years, in the long term, between events of a given magnitude. An event with a return period of 100 years is denoted as a 1 in 100-year event. The return period may be more clearly explained in terms of its probability of occurrence (or Annual Exceedance Probability or AEP): a 1 in 100-year event has a 1% probability of occurrence in any given year. The fact that an event of large magnitude has occurred in the recent past does not change this probability. Similarly, a 1 in 20-year event has a 5% probability of occurrence in any given year.

Intensity-Duration-Frequency (IDF) curves: An Intensity-Duration-Frequency curve is a tool that helps engineers calculate flows and water levels, and design safe structures to a consistent level of risk protection. It is the result of a statistical analysis of long-term rainfall data that relates the duration of rainfall events to their peak intensities, for a given frequency of occurrence. It is used to produce a historically representative estimate of a rainfall event with a given frequency of occurrence or return period.

Wave setup - the increase in mean water level, due to the presence of breaking waves. It is typically a non-negligible component of the storm surge in exposed areas with wide beaches. Essentially an increase in the storm surge water level against the shore.

Wave runup - the vertical extent of the wave uprush on the coastline slope, which can lead to erosion and local flooding.

Wave overtopping - For areas with built coastal defences, the amount of water discharged over a coastal defense structure.

Lidar: Lidar is a method for measuring distances by illuminating the target with laser light and measuring the reflection with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the target. Lidar data are represented as a 3D point cloud.

Topographic Data: Topographic data are information about the elevation of the surface of the Earth. There are two main ways to represent topographic data on a map. The first represents information on a topographic quadrangle map, with contour lines, roads, streams, railroads, towns, etc. The second uses grids of data, for which each cell in the grid represents the elevation at a certain point on the Earth. Grid data are commonly referred to as Digital Elevation Models or DEMs.

Bathymetric Data: Bathymetric data are the underwater equivalent of topographic data. It is generally collected using bathymetric lidar in shallower water and multibeam sonar in deep water. Using sonar, depth is estimated by measuring the time it takes for a beam of sound to travel from a sounder at the surface of the water to the seafloor or riverbed and be reflected to the sounder.

Hydrologic Analysis: A hydrologic analysis allows the estimation of runoff flows from a watershed into a watercourse. It is not intended to produce water levels, only flows. A hydrologic analysis can be conducted at a single point, or at many points.

Hydraulic Modelling: Hydraulic modelling is the assessment of water levels in a hydraulic conveyance system (e.g., river) that are reached when flows are entered into this system. Water levels will be dependent on factors such as channel shape, slope, roughness, bends, constructions, storage, structures (e.g., dams), etc.

Calibration: Model calibration is the process of reproducing measured flows and water levels using only climate data (and tidal water levels if needed) as input for a model run. The objective is to adjust the hydrologic and hydraulic models to be representative of the watershed and drainage system, so that it can produce realistic estimates of peak water levels during extreme events. Calibration is conducted by first identifying the most representative measured flood events, which are typically those closest to the design events (the 5% AEP and 1% AEP events). Rainfall, flow, and when possible, water level data are collected, and the model is run to see if the model results match the recorded flows and water levels (including the accreting and receding limbs). If this is not the case, the model parameters must be adjusted to allow the model to match the measured curves closely as possible. The adjustment process, however, is the core of the calibration effort.

CGVD2013 geodetic vertical datum: This height reference system replaced the Canadian Geodetic Vertical Datum of 1928 (CGVD28), which was adopted in 1935. CGVD2013 is defined by the equipotential surface ($W_0=62,636,856.0 \text{ m}^2\text{s}^{-2}$), which represents the coastal mean sea level for North America. CGVD2013 corrects for the distortions in CGVD28 that range from -65 cm and +55 cm, nationally. The largest absolute changes are in the Maritimes where the new datum will be higher by 65 cm, meaning lower elevations for the region.

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Appendix A: Guidance Document

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CHAPTER 1 **GENERAL PROCESS**

1.1 Introduction

Nova Scotia is a province with wide ranging topographic, hydrologic, soil, sediment and coastal characteristics, this document presents an adaptable approach that allows municipalities to customize the analysis to the more relevant factors that influence flooding risks. Flood scenarios associated with a specific return period need to produce flood extents that are based on reasonably foreseeable mechanisms that generate high water levels, for that return period.

The steps outlined in the Guidance document will allow the municipality to identify the mechanisms that together produce conditions that would occur in the watercourse during floods. Careful consideration of the various flood mechanisms that may exist in the study area will allow the generation of flood extents that are representative of the actual floods experienced at the site.

The following sections describe the process to be followed by the municipality through the project. It includes a description of each step that will support the selection of flood mechanisms. They can then be checked in the Checklist presented in Chapter 5 and included in the Request for Proposals for the flood mapping study, to form the Scope of Work.

1.2 Steps to be taken by the Municipality

1.2.1 Flow chart of main steps

Following the expression of need for a flood study, the municipality will need to review current land use planning documents, as well as existing and future land use maps. This will help define the level of study needed in various parts of the watershed. The municipality should use the following general steps to inform and prepare the RFP document. The municipality may want to solicit expertise in public consultation to carry out those steps, collect, and report the information shared. The flow chart presented in Figure 1 provides steps that will allow for RFPs to be developed that include relevant information for the flood studies. Initial steps to support the identification of flood mechanisms and the development of the RFP are listed in Figure 1.

For the study scope to be meaningful and representative of the existing flood mechanisms, it is important that the municipality take steps to identify the main causes of flooding and key vulnerabilities in the system. The central purpose of the flood mapping study is to provide support for future development regulations in the floodplain areas. Therefore, the flood maps need to be informed by the local experience of flooding and show the vulnerabilities along the watercourse or coast. The earlier the

stakeholders, community members, and the public are involved in the process, the more likely the new flood lines and associated regulations will be readily adopted. If there are First Nations communities that share the watershed, the municipality or its representatives will need to meet with them to share and gather information. Additional considerations when engaging First Nations communities is included in Section 1.2.2.

Even if accurate flood maps indicating high-risk zones are maintained, it is necessary to gain public support to turn these maps into action. Media and public discourse demonstrate that public perspectives can complicate the rollout of flood mapping. Flood mapping initiatives and outputs need to be communicated in a way that builds public buy-in and constructive engagement, while avoiding pushing people into defensive positions. Information relating to communication strategies and various perceptions to be aware of, before the coordination of the various meetings, is presented in Sections 1.2.3 and 1.2.4.

In addition to historical and anecdotal information on flooding, water level data will need to be collected to better inform the identification of flood mechanisms. It is understood that most municipalities will not have the capacity to carry out this work and will need to obtain consulting services to support the collection and interpretation of water level data and the identification of relevant flood mechanisms. A data gap analysis before or during the initial stages of the project will help determine what additional data gathering may be required before accurate flood lines can be developed. At minimum the findings of the data gap analysis should be included in the final report so that limitations of the modelling can be understood and planning for future flood line mapping can incorporate additional data gathering.

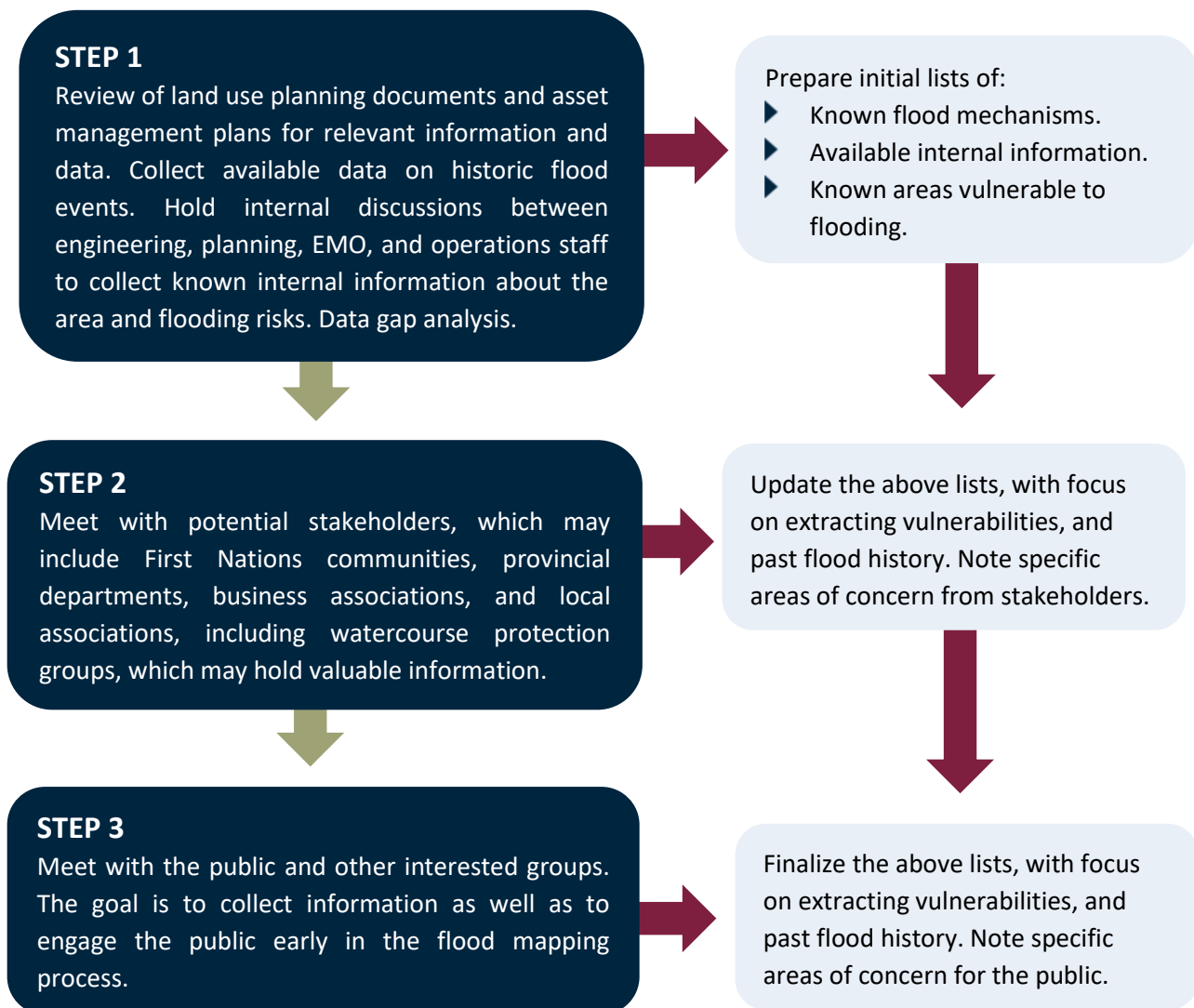
In Step 2 of Figure 1, vulnerabilities are discussed. Vulnerabilities in this context specifically relate to land use, infrastructure, or services that would be negatively impacted by flooding. A few examples include: residential areas, hazardous material storage, contaminated sites, emergency and long-term care facilities, emergency vehicle parking, daycares, farmland that would be damaged by saltwater, bridges, dykes, shorelines that are eroding close to buildings, roadways servicing emergency response and long-term care, communications, drinking water, power supply, etc.

It is important to identify vulnerabilities prior to initiating the study, such that discussions can be held to identify which vulnerabilities are sufficiently important to influence the flood mapping study. For example, if a hospital is close to a potential floodplain, special consideration should be given to understanding the flood risks at that location. Considerations could include:

- Looking at less apparent, but still potentially damaging, flood mechanisms
- Selecting more conservative parameters in the flood model
- Including scenarios that may be less likely (e.g. higher growth future development scenarios, upgrade of hydraulic structures, etc.), but that could lead to increased flooding at the site.

Following this, a municipality will use all the information gathered to decide which flood mechanisms to include in the study. Note that there will be another opportunity to review this selection at the beginning of the flood mapping project during discussions with the selected consultant.

Figure 1: Steps Prior to Conducting the Flood Study to Support Development of the RFP



1.2.2 Engaging First Nations Communities

Land management issues are a key area of concern for many First Nations communities because their cultural practices, traditions, spirituality, and well-being have always been intricately linked to the land. Access to land and participating in land use decision making processes is sought by First Nations communities for purposes of nourishing their cultures, helping to exist sustainably, and acquiring communal benefits from lands and resources.

First Nations hold a wealth of knowledge about the diversity and interactions among plant and animal species, landforms, watercourses, and other biophysical features. Municipalities and consultants may benefit from this knowledge as they define the flooding mechanisms prevalent in the study watershed. However, the capacity of First Nation communities to engage varies and can be limited; decision-makers may hold multiple positions in their communities and often seek input from the membership before a decision is made. Consideration and time should be allowed for decision makers to juggle roles and

consult community members. Municipalities and consultants should factor this into their project timelines.

Early engagement demonstrates commitment from the municipality and consultants and builds the First Nation's connection to the project as they see their contributions and input shaping its outcomes. Early engagement also provides greater opportunities for the development of resulting land use plans that avoid impacts to Aboriginal interests and are more responsive to the broader interests and values of the First Nation. While there is no standard formula for a good relationship, the common characteristics are trust, goodwill, respect, commitment, and transparency.

1.2.3 Meeting with the public

The intent of including input from all potentially affected parties at the outset of the project is to follow a process that is inclusive and respectful of all involved groups and members of the public. Since they will be impacted by any development controls imposed because of the study, it is important that they understand that the goal is to protect public safety, and that a thorough process has been followed. Of equal importance is the fact that this process provides an opportunity for relevant information to be gathered from the community. This information forms the basis upon which much of the assessment will rest, and therefore needs to be as extensive as possible.

While the importance of protecting public safety is understood by all, impacted landowners and the local community may be concerned about the potential restrictions that can be placed on the development of properties. To minimize future conflict when making changes to land use zoning and planning documents to align with the results of the flood study, it is important to engage the local community early in the flood study. If the community's first exposure to the flood lines is when land use regulations are being developed, it is likely too late. The flood study is composed of a significant amount of information and will take time for the average citizen to understand. If they are not involved in the process, some community members may feel that there is not enough opportunity to suggest changes to the assessment or proposed regulations.

Engaging the community to collect information about their experience with flooding can have a positive impact on public perceptions of the study and its outcomes. Flooding can be traumatic for people and the municipality should be prepared to have meaningful conversations with those who have experienced loss due to a flood event. On the other side there may be individuals who do not see the value in restricting development, but by including them in the assessment before any analysis is conducted, they will have an opportunity to voice their concerns and hopefully have a positive impact on defining the study's parameters. By engaging the public early in the process, a municipality will often have greater support from its constituents and end up with a study that is better supported by local information.

A typical approach to an engagement meeting would include:

- 1) Presentation of background information that led to the initiation of the project. This can be known historic flooding information, the Municipal Climate Change Action Plans, known safety concerns, or any other relevant information. This is typically best achieved using a series of posters in an Open-House style of public meeting, where one to one discussion is facilitated.

- 2) Provide large maps, on which members of the public can note extents of past floods, or vulnerable infrastructure. This information can later be entered in a GIS database for reference.
- 3) A questionnaire to fill out, to record relevant information. Suggestions include:
 - a) Can you recall the dates during which you witnessed flooding in this area? (refer to a map)
 - b) Can you draw on one of the provided maps a line showing the extent of flooding that you are aware of, noting the date on the line?
 - c) In your opinion, what are the leading causes of flooding and why?
 - d) Please note which roads you would need to use to access emergency services or supplies.
 - e) Do you have a Municipal / Town water supply connection, or are you on a well?
 - f) Please note any areas that is in your opinion vulnerable during floods.

As previously stated, one the main goals of this type of early engagement will be to gather information on potential flood mechanisms to include in the study RFP. To support and inform this process, descriptions of each mechanism are presented in Chapter 2, as well as a check list that can be included in meetings and/or the RFP.

1.2.4 Recommendations for Municipal Communications

Step 1: Reflect

As a municipality, it will be important to understand the core reasons for opposition to flood mapping and the social science theories¹ that help explain them, as this will help generate empathy for citizens in advance of the project. Empathy will help municipalities and their representatives design thoughtful engagement processes that consider the concerns of citizens and strengthen the likelihood of citizens perceiving the municipality positively.

It is also useful to take an informal audit of trustworthiness within your municipality, both citizen-to-municipality and citizen-to-citizen. This may include reflecting on and learning from past public engagement campaigns and program rollouts and any conflicts that arose, even if they are not flood related. Trust can be repaired through acknowledgement, apology, taking responsibility for past harms, and working to avoid such issues in the future. Trust repair is difficult but critical work if citizens are going to be willing to engage. Municipalities can build trust through competent communication that demonstrates ethical care and reliability.

There also needs to be a political will within the municipality to stand by the flood mapping product and implement policy to protect future as well as current citizens. It may be helpful to develop some guidelines about how different categories of risk will be handled even before risk is assigned to specific locations. Key operating principles should be discussed with councillors and other elected officials (e.g., MLAs), and document whatever is decided on so it can be revisited later.

¹ For a discussion of social science interpretations of media discourse on flood mapping support and disapproval See the Additional Information section at the end of Appendix A. Adapted from a report on Flood Mapping: Navigating Multiple Perspectives by MJ Valiquette, Simon Couper and Kate Sherren from the School for Resource and Environmental Studies, Dalhousie University.

Step 2: Involve citizens when engaging with experts

Most municipalities will not have the in-house flood mapping capabilities that will be sufficient to meet the technical specifications expected by the Provincial government. Any consultants hired to do such work should have not only technical but also public engagement competencies. The consultants will not only be technical experts but will also be proxies for the municipality, and any relationship failures will reflect upon the municipality and the resulting product. Ensure that the consultants hired have a track record of productive engagement with the public.

For citizens to trust consultants they must see them as competent in terms of their related experience and abilities. The best way to ensure this is to involve citizens. This could include involving citizen members in a flood mapping project steering committee or creating a separate citizen's flood mapping advisory committee. Citizens should be chosen for their diversity and capacity to represent different perspectives (including youth, new residents, and others who may vote in lower numbers and thus be likely underrepresented on council), but also for the esteem by which they are held in the community. Meaningful involvement will help citizens feel that they are being well represented, but also leverage cognitive shortcuts: if people they know and respect advocate for flood mapping and stand behind the final product, other residents are less likely to reject the outcome.

Step 3: Demonstrate the shared challenge and shared responsibility

Before flood mapping is carried out it is important to show citizens that it is needed and will be for the public good. Lay out all the problems that can arise because of flood mapping, discuss climate trends that indicate a worsening trajectory, and invite conversation on the shared challenge of adaptation. Flood mapping is only one response to adaptation; municipalities should be prepared to hear others. Municipal representatives should lead this kind of meeting and avoid showing any existing flood delineations in their municipality, as citizens may attach to those in unhelpful ways. Stories and photographs of extreme events in the area, or nearby, can be used, however. This reminder of adverse impacts will make the issue salient without triggering instinctive responses, which will undermine the careful reflection required to tackle the complexity of flood adaptation.

When a municipality gives residents complete information about the costs and benefits of flood mapping, and then includes residents in developing responses to the mapping, residents are much more likely to engage and accept the outcomes. If participants understand the necessity and benefits of flood mapping, then they can also feel more motivated and knowledgeable in their ability to influence flood mitigation strategies.

Step 4: Leverage and incorporate local knowledge early

Residents will be more likely to reject flood mapping if they are not involved and the resulting maps do not reflect their experience. This can be avoided in part by recognizing local expertise and inviting citizens to meaningfully participate in the project (e.g., understanding historical flooding). However, engagement should clearly convey that historical experience is only one dataset feeding into the analysis and that it is not a perfect predictor for future flooding, especially as the climate changes.

Information should be tailored to meet people at their level of readiness and willingness to adapt to flooding. Meetings should be run to promote respect, comfort, and competency amongst participants. Consider asking them to bring their own historical photographs of floods, so these conditions can be recorded for specific sites. Maps used in the meetings should incorporate landmarks that citizens will be

familiar with and navigate by. Make sure the chairs are comfortable and that people have time to stretch and chat over good coffee. Use silent ballots where social pressures might make voting or other input difficult. Finally, consider varying meeting formats to maintain citizen interest, perhaps even holding them at sites near floodplains or coasts so that the meeting can discuss issues in-situ.

Step 5: Provide a counter-narrative to the media

Media coverage plays a significant role in extending the reach of flood mapping messages; the media is instrumental in creating frames in public debate. It is imperative to ensure continual and positive discourse with the media. Try to frame messages that emphasize local engagement and benefits. Risk perception studies have found that residents’ positive attitudes towards flood mapping increase after intensive media campaigns that feature consistent and targeted framing about the benefits of flood mapping.

Overworked journalists are highly responsive to complaints by unhappy citizens. Many of the significant challenges to flood mapping and coastal adaptation in the past few years have been driven by citizens (Big Lake, Hantsport, Shubenacadie). Such stories heavily influence public opinion. It is critical to cultivate a narrative in the media utilizing citizens who have been disadvantaged by the lack of flood mapping.

Step 6: Commit to transparency

Municipalities should adopt a communication strategy that addresses cognitive biases and presents evidence for the need to perform flood mapping. Sharing information through social networks and social media allows for broad interaction and builds trust between individuals, the government, and other stakeholders.

Advance communication tools such as geovisualizations (i.e., maps with animations) can strengthen connection to place and convey complex information in an accessible way. However, these tools also demand expertise that may make them prohibitively expensive. If utilized, geovisualizations and similar tools should be employed at the conclusion of the study to communicate the results.

Publicly available maps are key to reducing risk. Information on these maps should be easily accessible (e.g., by address, or easily navigated interface) and allow for interpretation by non-experts (e.g., using landmarks and intuitive colour choices). Information on how users can interpret their flood risk level (i.e., frequency and amount of flooding) and how to reduce it (i.e., evacuation routes, property-level protection measures and flood insurance).

Tactics for Stakeholder Engagement

Champions Briefing	Hold briefings for municipal representatives, employees, and other key influencers to ensure they understand your initiative and are equipped to be champion it with their networks. Consider developing talking points and a presentation that your champions can use.
Media Release	Develop and deliver media releases at key milestones, communicating the drivers, process and progress updates.
Media Event	Hold media events at key milestones, including initiative launch and to communicate progress updates. In addition to municipal representatives,

	consider making your consultants, initiative champions and engaged residents available to local media.
Materials	Consider developing talking points, a presentation slide deck, a brochure or one-page summary at the outset of your initiative. Develop reports at key milestones to communicate progress.
Website	Develop a website or allocate part of an existing municipal website to communicate initiative background and progress information.
Social media	Use social media channels to provide brief updates on your initiative. These channels can be particularly effective for demonstrating citizen engagement e.g. post photographs of input sessions.

1.3 Water level and rainfall measurements

Meeting with operations staff, local groups, First Nations communities, and the general public may produce an understanding of the presence of the most common flooding mechanisms (e.g. ice jams or floods associated with snowmelt), but may not shed light on some more complex mechanisms, such as tidal amplification or seiching. It is important to collect this information prior to the flood study, because those mechanisms can only be identified through field measurements of several weeks, and also because they involve an additional amount of modelling that would increase the level of effort for the study. Identifying those mechanisms can be challenging, and it is likely most municipalities will require consultant services to carry out this scope of work.

1.3.1 Role of a consultant before the Flood Study to support preparing the RFP

This section outlines the role of a consultant for the analysis of the data and in support of the preparation of the RFP. This could be the same consultant that will carry out the flood study, a separate consultant engaged just to help develop the RFP, or the client engineer that was described in the overview document and will review the final results of the flood study.

- The consultant will need to analyse the data, as well as the information gathered by the municipality, and provide recommendations to include other flood mechanisms where the consultant deems appropriate.
- On items where the municipality is making decisions, the consultant will provide clear recommendations supported by professional expertise and analysis.
- The consultant should be able to defend the analyses provided against questions from the public, other consultants, agencies, as they occur.
- The consultant will need to have a team that is appropriately qualified to do this work, and that allows the analysis to be completed in a defensible manner.
- The consultant will provide input to the municipality on the specifications and guidance items they feel are not appropriate for the specific study area, with the intent that the study will be as scientifically defensible as possible.
- The consultant will have appropriate professional liability insurance.
- The consultant will have the ability to stamp report and maps by a professional engineer qualified to practice in the Province of Nova Scotia.

1.3.2 Identification of tidal amplification and seiching

Tidal amplification and seiching can typically be detected by analysing water level measurements at coastal sites and comparing them to expected peak tide levels from the closest harbour and tidal information available from the Canadian Hydrographic Service. In addition, rainfall data may be sparse, and water course water level data are often not available from the Environment Canada flow gauging stations (only flows). Therefore, rainfall and water level measurements upstream of the tidal influence are also extremely valuable.

To supplement existing anecdotal information and provide consistent data measurements to support model calibration, it is required that the following measurements are collected for a duration of 1 month minimum, between the months of October to May (to avoid the summer dry and calm conditions). If there are issues with the instrument (impacted by ice, sediment, erosion, or tampering), then the monitoring period should be extended to obtain 1 month of reliable data, with at least 2 weeks of continuous measurements.

- Rainfall measurements with a rain gauge capable of obtaining 5-minute interval rainfall measurements. The rain gauge should be placed in the watershed of the watercourse studied.
- Water level measurements (related to the CGVD2013 geodetic vertical datum) upstream of the tidal influence (where there are no increases in water levels twice a day), within the study area.
- Water level measurements in the study area and within the tidal influence (that would be below mid-tide level or lower).


If preliminary historical, anecdotal, and other evidence indicates that the watershed does not include riverine flooding risks; the rainfall gauge and the water level measurements upstream of the tidal influence can be omitted. Similarly, if evidence suggests that the site only experiences riverine flooding risks, the water level measurements within the tidal influence can be omitted.

Once the water level measurements within the tidal influence have been collected and graphed, they will need to be compared to the tidal predictions from Fisheries and Oceans Canada for the closest site. The data will need to be converted from Chart Datum to CGVD2013 to compare to the measurements. If the peak water levels are different, this indicates the presence of tidal amplification or seiching. Tidal amplification will consist of increased tidal height peaks, while seiching will consist of oscillations that continue to occur outside of the tidal peaks (several peaks between high tide times). If any of those mechanisms are detected, they will need to be included in the scope of work for the flood study.

A review of the data and the possible presence of tidal amplification or seiching will need to be made by the selected consultant to confirm that the scope of work should include those flood mechanisms.

CHAPTER 2 **MINIMUM SPECIFIED STANDARDS**

This chapter discusses the baseline standards that should be followed in Nova Scotia. These are to be applied to *all* flood mapping studies. For more detail on the minimum specified standards refer to Chapter 1 of Appendix B: Technical Specifications. Additional elements can be studied if they are found to be present (Chapter 3). All flood mapping studies carried in Nova Scotia must consider the following:

Specified Standards	Return period or frequency of flood events to analyse	Statement of Provincial Interest	1% AEP (1 in 100 Year event) 5% AEP (1 in 20 Year event)
	Projection Horizons for the analysis of future flood events	Land Use Planning Horizons	2050 (25-30 Year planning horizon) 2100 (75-80 Year planning horizon)
	Required Analysis Scenarios		
			 Precipitation Coastal Water Level Climate Change

2.1 Return period or frequency of flood events to analyse

The current Statement of Provincial Interest on Flood Risk Areas establishes the 1 in 20-year return event as the floodway and the 1 in 100-year return event as the floodway fringe extents. This is to be considered the minimum acceptable provincial standard. These events are more clearly explained in terms of probability of occurrence every year or Annual Exceedance Probability (AEP). The 1% AEP (equivalent to the concept of the 1 in 100-year return event) and 5% AEP (equivalent to the concept of the 1 in 20 year return event) should be used by both the municipality and the consultant when carrying out the flood study and engaging with stakeholders and the public.

2.2 Projection Horizons for the analysis of future flood events

In conjunction with the development of these specifications, the Province consulted with multiple academic institutions to develop a standardized framework for the selection of scenarios and the incorporation of future climate changes into riverine and coastal flood mapping in Nova Scotia. Literature reviews were conducted in various fields, the results were discussed with the province in two workshops, and the outputs of the work were summarized in a set of specifications and recommendations: the **Standard for the incorporation of climate change into riverine and coastal flood mapping in Nova Scotia** (Jamieson, R., Kurylyk, B., Rapaport, E., Manuel, P., Van Proosdij, D., Beltrami, H., Hayward, J., KarisAllen, J., Clark, K., Tusz, C., Jahncke, R., García-García, A., & Cuesta-Valero, F.,J. (2019)). Henceforth this document will be referred to as the **Climate Change Standard**. The **Climate Change Standard** is included in the RFP package and provided to the consultants with the **Nova Scotia Municipal Flood Line Mapping** document and **Appendix B: Technical Specifications**.

As per the **Climate Change Standard**, the time horizons to be used for flood mapping of future conditions are 2050 and 2100. Adjustments to rainfall and coastal water levels to account for climate change should follow this document.

The municipalities will provide information to the selected consultant on the potential future changes to land use at those time horizons. However, the consultant will also need to refer to the applicable Municipal Planning Strategies to understand current and future land use in the study area. Municipalities need to ensure that the consultant has access to the most up-to-date version of their Municipal Planning Strategy and Land Use Bylaws.

2.3 Required Analysis Scenarios

The minimum analysis scenarios prescribed by the **Climate Change Standard** are for precipitation and coastal water levels (storm surge and tide), for both current and future conditions.

2.3.1 Precipitation:

Current: Current 5% and 1% AEP precipitation events are obtained from the nearest Environment and Climate Change Canada station with IDF curves. The duration of the design rainfall events shall be 48 hours.

2.3.1.1 WINTER RAINFALL EVENT

In addition to the scenarios prescribed by the Province through the **Climate Change Standard**, winter rainfall events shall be investigated. Since winter conditions in Nova Scotia (i.e., December 1st to April 1st) include many freeze-thaw cycles, the likelihood of rainfall (as opposed to snowfall) occurring during winter is high and generally expected to increase with Climate Change. This should be investigated as part of the minimum scenarios.

2.3.2 Coastal Water Levels:

Current: The continuous surface model based on oceanographic models, observed water levels, GPS observations, sea level trends, satellite altimetry, and a geoid model provide more accurate flood modelling (Robin et al., 2014) provides better resolution at the local level, particularly for areas that are not close to a real-time tide gauge.

Caution in the application of this approach should be applied where there is the possible risk of loss of public confidence in flood extents depicted if extreme water level projections decrease (due to decreases in modelled HHWLT). This is precisely the case for the Upper Bay of Fundy. At present, it is recommended that the new 2017 HHWLT values NOT be applied in areas of the Upper Bay of Fundy where there are extensive intertidal zones which are known to be poorly resolved in oceanographic models.

The following section identifies and highlights the need to consider additional input scenarios to provide a more representative approach (e.g., return periods of snowpack depth, climate change impacts on tidal amplification, etc.) to overall flooding risks at the site.

CHAPTER 3 LIST OF POTENTIAL FLOOD MECHANISMS

This section provides information on various additional mechanisms that may contribute to high water levels. Riverine, coastal, and estuarine mechanisms that contribute to high water levels under current scenarios are presented first. These are then considered with future changes to land use and climate. The mechanisms are provided in a checklist and include a Factor of Safety. This Factor of Safety accommodates mechanisms that are expected to be present in the area but can not be properly studied in the flood assessment. The municipality will need to review the mechanisms and use any existing information (historical, anecdotal, previous studies, etc.) to determine which mechanisms to include in the scope of work for the flood study.

Potential Flood Mechanisms			Future Scenarios		
	Current Scenarios		Mechanisms Relevant in Estuarine Floodplains	Land Use Change	Climate Change
		Mechanisms Relevant in Riverine Floodplains	<i>Ice jamming</i> <i>Snowmelt during a rainfall event</i> <i>Dam operation</i> <i>Changing risks according to season</i> <i>Hydraulic structure operation</i> <i>Debris jamming</i>		
		Mechanisms Relevant in Coastal Floodplains	<i>Wave setup</i> <i>Wave run-up and overtopping</i> <i>Tidal amplification</i> <i>Seiching</i>		
		Joint Probability Analysis	<i>Storm surge and rainfall</i> <i>Other combination of events</i>		

3.1 Criteria and Roles for Selecting Mechanisms

Chapter 1 sets out what information needs to be collected by municipalities prior to procuring flood mapping. Depending on budget considerations, preliminary data and information gathering, and advice from the client engineer, the municipality should be able to identify the relevant flood mechanisms to include in the flood study. The selected consultant will review the selected flood mechanisms proposed by the municipality and confirm that these are appropriate. The client engineer can also provide comments if there is disagreement between the municipality and the consultant.

Thus, the criteria for determining site-specific flood scenarios are:

1. Extracting historical records and local knowledge (municipality)
2. Conducting water level measurements (municipality and/or consultant)
3. Expert experience (consultant)
4. External experience (client engineer)

3.2 Checklist of Flood Mechanisms

The flood mechanisms presented in Table 3.2 are further described in the following sections. The completed checklist will inform the scope of work for the flood study and would be in addition to the Minimum Specified Standards (Chapter 2).

By using the checklist in the development of the Request for Proposals the municipality has a starting point as they try to identify flood mechanisms. Any data gathering (e.g., water level measurements) or meetings with staff, stakeholders, community groups, interested parties, and the public will also support the identification of additional flood mechanisms.

If a mechanism is known to exist, but available expertise, data, or budget, do not allow those mechanisms to be studied, the Factor of Safety included in the table can be used. This approach is supported by Nova Scotia's existing precautionary principle contained in the province's Environment Act (1994), to address uncertainty: "the precautionary principle will be used in decision-making so that where there are threats of serious or irreversible damage, the lack of full scientific certainty shall not be used as a reason for postponing measures to prevent environmental degradation" [Section 2(b)(ii)].

Climate change is layered on existing scenarios. Therefore, the scenarios identified in the checklist will have their rainfall amount and sea levels, increased by the respective values prescribed in the **Climate Change Standard**.

Further general guidance is provided in this chapter to support the inclusion or rejection of different mechanisms. Requirements that are more relevant to conducting the assessment itself (topographic data, hydraulic structure surveys, interaction with collection system, hydrologic and hydraulic modelling requirements, model calibration requirements) are only included in Appendix B: Technical Specifications.

The checklist provided below will be initially filled out by the municipality and supporting consultant, during the preparation of the RFP, and appended to the RFP. It will then be reviewed and confirmed by the consultant selected to carry out the flood study. One checklist should be filled out for current climate conditions, an additional two items are added for future conditions, which would include climate change impacts.

Table 3.1: Checklist of Potential Flood Mechanisms

Number	Flood Mechanism (Check if believed to be present)
<i>Existing Climate Conditions</i>	
Riverine Flooding	
1	<input type="checkbox"/> Snowmelt during a rainfall event
2	<input type="checkbox"/> Ice jamming
3	<input type="checkbox"/> Debris jamming
4	<input type="checkbox"/> Dam operation
5	<input type="checkbox"/> Hydraulic structure operation
6	<input type="checkbox"/> Changing risks according to season
Coastal Flooding	
7a	<input type="checkbox"/> Wave setup
7b	<input type="checkbox"/> Wave run-up or
7c	<input type="checkbox"/> Overtopping
8a	<input type="checkbox"/> Tidal amplification
8b	<input type="checkbox"/> Seiching
Joint analysis of various events:	
9	<input type="checkbox"/> Storm surge and rainfall
10	<input type="checkbox"/> Other combination of events
11	<input type="checkbox"/> Other:
<i>Future Climate Change Conditions</i>	
12	<input type="checkbox"/> Additional development scenarios
13	<input type="checkbox"/> Risk-Based Analysis

More detail on each flood mechanism is presented below. They are mainly for the use of the consultant but are presented here to provide more information to support the selection of flood mechanisms if needed.

3.3 Mechanisms Relevant in Riverine Floodplains

In addition to the extreme precipitation scenarios, there are many other scenarios that can be considered for riverine floodplains. Depending on the watershed, winter conditions may have a significant impact on water levels; the municipality should include winter conditions in the analysis. These include the following; however, additional conditions can be added if other specific mechanisms have been identified.

- 1. Snow accumulation and snowmelt during a rainfall event**
- 2. Ice jamming**
- 3. Debris jamming**
- 4. Dam operation, where present**
- 5. Hydraulic structure operation**
- 6. Seasonal conditions**

1. Snow Accumulation and Snowmelt during a Rainfall Event

This is important to include if snow accumulation can reach high depths (more than one metre), or if the watershed is very large and susceptible to effects of snowmelt over long durations (if it includes several large lakes for example), or if vulnerabilities exist close to lakes, that could be impacted by snowmelt.

2. Ice Jamming

Rivers in Nova Scotia very often are the subject of ice jams. If ice jams have been historically noted as creating flooding risks to developed or potentially developed areas, ice jam modelling should be considered. Ice thickness measurements should be obtained from a location as close as possible to the study area.

3. Debris Jamming

Rivers in Nova Scotia can be subjected to debris jams. If debris jams have been historically noted as creating flooding risks to developed or potentially developed areas, debris jam modelling should be considered. Since debris jams can be very different each time they form, the analysis needs to rely on as much field and anecdotal data as possible.

4. Dam Operation, where Present

Where dams are present, the owner of the dam structure should be contacted and the operational procedures for the dams under various weather conditions should be obtained. The Dam Safety Review reports should be obtained and reviewed. From this, the scenarios potentially producing the greatest water levels in the downstream watercourse should be extracted from the reports, to identify the conditions producing the highest water levels.

5. Hydraulic Structure Operation, where Present

Hydraulic structures can have many different configurations, and can include operated weirs, gates, orifices, penstocks, flow diversions, pumps, or any other type that could impact flows or water levels. If parts of the operational procedure of a hydraulic structure has the potential to increase flood risk, it should be included in the analysis. Similarly, if there is even a small likelihood that a structure could become stuck (such as a gate), then it should be included in the analysis.

6. Seasonal Conditions

Seasons will affect the surface roughness of the land cover types, as well as the infiltration potential. If it is expected that seasonal conditions, outside of the rainfall on frozen ground scenario (which is already included) can cause increased flooding risks, this should be included. This should be included if vulnerable seasonal activities take place in the floodplain and should be specifically identified, such as industrial activity or seasonal farming activities.

More scenarios may exist, depending on the specific characteristics of the watersheds of the target watercourse. For example, there are many tide gates in Nova Scotia, which can be operated in various manners, and which can also become blocked by debris, ice, or sediment accumulation. It will be up to

the municipality and the consultant carrying out the analysis to identify any additional characteristics that may influence flooding risks.

3.4 Mechanisms Relevant in Coastal Floodplains

In addition to the minimum required scenarios, several others may need to be considered if relevant at to the study area. These can include:

7. Short Wave Processes

These processes can increase water levels at the coastline and need to be evaluated where vulnerable infrastructure exists. Risks from short wave processes are evaluated through wave height and period for locally generated wind waves or ocean swell. These can be based on standard equations for enclosed bays for wind driven waves or nearshore wave modelling for sites where wave energy is impacted by ocean swells. Consultants will need to use specialized software or established standard methodology.

Short wave processes include:

- ▶ **7a. Wave setup** - the increase in mean water level, due to the presence of breaking waves. It is typically an important component of the storm surge in exposed areas with wide beaches. Since this is essentially an increase in the storm surge water level against the shore, it needs to be considered where small variations are important to the protection of the site.
- ▶ **7b. Wave runup** - the vertical extent of the wave uprush on the coastline slope, which can lead to erosion and local flooding. Like wave setup, it should be included in the analysis where the site could be vulnerable to such effects. If built coastal defences exist in the area, the wave overtopping mechanism may be more applicable.
- ▶ **7c. Wave overtopping** (if applicable) - For areas with built coastal defences, the amount of water discharged over a coastal defense structure. If coastal defense structures exist in the area, and are vulnerable to water overtopping, this process should be included in the analysis.

8. Long Wave Processes

Long waves may increase the coastal flood level as follows:

- ▶ **8a. Tidal amplification** - occurs when the tide moves inland in a gradually narrowing inlet, which may cause amplification of the tidal height. If the coastal inlet seems to be funnel shaped, this should be considered. It is noted that this is a difficult phenomenon to visually witness, as it will occur gradually over several kilometres. This is where water level measurements are valuable to support the identification of this process.
- ▶ **8b. Seiching** - refers to a standing wave from the natural oscillation within a partially closed body of water. It is typically present around harbours and coastal inlets and can be triggered by wind or waves breaking on a nearby wide beach. Standing waves can lead to higher water levels than otherwise expected against the coast, and should be evaluated where partially enclosed areas exist, and/or where they have been experienced by local boaters or fishermen. If such experience exists, this process should be included in the analysis.

Note: Tsunamis are a type of long period wave triggered by earthquakes or landslides. However, because of Nova Scotia's position on a trailing-edge plate margin, the risk of a tsunami is very low (the last occurrence was in 1929 off the coast of Newfoundland). As such it is typically not accounted for in local flood studies.

3.5 Mechanisms Relevant in Estuarine Floodplains

In addition to the processes mentioned above, estuaries may require joint consideration of extreme rainfall and storm surge. Storm systems can lead to co-occurring storm surges and extreme rainfall. In this case, it is important to consider them jointly because the impact on water levels of their co-occurrence is greater than the sum of their individual impacts. If vulnerable populations or infrastructure exists in areas that are affected by both the tides and river levels, a joint analysis is recommended. If a joint analysis is selected, the consultant will need to:

- ▶ Use the closest long-duration tide gauge and rain gauge records
- ▶ Conduct appropriate statistics on the co-occurrence of extreme rainfall and storm surge events based on the measured records
- ▶ Adjust the design events to better represent the results obtained

3.6 Mechanisms Relevant to Future and Climate Change Conditions

3.6.1 Additional development scenarios

In addition to the baseline scenarios for the flood line criteria that apply to existing development conditions, the municipality must consider potential future scenarios that are specific to the study area. These may include modifications to the current state of development of the watersheds, or the current state of the drainage system. It may also include the possibility of ideal future stormwater management, for example, wherein the widespread implementation of stormwater best management practices is able to return the watershed hydrology to pre-development characteristics. If the checklist item for additional development scenarios is selected, the municipality is requiring more than one future development scenario to be investigated.

The projected horizons for future development shall extend to two-time horizons and consider any public safety requirements and development restrictions:

1. **2050** - mostly reflecting currently approved development. Zoning maps in a land use bylaw may only extend a few years and primarily reflect shorter term development
2. **2100** - to include expected future development. Generalized Future Land Use Maps should indicate areas of expected change and are based on Municipal Planning Strategies..

Since the principal use of flood maps is to inform Land Use By-laws and Municipal Planning Strategies, the maps should provide insight into future conditions. As such, climate change will form a necessary part of future conditions analyses and needs to be carefully considered.

3.6.2 Risk-Based analysis

In the Appendix B: Technical Specifications, consultants are directed to simply layer climate change on existing scenarios. The municipality can however select a risk-based analysis (#13 in the Checklist of Potential Flood Mechanisms). A risk-based analysis allows for a more in-depth look at the impact of uncertain events, such as greater climate change scenarios, or any other scenario in addition to the ones already listed. The analysis will show what areas (i.e., land use types, infrastructure, etc.) can be flooded in various scenarios. This allows municipalities to identify vulnerabilities and can help to define which specific uncertain scenarios should be included.

A risk-based analysis considers the effect of larger than anticipated events on vulnerable populations, land uses, services, communication, and infrastructure. This is especially relevant to climate change analyses since the selection of a climate change event can be very uncertain. Using a risk-based approach will allow municipalities to visualize the risk that is placed on the vulnerable areas if actual change is underestimated. The municipality can then make informed choices about modifying the floodplain boundary at locations identified as vulnerable, changing land use planning policy, or implementing mitigation measures including retreat².

Both the Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation, 2019, and the Municipal Flood Line Mapping: Planning Horizons and Considerations, 2019, advise that risk-based analysis provides better information to support decision-making. This approach is also consistent with the Nova Scotia's precautionary principle to address uncertainty in the Environment Act as noted earlier.

² For example, in HRM, the uncertainty was related to which climate change scenario to include in the analysis. A risk-based analysis was carried out and since no additional vulnerabilities were identified with a more conservative climate change scenario, the most conservative climate change scenario was selected.

CHAPTER 4 **TENDERING & IMPLEMENTATION**

As noted in Chapter 1, the first steps include meeting with various stakeholders to assemble information relevant to flooding risks and vulnerabilities and collecting preliminary data. This will inform and guide development of the flood study parameters and lead to the selection of flood mechanisms. External expertise may be required for the municipality to collect and interpret preliminary data measurements.

Once the various potential flood mechanisms have been selected, the municipality will be ready to tender the flood study. The checklist of flood mechanisms (Table 3.1), together with Appendix B: Technical Specifications, should be sufficient to clearly define the scope of work that the selected consultant should follow.

4.1 Tendering

The Appendix B: Technical Specifications is intended to provide a consistent basis for conducting a flood mapping study in Nova Scotia. Consequently, it should include sufficient technical information to allow the municipality to tender the flood mapping study. Overall, the Municipal Flood Line Mapping Documents have been created to support municipalities in procuring flood line mapping and allow the development of technically sound and complete analyses.

In carrying out the flood study there are several tasks that fall to the municipality that can be carried out directly or contracted out:

1. Conducting the stakeholder and community engagement.
2. Discussing and finalizing a list of flood processes to include in the study.
3. Tendering the project.
4. Conducting a review, both internally and through a client engineer reviewer.

4.2 Required qualifications of consulting firms

Consulting firms bidding on the Request for Proposals shall meet the following minimum requirements:

- Professional Engineering License to Practice in Nova Scotia
- Company experience in flood mapping studies of no less than 10 years. This must include both riverine flood mapping and coastal flood mapping.
- Project Manager experience in flood mapping studies of no less than 5 years.
- Project Manager to have experience clearly communicating the results of past projects to municipalities, stakeholders, and the public both in written reports and presentations.
- At least 3 suitably representative project examples.

- Technical support engineer of no less than 5 years of experience in hydrology and hydraulics.
- Worker’s Compensation certification.
- Liability insurance.
- A person of contact within Nova Scotia.

The successful proponent’s firm is expected to have experience creating flood studies and flood maps. This includes locating and evaluating data, collecting historical flooding information, building, and evaluating hydrologic and hydraulic models, determining coastal flooding, and clearly communicating modelling results. The firm is expected to have experience in both fluvial and coastal flooding studies with a demonstrated understanding of flooding in Nova Scotia, hydrotechnical modeling, familiarity with available data, foreseen data gaps, and data collection strategies.

The successful proponent’s proposed resources should be varied and may include engineers, planners, scientists, climatologists, technologists, and technicians. Ideally each resource would have experience working on flood studies. Consultants should be expected to present their analyses in front of Council, the public, or third-party experts. Consultants should also be available to respond to concerns raised by the public, with the municipality acting as an intermediate.

4.3 Contracting the a client engineer

Ideally, a separate tendering process will be required for the client engineer. Within the tendering documents, a specific cost should be requested for review of the flood mapping report and analysis. This can be included in a tender for the collection of preliminary data discussed in Chapter 1 or for a standalone third-party reviewer. Bidders should be allowed to submit proposals and costs for both, or just one of the two scopes of work. This will allow smaller consultants to submit proposals, who may be very qualified to conduct a review, but who may not have the team size required to conduct a full study and mapping effort.

4.4 Municipal Review

The Municipality will review the deliverables to ensure:

- The various items requested are included in the deliverables
- The analysis appears to include the various mechanisms requested
- The report is clear and well written
- The maps are readable, and the GIS files can be opened and are in the correct format with appropriate metadata
- The report generally meets the expectations of the Municipality.

4.4.1 Reporting deliverables

The maps are to be accompanied by a report. This report should include, at a minimum:

- Background of the study, purpose of the investigation and objectives.
- Hydrologic and hydraulic setting.
- Previous history of flooding (that is known).
- Data availability, and for each set available quality and span. Data gaps and QA/QC to be documented.

- Survey summary maps.
- Hydrologic assessment approach, with supporting rationale.
- Details of hydrologic assessment.
- Hydrologic assessment results, calibration results if modelling was undertaken.
- Hydraulic assessment approach, with supporting rationale.
- Details of hydraulic assessment.
- Hydraulic assessment results, calibration results, sensitivity testing and associated discussion.
- Calibrated model parameters to support review by the municipality or their client engineer.
- A table listing the structures that either surcharge or are overtopped, noting the peak flow to each structure and the overtopped flow, for each of the four flood events.
- Discussion on the estimated level of quality of the study, and the main limitations/sources of uncertainty (these should be explained based on availability and quality of data, assessment approach, modelling challenges, etc.).
- Recommendations for further efforts to improve the next flood mapping study, including potential additional data collection.

4.4.2 Mapping Deliverables

In addition to the report, the maps should be delivered both in pdf format and in a GIS Geodatabase (flood outlines) as a minimum. All maps (e.g. velocity, depth, and hazard) should also be delivered in GIS raster file format, to the municipality and to the Department of Municipal Affairs and Housing. Model files for the requested scenarios should be included in the deliverables, with the necessary data to allow the user to run the models for the various scenarios investigated with the GIS data files. A Map Package is also to be created to allow the mapping layouts to conserve the data links.

The GIS maps layers shall include the following:

Map Type	Layer	Name assigned to layer
Flood Extents	1% AEP Current Climate	Floodline_1_AEP_Existing
	5% AEP Current Climate	Floodline_5_AEP_Existing
	1% AEP Current Climate	Floodline_1_AEP_CC
	5% AEP Current Climate	Floodline_5_AEP_CC
Depth Maps	1% AEP Current Climate	Depth_1_AEP_Existing
	5% AEP Current Climate	Depth_5_AEP_Existing
	1% AEP Current Climate	Depth_1_AEP_CC
	5% AEP Current Climate	Depth_5_AEP_CC
Velocity Maps	1% AEP Current Climate	Velocity_1_AEP_Existing
	5% AEP Current Climate	Velocity_5_AEP_Existing
	1% AEP Current Climate	Velocity_1_AEP_CC
	5% AEP Current Climate	Velocity_5_AEP_CC
Hazard Maps	1% AEP Current Climate	Hazard_1_AEP_Existing
	5% AEP Current Climate	Hazard_5_AEP_Existing
	1% AEP Current Climate	Hazard_1_AEP_CC
	5% AEP Current Climate	Hazard_5_AEP_CC

The municipality can also request the preparation of other forms of data presentation, such as more focused maps at specific scales with specific information (e.g., property boundaries), but also 3D renderings or animations of specific flood scenarios showing the water levels rising, following the model output. If these additional visualizations are requested, they should be included in the original RFP scope of work.

4.5 Approval Process

The formal acceptance of the report and flood maps by both the municipality and the client engineer reviewer, will be required before the report is approved.

4.6 Next Steps

Following the completion of the flood mapping study, consideration will need to be given to the development of a flood mitigation plan. One important outcome of the identification and analyses of flood mechanisms is that it helps to explain the causes of flooding. Once the causes are known, then mitigation can address the causes rather than just the symptoms of flooding. The results of the flood study will therefore be key to the preparation of a flood mitigation plan.

Planning tools such as setbacks, zoning regulations, development controls, and land use restrictions are the most effective at preventing damage and loss due to flood events. Some attention should also be given to green infrastructure, or restoration of natural systems that promote the infiltration of stormwater, thereby reducing flooding risks.

Depending on the layout of the floodplain and the level of development in the watershed, a Stormwater Management Plan may be an important means of reducing flood risk. The plan will help identify flooding risks within the stormwater conveyance system at the street level; work that could not be adequately carried out without the definition of the floodplain as a first step.

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ADDITIONAL INFORMATION

Adapted From FLOOD MAPPING: NAVIGATING MULTIPLE PERSPECTIVES by MJ Valiquette, Simon Couper and Kate Sherren, School for Resource and Environmental Studies, Dalhousie University

Media Analysis: Perspectives On Flood Mapping

Media analysis of public comments about inland and coastal flooding reveals that the majority of Canadians view mapping as an important issue, yet other articles highlight widespread opposition to flood mapping. A frequently voiced concern that Canadians express is the unnecessary burden that mapping places on their current home values and on community development. A systematic media analysis helps gauge public responses to flood mapping and the roots of these responses in social theory.

Method

Looking at local, regional, and national newspapers (through a database), we identified 112 articles over the past five years that include keywords like 'resident', 'flood map', and 'coastal'. Of these, only 47 articles (42 per cent) provided direct quotes from residents. Most of the articles (at 65/112 = 58 per cent) provided direct quotes from local experts and representatives from municipal, provincial, and federal governments.³

Using qualitative data software NVivo and Excel, we organized and analyzed the articles to identify themes from the residents' comments. We first sorted comments based on flood mapping support and opposition, and then refined the comments further into themes including personal safety and high insurance rates.

Thematic Coding Results

Flood mapping support

Most of the articles (87/112 or 78 per cent) quote experts that approve of flood mapping or approve of the need to update flood maps. These articles frame the lack of quality flood mapping in Canada as negative. Varied experts in these articles note that federal, provincial, and municipal governments are failing their citizens because Canada lacks coordination and implementation of flood mapping.ⁱ Only 22 of the articles that approve of flood mapping include quotes from residents supportive of the action. In these articles, citizens often state their desire to know that their financial security is at risk before building, investing in or simply living at their homes.ⁱⁱ The following sections describe the key messages that emerged from those articles.

We want to know about the potential loss of a home or asset before investment

In all 22 of the articles that convey flood mapping support, people want to know about potential loss that could result from flood mapping. For example, an article about rising rivers across Canada

³ Limitations to media analysis include finding quotes from citizens rather than providing a government/expert perspective and representing comments related to local jurisdictions. Within this analysis 40% of the articles originate from Quebec, with another 40% representing the Maritimes, and 20% representing articles originating from Ontario, Alberta, and British Columbia. Moreover, many articles that reference flood mapping might also focus on the complex subjects of climate change, flood adaptation/mitigation, housing markets, and the insurance industry.

points out the need for flood mapping, with a resident stating that if she knew the flood risk of living near the Ottawa River then she “wouldn't have bought the home.”ⁱⁱⁱ

While the majority of 2019 media articles from Quebec focus on mistakes in a province-wide flood mapping program, articles from 2018 focused on the need for flood mapping. In that year, people expressed dismay after learning that their homes were close enough to the St. Lawrence river to experience flooding.^{iv} Residents want correct information about flood risk before land/property purchase. Residents received confusing or incorrect information about the flood risk, or no information, prior to their investment. Moreover, a British Columbia resident states that he understands the need for up-to-date flood maps to learn about the risk of losing his home, while also stating that flooding is “quite stressful.”^v

We want access to up-to-date flood maps

Residents convey their disappointment at the lack of flood mapping information available to them. For example, articles from New Brunswick in 2018 positively discuss the fact that coastal residents in 2019 will have access to up-to-date maps to assess impacts from floodwaters.^{vi} Likewise, an article and resident perspective in Nova Scotia comments that “mapping substantiates the risk.”^{vii}

We want economic benefits or opportunities from flood mapping

Three articles note the economic opportunities of flood mapping. An opinion piece from Nova Scotia begins by stating that the global business and insurance industries all agree that “every dollar spent on adaptation measures [such as flood mapping] saves four dollars in repair and rebuilding costs.”^{viii} The article later notes that the province is well suited to mapping work and coastal land-use planning, potentially bringing needed jobs.

We want to feel safe and secure

Four of the supportive articles quote residents’ desire for individual safety. An article in the analysis notes that municipal representatives echo sentiments shared by residents where “everybody wants to feel safe in their community.”^{ix} The articles that focus on public safety reference the ability for flood maps to indicate personal risk. A resident in Quebec says “I think [planning is] a good step,” adding that he's looking forward to hearing how he can best “protect himself from flooding.”^x

We want to protect landscapes we care about through adaptation and mitigation

Six of the supportive articles imply the need to protect landscapes wherein the use of “aging dikes combined with documented rising water levels and increased frequencies and intensity of weather events enhances the need for floodplain mapping.”^{xi} Experts reference varied approaches to climate mitigation.^{xii} Residents largely, however, recommend the adaptation option of building homes and dikes higher in flood approval articles.^{xiii}

We decided that it is not worth the risk to rebuild on our familial home/land

Three articles quote residents expressing sadness at moving away from their homes, but they would rather avoid the risk of flooding. The residents that commented on leaving their homes have experienced flooding but will not risk another flood. After expressing her sadness at leaving, a resident in New Brunswick states that “even today when you look at how far away the lake is, it's hard to believe that the flood actually happened.”^{xiv}

We want government action to provide mapping and flood risk information

The majority of the supportive articles cite the need for help from government to perform necessary flood mapping, and are critical of the current lack of standardization in provincial maps.^{xv} “The provincial and federal governments seem very slow to recognize the concerns that we as residents are trying to portray to them.”

Flood mapping disapproval

Media analysis also resulted in 25 articles (22 per cent) with direct quotes – including from local residents – opposing flood mapping activities. Opposition often occurs if a flood map indicates that an individual’s home is in a high-risk flood zone, because that home may be subject to higher insurance rates, delays related to home build or renovations, or resale challenges. A flood map that dissuades development means that people cannot live at or near what are often desirable waterfront properties. Nova Scotians, like many Canadians, have lived by water for centuries, so waterfront homes or properties are often handed down in families. The following themes emerging from the oppositional articles.

We do not want to lose our homes, potential homes, or largest assets

All of the oppositional articles express concern for potential or recent loss. For instance, protests in 2016 delayed a Shubenacadie River floodplain rezoning plan due to concerns over property values. A resident notes that designating his home as high flood risk meant that his property is going to drop its value by 30 to 40 per cent.^{xvi} Similarly, a new designation applied to a property after mapping in provinces (like Quebec) has led to construction freezes after a flood – leaving residents homeless.^{xvii}

Residents worry about flood mapping lowering the value of their homes and losing their homes. The majority of comments express the difficulty of selling a property, or taking government buyouts, and being forced to move at a financial loss. An article that quotes a couple in New Brunswick notes that they lived in their house since 1987, they have a mortgage, and they cannot afford to buy or build a new home. In order to prevent further flood damage, they recently lived in their camper and spent \$50,000 to raise their home by 7 feet.^{xviii} Like this couple, residents all over Canada cite the concern of property due to flood mapping and consequent housing devaluation.

We do not need access to up-to-date flood maps

Some oppositional comments express confusion at the need for up-to-date flood mapping. Many 2019 public comments from Quebec note the erroneous inclusion of citizens properties within the province’s recently made and inaccurate flood zone maps, alongside previously out-of-date and inaccurate flood maps.^{xix}

We do not want to experience high insurance rates

Five articles (5/25 = 20 per cent) that focus on flood mapping loss also mention loss or potential loss of an individual’s property through increasing insurance rates or lack of insurance.^{xx} Although four articles state that insurers offer products for overland and coastal flooding, they also note that high-risk homes may be uninsurable, or if insurance is available, it may be unaffordable.^{xxi}

We already feel safe and secure at our property due to flood mitigation and adaptation measures

Four articles that criticize government flood maps call on the government to re-implement hard structures, such as dikes or berms, or require homeowners to raise their properties.^{xxii}

We already feel safe because we rarely experience flooding

Similarly, residents in nine articles that critique recent flood maps reference their lived history at that location, note that their property did not flood during significant flood events, and conclude that their homes/communities should not be placed in those flood zones.^{xxiii} In 2016, when East Hants designated a high-risk floodplain along the Shubenacadie River, resident responses compared

other communities by stating "It's not something that floods regularly, like the town of Truro. Even Elmsdale floods more than Shubenacadie does."^{xxiv}

We know how to protect landscapes that we care about

Residents in Nova Scotia, and elsewhere, have dealt with flooding marshland for centuries. An article notes that farmers reclaimed land from tidal marshes using ancient drainage systems, first constructed by Acadian settlers in 1671. A resident in Amherst speaking about his farmland notes that "there's a lot of history to how that marshland got developed, how fertile that soil is, and why we should be protecting it."^{xxv}

We have a strong connection to our familial home/land

Media analysis indicates residents' aversion to leave their familial homes. Many homes in high-risk zones have been in the same families for generations and residents worry about their potential loss. For instance, a couple from Alberta initially agreed to a provincial buyout to demolish their home because they discovered that their house would not be able to be sold later. The article states, however, that because it was their "home" they decided to "fight to keep it."^{xxvi}

We want government action to remove us from the risk flood mapping presents

Many residents would rather see inaction or retraction, as evidenced by seeking to be removed from high-risk designations. One Sainte Anne-de-Bellevue resident included in a mapped flood zone quipped that for his home to qualify as being in the proposed flood zone, "the Arctic would have to melt."^{xxvii}

Social Science Interpretations Of Media Discourse

The 47 articles analyzed above convey mixed and contradictory perspectives. Some government officials and experts highlight the need for flood mapping. Residents, meanwhile, wish mapping had occurred before they bought, while others oppose the idea largely because they want to be able to stay, develop or sell. This is an intractable problem if all individuals are treated the same – current residents and potential future ones – but is easily resolved toward the status quo (no mapping) in a democratic system that privileges current voters and taxpayers.

Social science can help explain individual opposition to flood mapping through many overlapping theories, including, but not limited to, multiple forms of cognitive biases and bounded rationality in decision-making. Contrary to our self-image, humans do not follow exclusively rational decision-making behaviour. Daniel Kahneman notes there are two modes of operation of the brain:^{xxviii}

- **System 1:** quick, instinctive and, sometimes, emotional responses to daily decisions. We make these decisions quickly, in which case System 1 is prone to certain biases, limitations, and systematic errors.^{xxix}
- **System 2:** effortful and slow thinking that requires considerable concentration. When it is engaged, it is sometimes able to override system 1 biases.^{xxx} This kind of careful reflection is what we hope to foster when we use the 'reasonable person model' described later.

Because careful thinking requires more energy, System 1 often takes over decision-making, particularly when a person feels they are under threat. System 1 thinking then biases our perceptions^{xxxi} and affects our ability to make connections, analyze information, and draw conclusions.^{xxxii} **Bounded rationality** means we can often take short-cuts in our thinking, relying on

the opinions of other people like us (Normative bias) or using other heuristics like political values, or filter out things we do not think we need to know, like gradual changes in our surroundings.

In social science, **loss aversion** refers to people's tendency to prefer avoiding losses over acquiring equivalent gains. For instance, if someone loses a house to flooding, there is a possibility that they will re-build at that same location because they might feel that the loss of leaving is larger than the possible gain of relocation.^{xxxiii} This happens in part because what a resident already has is a known, and what she does not is uncertain. This uncertainty is also most of what drives **status quo bias**.

Similarly, **cognitive dissonance** refers to a situation involving conflicting beliefs and behaviors. Someone experiencing this seeks to align their beliefs with their actions, to avoid the discomfort of dissonance, but because actions are harder to change, often end up changing their beliefs to suit their actions. For instance, dissonance could occur if residents are aware of flood risk, but want to rebuild their home in a floodplain. They might suppress their belief in flood risk so that they can rebuild without worry.

Solution aversion works much the same way, and like cognitive dissonance it is also typically unconscious. This is where a strong dislike of a solution - such as the need to move one's home or relocate - causes someone to reject the problem that a solution has been identified to solve. As such, someone who does not have a waterfront home may find it easy to say that coastal threats are high and more regulation is needed on the coast, whereas someone with waterfront will reject the idea that coastal threats are high as the solution is abhorrent to them.

There are many examples where pre-conceived notions of flood risk inform the decision to approve or disapprove flood mapping. **Motivated reasoning** occurs when people primarily use reasoning to justify pre-conceived notions rather than carefully reviewing new or other information.^{xxxiv} For instance, a resident might oppose flood mapping by stating: *"My property got floodplain zoned, I can't sell it at full value. It's been like that for 20 years, it hasn't flooded, this is all bull."*^{xxxv}

Finally, **climax thinking** happens when an individual perceives their current landscape as the one that is the "intended end point for their given context."^{xxxvi} Climax thinking provides an "emotional 'lock-in'" and "social infrastructure that rejects change to retain identity, remain in an area, and/or honour past generations."^{xxxvii} Climax thinking is exemplified by rejection of the need to accept new conditions (e.g. new floodplain delineations) in places they care about, but insisting they are entitled to keep living as they have planned.

Social Leverage Points For Better Public Discourse

Social scientists address the above cognitive biases and limited reasoning by using the reasonable person model, trust theory and communicative frames.

The **reasonable person model** stresses the fact that most individuals are more likely to be reasonable when they are provided with a comfortable setting and consideration of their cognitive needs (e.g. good coffee, breaks); tools to understand a situation; the sense that they feel heard and respected; and assurance that their engagement can make a difference.^{xxxviii} When we want

meaningful engagement from the public, it is important to create the conditions in which people can use their System 2 brains. This means providing a room with natural light, good coffee, snacks and breaks. This means designing interactions for the kind of knowledge and relationships that attendees have, rather than expecting them to engage in unfamiliar activities or those that expose them uncomfortably to peers. This also means engagement that is meaningful rather than tokenistic.

Leveraging the reasonable person model calls for an understanding of **trust ecology**, or what makes a person willing to accept their vulnerability to another person or organization when future conditions are unknown. Marc Stern and colleagues have described the antecedents of such trust in terms of the characteristics of the 'trustee' (the entity being trusted): **ability** (technological competency), **integrity** (moral competency), **benevolence**, and also the subjective variable of **charisma**, which can only be attributed to an individual rather than an organization. In the context of flood mapping, this involves:

- Perceived ability of the municipality to run a fair and rigorous process of flood mapping, and the ability of the consultants that are hired to do that work competently;
- The demonstrated integrity of the municipality in its past dealings with citizens, and the integrity of any hired consulting firm with their clients;
- Whether citizens feel that their municipality is seeking to 'do the right thing' by their citizens by carrying out flood mapping; and,
- The personal characteristics of those individuals with whom citizens interface in the process of flood mapping.

Researchers have found also that **social trust** (aka interpersonal trust) can be more important to behaviour change than institutional trust. Whether people accept flood mapping may have as much to do with how they feel about their fellow citizens, and the relational dynamics of who is seen to 'win' and to 'lose' by that process, as how they feel about any municipal representatives or hired consultants.

Finally, studies indicate that people often think in terms of unconscious structures called "frames."^{xxix} Social scientists often use communicative **frames** to convey information and elicit specific influence responses. Often, we can elicit certain responses by changing the language of a message. However, framing must be relatable to the reader and work emotionally. Meaningful or moral framing is based on the premise that people of varying backgrounds might place importance on different moral values to enhance an argument.^{xl} Recent focus groups with coastal residents in Nova Scotia suggest that two moral framings increase citizen's perceptions of the importance of acting sooner than later: a **future framing** (we have a duty to act to protect future coastal generations) and a **collaborative framing** (we have worked together in the past to overcome great challenges, and can do so again).

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DRAFT Nova Scotia Municipal Flood Line Mapping

Appendix B: Technical Specifications


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This chapter discusses the baseline standards that should be followed in Nova Scotia. These are to be applied to *all* flood mapping studies. Additional elements can be studied if they are found to be present, which are described in Chapter 2.

In this chapter, a discussion is presented on how to interpret return periods for various events, and more specifically, flood events, which are the result of a combination of factors. Projection horizons are defined, and a description of the minimum criteria to be applied in the analyses is presented.

Specified Standards	Return period or frequency of flood events to analyse	Statement of Provincial Interest	1% AEP (1 in 100 Year event) 5% AEP (1 in 20 Year event)
	Projection Horizons for the analysis of future flood events	Land Use Planning Horizons	2050 (25-30 Year planning horizon) 2100 (75-80 Year planning horizon)
	Required Analysis Scenarios		
			
			Precipitation Coastal Water Level Climate Change

1.1 Return period or frequency of flood events to analyse:

1.1.1 Application

The current Statement of Provincial Interest on Flood Risk Areas establishes the 1 in 20-year return event as the floodway and the 1 in 100-year return event as the floodway fringe extents. This is to be considered the minimum acceptable provincial standard. These events are more clearly explained in terms of probability of occurrence or Annual Exceedance Probability (AEP). The 1% AEP (equivalent to the concept of the 1 in 100-year return event) and 5% AEP (equivalent to the concept of the 1 in 20 year return event) should be used by both the municipality and the consultant when carrying out the flood study and engaging with stakeholders and the public.

1.1.2 Analysis

The province requires that flood extents be provided according to 1% and 5% AEP. In some cases, the probability of flooding events is causally linked to the probability of higher precipitation or coastal water level (i.e., the 1% precipitation or coastal water level event causes the 1% flood event). However, in many other cases, there are additional inputs and processes that influence flooding and AEP. To give an example, water levels may be locally increased because of tide gate operation or blockages within the system. Therefore, flood scenarios associated with a specific AEP need to produce flood extents based on any reasonably foreseeable mechanism that generates high water levels. The objective is to select a representative set of scenarios and conditions that together, can produce a more realistic and locally appropriate set of flood lines associated with a given AEP.

1.2 Projection Horizons for the analysis of future flood events

In conjunction with the development of these specifications, the Province consulted with multiple academic institutions to develop a standardized framework for the selection of scenarios and the incorporation of future climate changes into riverine and coastal flood mapping in Nova Scotia. Literature reviews were conducted in various fields, the results were discussed with the province in two workshops, and the outputs of the work were summarized in a set of specifications and justification/recommendation: the **Standard for the incorporation of climate change into riverine and coastal flood mapping in Nova Scotia** (Jamieson, R., Kurylyk, B., Rapaport, E., Manuel, P., Van Proosdij, D., Beltrami, H., Hayward, J., KarisAllen, J., Clark, K., Tusz, C., Jahncke, R., García-García, A., & Cuesta-Valero, F.,J. (2019)). Henceforth this document will be referred to as the **Climate Change Standard**. The **Climate Change Standard** is included in the RFP package and provided to the consultants with the **Nova Scotia Municipal Flood Line Mapping** document and **Appendix B: Technical Specifications**.

As per the **Climate Change Standard**, the time horizons to be used for flood mapping of future conditions are 2050 and 2100. Adjustments to rainfall and coastal water levels to account for climate change should follow this document.

The municipalities will provide information to the selected consultant on the potential future changes to land use at those time horizons. However, the consultant should also refer to the applicable Municipal Planning Strategies to understand current and future land use in the study area.

1.3 Required Analysis Scenarios

The minimum analysis scenarios prescribed by the **Climate Change Standard** are for precipitation and coastal water levels (storm surge and tide), for both current and future conditions. Since watersheds can vary greatly in size across the province, and several have a time of concentration larger than 24 hours, the standard duration of rainfall events is set to 48 hours. The 24-hour total rainfall amount will still follow the IDF data, but the accreting and receding limbs will be extended to include the additional data up to 48 hours.

1.3.1 Precipitation:

Current: Current 5% and 1% AEP precipitation events are obtained from the nearest Environment and Climate Change Canada station with IDF curves. The duration of the design rainfall events shall be 48 hours.

1.3.1.1 WINTER RAINFALL EVENT

In addition to the scenarios prescribed by the Province through the **Climate Change Standard**, winter rainfall events shall be investigated. Since winter conditions in Nova Scotia (i.e., December 1st to April 1st) include many freeze-thaw cycles, the likelihood of rainfall (as opposed to snowfall) occurring during winter is high and generally expected to increase with Climate Change. This should be investigated as part of the minimum scenarios. The following characteristics are to be followed:

Rainfall on Frozen Ground Conditions

It is to be assumed that the ground is 100% impervious. The surface roughness of the various watershed land cover types (grass, light forest to dense forest, wetlands, light development to dense

development, etc.) can be kept the same, as it is likely that the various land cover types would generally maintain their surface roughness (grass would be covered in snow, forest surfaces would remain uneven, and roads and parking lots would be ploughed).

1.3.2 Coastal Water Levels:

Current: The creation of Hydrographic Vertical Separation Surfaces (HyVSEPS) for tidal variables (e.g. HHWLT) based on oceanographic models, observed water levels, GPS observations, sea level trends, satellite altimetry, and a geoid model provide more accurate flood modelling (Robin et al., 2014). The continuous surface model provides better resolution at the local level, particularly for areas that are not close to a real-time tide gauge. It provides a common reference frame for tying in Chart Datum (CD) to both CGVD28 and CGVD2013, linking marine to terrestrial surfaces. Given the range of CD to geodetic conversions provided in previous technical reports, and low confidence in predictions at numerous CHS stations, it is recommended the previous approach of tying Relative Sea Level Rise (RSLR) projections to Higher High Water Large Tide (HHWLT) at Canadian Hydrographic Survey (CHS) stations be abandoned and replaced with the use of HyVSEPS and the new RSLR surface from the Geodetic Survey of Canada.

Caution in the application of this approach should be applied where there is the possible risk of loss of public confidence in flood extents depicted if extreme water level projections decrease (due to decreases in modelled HHWLT). This is precisely the case for the Upper Bay of Fundy. At present, it is recommended that the new 2017 HHWLT values NOT be applied in areas of the Upper Bay of Fundy where there are extensive intertidal zones which are known to be poorly resolved in oceanographic models.

Estimates of a location's high water distribution, which forms in response to high tides and storms, are needed to assess how and when flood frequencies are likely to change under future RSLR. A variety of approaches have been applied in the past including establishment of a benchmark storm, hindcasting based on historical wind speeds, applying return probability statistics to long term records (> 19 yr) of total sea levels from tide gauge data, or storm surge modelling. These storm surge events are typically added to RSLR and HHWLT to determine an upper bound of flood hazard conditions. For further information and data sources see Appendix D of the **Climate Change Standard** (Refer to Section 5: Storm Surge – Extreme Water Levels).

Descriptions of coastal process terms used in this standard are provided below:

1. Higher High Water Large Tide

The HHWLT is the average of the highest high waters, one from each of 19 years of predictions. The value should be obtained from the most representative tide gauge station from the Canadian Hydrographic Service. A representative tide gauge station is generally available for most areas around Nova Scotia, except in areas with limited coverage and/or a rapidly varying tidal range (including but not limited to the Bay of Fundy and Minas Basin, tidal inlets, Bras d'Or Lakes). In those instances, local tide gauge measurements of at least 1 month in duration should be undertaken to develop an estimate of the HHWLT, possibly combined with a calibrated hydrodynamic model as required, for example in the upper Bay of Fundy or the other examples noted above.

2. Storm Surge

Storm surges are created by meteorological effects on sea level, such as wind set-up and low atmospheric pressure, and can be defined as the difference between the observed water level during a storm and the predicted astronomical tide. The event with the relevant return period should be selected. The value should be derived from long-term tide gauge measurements for the area, and/or modeling. Typically, estimation of the N year return value should be based on an observation record at least N/3 years long. The permanent operating tide gauges relevant for NS coastal waters are at Halifax, Sydney, Yarmouth, Saint John (Lower bay of Fundy) and Charlottetown (Northumberland Strait). Additional tide gauge sites in NS with past multi-year records include Pictou and Point Tupper.

It is cautioned that plausible upper limit storm surges due to a direct hurricane hit may exceed estimates based on limited and localized historical observations. This is particularly relevant along the coastline facing the Atlantic Ocean, as recorded in Halifax Harbour during Hurricane Juan in 2003. Also, the Bay of Fundy's Saxby Gale in 1869 is an example of extreme event not included in recorded data. Typical 1% AEP storm surge values in the region can range from 1 to 2 m. Storm surges tend to be more severe within shallow areas, bays, or estuaries. In terms of broad geographical areas, storm surges tend to be highest within the following areas, in decreasing order of intensity: 1) NS North shore and Upper Bay of Fundy, 2) Atlantic, 3) lower Bay of Fundy

3. Sea Level Rise

This should be considered using the relevant emissions scenario (RCP8.5) and time horizon (2050 and 2100), as specified in the **Climate Change Standard**. SLR will accelerate due to climate change, causing increased risks of coastal erosion and flooding. As a result, extreme water levels with a low return period today will be common in a few decades.

The following section identifies and highlights the need to consider additional input scenarios to provide a more representative approach (e.g., return periods of snowpack depth, climate change impacts on tidal amplification, etc.) to overall flooding risks at the site.

POTENTIAL ADDITIONAL FLOOD MECHANISMS

This section provides information on various additional mechanisms that may contribute to high water levels. Riverine, coastal, and estuarine mechanisms that contribute to high water levels under current scenarios are presented first. These are then considered with future changes to land use and climate. The mechanisms are provided in a checklist and include a Factor of Safety. This Factor of Safety accommodates mechanisms that are expected to be present in the area but can not be properly studied in the flood assessment.

Potential Flood Mechanisms		Future Scenarios	
		Land Use Change	Climate Change
Current Scenarios	Mechanisms Relevant in Estuarine Floodplains	Land Use Change	Climate Change
	Mechanisms Relevant in Riverine Floodplains		
	Mechanisms Relevant in Coastal Floodplains		
	Joint Probability Analysis		

2.1 Criteria and Roles for Selecting Mechanisms

In the **Appendix A: Guidance Document**, municipalities procuring flood mapping are directed to obtain records of historical events, and consult with staff, stakeholders, and local experts to understand local flood mechanisms. Water level measurements should also be collected prior to the flood study, to better understand the presence of certain mechanisms. Some municipalities may have the capacity to carry out water level monitoring themselves, but most will not, and will rely heavily on consultants. This may mean there is a separate data gathering project or that the water level monitoring is included in the flood study.

Depending on budget considerations, preliminary data and information gathering, and advice from the consultant, the municipality should be able to identify the relevant flood mechanisms to include in the flood study. The consultant will review the selected flood mechanisms proposed by the municipality and confirm that these are appropriate. The client engineer reviewer will also provide comments on the selected mechanisms and help with a decision if there is disagreement between the municipality and the consultant.

Thus, the criteria for determining site-specific flood scenarios are:

1. Extracting historical records and local knowledge (municipality)
2. Conducting water level measurements (municipality and/or consultant)
3. Expert experience (consultant)
4. External experience (client engineer)

2.2 Checklist of Flood Mechanisms

The flood mechanisms presented in Table 2.2 are further described in the following sections. The completed checklist will inform the scope of work for the flood study and would be in addition to the Minimum Specified Standards (Chapter 1).

By using the checklist in the development of the Request for Proposals the municipality has a starting point as they try to identify flood mechanisms. Any data gathering (e.g., water level measurements) or meetings with staff, stakeholders, community groups, interested parties, and the public will also support the identification of additional flood mechanisms.

If a mechanism is known to exist, but available expertise, data, or budget, do not allow those mechanisms to be studied, the Factor of Safety included in the table can be used. This approach is supported by Nova Scotia's existing precautionary principle contained in the province's Environment Act (1994), to address uncertainty: "the precautionary principle will be used in decision-making so that where there are threats of serious or irreversible damage, the lack of full scientific certainty shall not be used as a reason for postponing measures to prevent environmental degradation" [Section 2(b)(ii)].

Climate change is layered on existing scenarios. Therefore, the scenarios identified in the checklist will have their rainfall amount and sea levels, increased by the respective values prescribed in the **Climate Change Standard**.

Table 2.2: Checklist of Potential Flood Mechanisms

Number	Flood Mechanism (Check if believed to be present)	Factor of Safety to include if it is present but cannot be studied (Check if included)
<i>Existing Climate Conditions</i>		
Riverine Flooding		
1	Snow accumulation and snowmelt during a rainfall event	Increase rainfall amount by Extreme Snow Depth Climate Normal from closest Environment Canada Station, over 24 hours. 1 cm of snow equivalent to 1 mm of runoff generated is suitable for this analysis.
2	Ice jamming	Add 0.3 m to all water level model results
3	Debris jamming	Assume structure is completely blocked with debris during event
4	Dam operation	Increase rainfall amount by the estimated volume impounded, divided by the tributary area, over 24 hours.
5	Hydraulic structure operation	Assume structure is closed during event
6	Seasonal conditions	Add 15% to rainfall amount
Coastal Flooding		
7a	Short wave process - wave setup	Add 20% of estimated maximum breaking wave height (e.g., 0.2 m for a 1 m breaking wave)
7b or 7c	Short wave process - wave run-up or overtopping	Add potential maximum estimated impact based on observations, to be between 1 and 5 times estimated maximum breaking wave height
8a	Long wave process - tidal amplification	A full assessment is required, since the impact can vary greatly
8b	Long wave process - seiching	A full assessment is required, since the impact can vary greatly
Joint analysis of various events¹:		

¹ If two events are in fact independent, combining them would lead to a return period of 1 in 10,000 years (or more if more events are combined). Research suggests that some areas show near-independence, while others show strong dependence (<https://info.ornl.gov/sites/publications/Files/Pub136789.pdf>). The main issue here is that there exists no analysis on this topic in Nova Scotia, so it is difficult to support one approach or another (i.e., complete dependence or complete independence). Historically, either the mechanisms are considered completely independently, or as proposed here, a 50% AEP is combined with a 1% AEP. This combination strikes an appropriate balance between conservatism and accuracy for the Factor of Safety.

The concept of joint probability does not only apply to estuaries, but also to other combinations of flood mechanisms. For example, the worst-case scenario for dam operation may coincide with the 1% AEP storm, in which case these should be considered jointly. The municipality may choose, for some site-specific flood scenarios, to consider several flooding mechanisms simultaneously. If this is the case, the consultant is to model these in combinations that are realistic for 5% and 1% AEP.

9	Storm surge and rainfall	Combine a 50% AEP rainfall event with a 1% AEP storm surge, and a 1% AEP rainfall event with a 50% AEP storm surge
10	Other combination of events	Add potential maximum estimated impact
11	Other:	Add potential maximum estimated impact
<i>Future Climate Change Conditions</i>		
12	Additional development scenarios	If required by Client, this needs to be included in the study
13	Risk-Based Analysis	If required by Client, this needs to be included in the study

Best efforts should be made to adhere to the instructions provided for each mechanism in the following sections.

2.3 Mechanisms Relevant in Riverine Floodplains

In addition to the extreme precipitation scenarios, there are many other scenarios that can be considered for riverine floodplains. Depending on the watershed, winter conditions may have a significant impact on water levels; the municipality should include winter conditions in the analysis. These include the following; however, additional conditions can be added if other specific mechanisms have been identified.

1. Snow accumulation and snowmelt during a rainfall event
2. Ice jamming
3. Debris jamming
4. Dam operation, where present
5. Hydraulic structure operation
6. Seasonal conditions

1. Snow Accumulation and Snowmelt during a Rainfall Event

To model this scenario, records of snow on the ground measured depths are to be obtained from the closest Environment Canada climate station with at least 20 years of data. The hydrologic model used needs to have snow accumulation and snow melting capabilities and be calibrated on events that include snow melt. Average values are to be obtained, as well as peak values, obtained from a statistical analysis, to derive the 1% AEP peak snow on the ground amount. Two scenarios are to be modelled:

- ▶ The 1% AEP winter rainfall event, with an average (50% AEP) snow depth that melts entirely within 24 hours.
- ▶ The 50% AEP winter rainfall event, with a 1% AEP snow depth that melts entirely within 24 hours.

The results showing the highest water levels is to be taken as representative of that scenario.

2. Ice Jamming

Rivers in Nova Scotia are often subjected to ice jams. If ice jams have been historically noted as creating flooding risks to developed or potentially developed areas, ice jam modelling should be

considered. Ice thickness measurements should be obtained from a location as close as possible to the study area site. If sufficient data are available, the procedure described in the Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation, 2019, should be followed. If insufficient data are available, modelling should be undertaken with a suitable ice jam model.

3. Debris Jamming

Rivers in Nova Scotia can be subjected to debris jams. If debris jams have been historically noted as creating flooding risks to developed or potentially developed areas, debris jam modelling should be considered. Since debris jams can be very different each time they form, the analysis needs to rely on as much field and anecdotal data as possible. An analysis of the data available needs to estimate the amount of blockage that would normally occur at least once a year, as well as a potential 1% AEP amount of debris blockage. Then modelling should map the highest of the annual debris jams with the 1% AEP rainfall, and the 1% AEP debris jam with the 50% AEP rainfall event.

Debris accumulation in alluvial fans is also a mechanism identified in the Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation, 2019 document, but it is less common in Nova Scotia due to the smaller watersheds and steeper slopes that exist compared to other provinces. If such a mechanism is identified, the procedures outlined in the federal document should be followed.

4. Dam Operation, where Present

Where dams are present, the owner of the dam structure should be contacted and the operational procedures for the dams under various weather conditions should be obtained. From this, the scenarios potentially producing the greatest water levels in the downstream watercourse should be extracted and tested in the model, to identify the conditions producing the highest water levels. A version of this scenario that has an estimated 1% AEP should be identified and added to the list of types of 1% AEP events.

5. Hydraulic Structure Operation, where Present

Hydraulic structures can have many different configurations, and can include operated weirs, gates, orifices, penstocks, flow diversions, pumps, or any other type that can impact flows or water levels. A good understanding of the hydraulic structures must be acquired and explained in the analysis. The likelihood of a given operational scenario or failure of a given structure must be estimated for average (50% AEP) rainfall conditions, as well as for extreme event (1% AEP) conditions. A combination of operation type and event that has an estimated 1% AEP should be identified and added to the list of types of 1% AEP events.

6. Seasonal Conditions

Seasons will affect the surface roughness of the land cover types, as well as the infiltration potential. In addition to the required scenario of rainfall on frozen ground, an analysis that includes consideration of seasonal effects should include scenario 1 described above. Dry summer conditions, spring snowmelt, and autumn conditions should be analysed. Each season should have a distinct set of events (specific to that season) to support model calibration. Five models should result from this analysis, which are (1) rainfall on frozen ground, (2) snow accumulation and snowmelt during a

rainfall event, (3) dry summer conditions, (4) spring snowmelt, and (5) autumn conditions. The outline of all model flood lines should be the result of this analysis.

More scenarios may exist, depending on the specific characteristics of the watersheds of the target watercourse. For example, there are many tide gates in Nova Scotia, which can be operated in various manners, and which can also become blocked by debris, ice, or sediment accumulation. It will be up to the municipality and the consultant carrying out the analysis to identify any additional characteristics that may influence flooding risks.

2.4 Mechanisms Relevant in Coastal Floodplains

In addition to the minimum required scenarios, several others may need to be considered if relevant to the study area and the municipality decides it is required. These can include:

7. Short Wave Processes

These processes can increase water levels at the coastline and need to be evaluated where vulnerable infrastructure exists. Risks from short wave processes require evaluation through assessment of basic wave parameters (wave height and period for locally generated wind waves or ocean swell). These can be based on simple parametric wind-wave growth equations for enclosed bays (e.g. Jonswap wind wave prediction charts), or nearshore wave transformation modelling for sites open to ocean swell (any site where wave energy includes a contribution from ocean swell, as opposed to wind waves). Wave parameters can then be used to evaluate the following effects that will influence flooding. These mechanisms need to be evaluated using specialized software, or established standard methodology, e.g. USACE Coastal Engineering Manual, 2002, or FEMA Coastal Flood Hazard Analysis and Mapping Guidance.

They can include:

- ▶ **7a. Wave setup** - the increase in mean water level, due to the presence of breaking waves. It is typically an important component of the storm surge in exposed areas with wide beaches. Since this is essentially an increase in the storm surge water level against the shore, it needs to be considered where small variations are important to the protection of the site.
- ▶ **7b. Wave runup** - the vertical extent of the wave uprush on the coastline slope, which can lead to erosion and local flooding. Like wave setup, it should be included in the analysis where the site could be vulnerable to such effects. If built coastal defences exist in the area, the wave overtopping mechanism may be more applicable.
- ▶ **7c. Wave overtopping** (if applicable) - For areas with built coastal defences, the amount of water discharged over a coastal defense structure. If coastal defense structures exist in the area, and are vulnerable to water overtopping, this process should be included in the analysis.

8. Long Wave Processes

Long waves (i.e., with periods typically exceeding 20 sec) may increase the coastal flood level as follows:

- ▶ **8a. Tidal amplification** - occurs when the tide moves inland in a gradually narrowing inlet, which may cause amplification of the tidal height. If the coastal inlet seems to be funnel shaped, this

should be considered. It is noted that this is a difficult phenomenon to visually witness, as it will occur gradually over several kilometres. This is where water level measurements are valuable to support the identification of this process.

- ▶ **8b. Seiching** - refers to a standing wave from the natural oscillation within a partially closed body of water. It is typically present around harbours and coastal inlets and can be triggered by wind or waves breaking on a nearby wide beach. Standing waves can lead to higher water levels than otherwise expected against the coast, and should be evaluated where partially enclosed areas exist, and/or where they have been experienced by local boaters or fishermen. If such experience exists, this process should be included in the analysis.

Note: Tsunamis are a type of long period wave triggered by earthquakes or landslides. However, because of Nova Scotia's position on a trailing-edge plate margin, the risk of a tsunami is very low (the last occurrence was in 1929 off the coast of Newfoundland). As such it is typically not accounted for in local flood studies.

2.5 Mechanisms Relevant in Estuarine Floodplains

In addition to the processes mentioned above, estuarine conditions may require that extreme rainfall and storm surge be considered jointly. Storm systems can lead to co-occurring storm surges and extreme rainfall. In this case, it is important to consider them jointly because the impact on water levels of their co-occurrence is greater than the sum of their individual impacts. If vulnerable populations or infrastructure exists in areas that are affected by both the tides and river levels, a joint analysis is recommended. If a joint analysis is selected by the municipality, the consultant needs to:

- ▶ Use the closest long-duration tide gauge and rain gauge records
- ▶ Conduct appropriate multivariate statistics on the co-occurrence of extreme rainfall and storm surge events based on the measured records
- ▶ Adjust the design events to better represent the results obtained

2.6 Mechanisms Relevant to Future and Climate Change Conditions

2.6.1 Additional development scenarios

In addition to the baseline scenarios for the flood line criteria that apply to existing development conditions, the municipality must consider potential future scenarios that are specific to the study area. These may include modifications to the current state of development of the watersheds, or the current state of the drainage system. It may also include the possibility of ideal future stormwater management, for example, wherein the widespread implementation of stormwater best management practices is able to return the watershed hydrology to pre-development characteristics. If the checklist item for additional development scenarios is selected, the municipality is requiring more than one future development scenario to be investigated.

The projected horizons for future development shall extend to two-time horizons and consider any public safety requirements and development restrictions:

1. To 2050, mostly reflecting currently approved development, and

2. To 2100, to include expected future development, based on municipal land use plans.

Since the principal use of flood maps is to inform Land Use By-laws and Municipal Planning Strategies, the maps should provide insight into future conditions. As such, climate change will form a necessary part of future conditions analyses and needs to be carefully considered.

2.6.2 Risk-Based analysis

In the Appendix B: Technical Specifications, climate change is layered on existing scenarios. Therefore, the additional flood mechanisms identified in the list above will have their rainfall amount and sea levels increased by the respective values prescribed in the **Climate Change Standards**.

The municipality also has the option available in the checklist of requesting a risk-based analysis. A risk-based analysis allows for a more in-depth look at the impact of uncertain events, such as greater climate change scenarios, or any other scenario in addition to the ones already listed. The analysis will show what areas (i.e., land use types, infrastructure, etc.) can be flooded in various scenarios. This allows municipalities to identify vulnerabilities and can help to define which specific uncertain scenarios should be included.

Both the Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation, 2019, and the Municipal Flood Line Mapping: Planning Horizons and Considerations, 2019, advise that risk-based analysis provides better information to support decision-making. This approach is also consistent with the Nova Scotia's precautionary principle to address uncertainty in the Environment Act as noted earlier.

A risk-based analysis consists of considering the effect of events that are larger than the design events on vulnerable populations, land uses, services, communication, and infrastructure. This is especially relevant to climate change analyses since the selection of a climate change event can be very uncertain. This analysis consists of selecting a range of events (minimum of 3) of equal or larger magnitude to the design event and conducting flood mapping using those. This allows for visualization of the risk that is placed on the vulnerable areas in case actual change was underestimated. The municipality can then make informed choices about modifying the floodplain boundary at locations identified as vulnerable, changing land use planning policy, or implementing mitigation measures including retreat².

This approach is entirely optional but is available in-case conditions that have not been considered in the specifications appear. The risk-based analysis method provides a procedure to evaluate the impact of including both those conditions in the analysis and not.

² For example, in HRM, the uncertainty was related to which climate change scenario to include in the analysis. A risk-based analysis was carried out and since no additional vulnerabilities were identified with a more conservative climate change scenario, the most conservative climate change scenario was selected.

TOPOGRAPHIC AND BATHYMETRIC DATA REQUIREMENTS

The necessary topographic data to be collected includes meteorological, topographic, bathymetric, hydrologic, hydraulic, and calibration data. It is extremely important to collect as much of the available data as possible, at the highest quality that can be reasonably obtained. Meteorological, hydrologic, hydraulic, and calibration data are discussed Chapter 7 (calibration data requirements); therefore, this Chapter will focus on topographic and bathymetric data.

Minimum Data Analysis Requirements

Minimum Topographic Data Requirements Bathymetric Data

3.1 Minimum Topographic Data Requirements

Topographic data in the watershed and along the watercourse has a significant influence on the resulting flood maps, for a range of reasons, as it directly influences the:

- precision of watershed delineation.
- quality of the cross-sections used in the model and therefore hydraulic calculations.
- precision of the water level calculation at each cross-section.
- level of detail of the flood delineation, between the cross-sections.

Since Lidar data has been collected for the entire province, it must be used as the topographic basis from which to delineate watersheds, extract model geometry, and upon which the floodline delineation is to be made.

If additional Lidar data is to be collected by the consultant, it will need to meet the provincial specifications in the document “LiDAR Data Acquisition and Quality Assurance Specifications”, 2012. The Lidar data are to be the “Bare Earth” model, meaning it should be pre-processed to have all above ground features (trees, power poles, buildings, bridges, etc.) removed. The Lidar metadata are to be checked to confirm that the Lidar surface matches the ground topographic survey points within acceptable tolerance levels (typically +/- 50mm on hard surfaces, and up to 300mm in forested areas).

3.2 Bathymetric Data

The collection of bathymetric survey data can be costly and requires suitable conditions in the watercourse, however, bathymetric data allows for the accurate representation of riverine and coastal hydraulic processes, particularly in deeper channels. Flood mapping studies in rivers with deep channels (>1 m) should include adequate resources and schedule to complete a suitable bathymetric survey. In many instances the cost for bathymetric survey can be a significant proportion of the overall project cost.

3.2.1 Watercourses

Bathymetric data in the watercourse is a key requirement where the Lidar data are not sufficiently representative of the watercourse (typically when the water depth is more than 1m). Judgement will have to be used by the consultant to decide whether additional bathymetric data are needed to model the watercourse with sufficient accuracy.

If the topographic surface has been mapped when the flows are low in comparison to the flood events, the relative error of not including the flow area of this low flow will be small. For example, if the depth of water under the Lidar surface represents a small fraction of the full water depth of the channel during one of the mapped events, the Lidar surface may be considered representative of the channel geometry for modelling purposes, provided that adequate roughness of the channel surface is applied.

If bathymetric data are to be collected, there are several options available, which are dependant on the specific characteristics of the watercourse.

<i>Manual topographic survey</i>	Smaller watercourses that are safe to traverse on foot
<i>Single beam echosounder</i>	Where the watercourse is regular, wide, and deep enough to allow the boat to follow clearly identified cross-sections
<i>Multibeam sonar</i>	Where the watercourse has uneven bathymetry, is sufficiently deep and may have high suspended solids
<i>Topo-bathymetric Lidar</i>	Where the watercourse is large, and the water is relatively clear. Can also apply to shallow coastal areas.
<i>Bathymetric Lidar</i>	For deeper areas where the watercourse / coastal area is large, and the water is relatively clear.

Shallower watercourses should be done with a manual topographic survey of cross-sections in the watercourse or using a GPS vertical satellite reference or tied to a local topographic reference monument. Where it is not safe to do so by hand, technology can be used with boats or floating instruments, or from the top of a hydraulic structure, to collect the data. At a minimum, the number of survey points along the underwater portion of the cross-section should be:

TABLE 3.2

- For watercourses less than 2m in width: 5 surveyed points
- For watercourses between 2m and 20m in width: 10 surveyed points
- For watercourses more than 20m in width: 20 surveyed points

Efforts should be made to capture the lowest point (thalweg) of the watercourse, since it impacts the cross-sectional area of flow, and hence the capacity of the watercourse. If there is an as-built drawing of a hydraulic structure which shows the watercourse cross-section, this can be used instead of a survey.

Topo-bathymetric Lidar (that can penetrate the water surface and provide a continuous surface from the land to the watercourse bathymetric surface) may be used where the water is sufficiently clear to

allow the light beam to reach the bottom surface of the watercourse. If using this technology, regular manual topographical measurements are needed to check the quality of the data in all representative areas.

Where the depth of water requires surveying to be conducted, cross-sections are to be measured at representative sections of the watercourse, including at every bend, narrower area, wider area, constriction and expansion, such that the geometry formed by connecting the cross-sections is hydraulically representative of the watercourse. If the depth of water in the Lidar surface is sufficiently low, cross-sections can be extracted directly from the Lidar data. Survey requirements around hydraulic structures are given in the following section.

3.2.2 Lakes

Lakes can be assumed to be a flat surface during the flood mapping assessment, however, where Lidar data are available, stage-storage relationships should be estimated in the flood plain areas. It is expected that LiDAR will be available in many instances and this should be reflected in the assessment of flooding in lakes.

Lake bathymetry data are available for many lakes in the province through the Nova Scotia Department of Fisheries and Aquaculture (over 1,000 lakes). If data are not available and lake bathymetry has the potential to impact peak flows, it will be necessary to conduct a bathymetric survey by boat to produce a lake bottom surface that is sufficiently representative of the actual bottom surface to model the impact.

3.3 Strategy for Minimal Data Availability

If conditions are such that it is not possible, due to access, safety, or budget constraints, to obtain the data to the level of detail required, discussions will need to be held with the municipality to identify where a reduction in data collection is acceptable. The consultant is to advise the municipality where a data reduction can result in a loss of quality, and how much quality will be lost in the resulting flood map. If the areas in question are deemed of significant importance for flood mapping by the municipality, the flood mapping work may need to be delayed until the data are collected, or a more conservative approach needs to be used. For example, lakes can be modelled as a flat surface, which will generate higher flows and higher (i.e., more conservative) downstream water levels. If this is the case, it will need to be very clearly documented by the consultant, so that the study and floodlines can be updated when the missing data becomes available.

DETERMINE HYDRAULIC STRUCTURE REQUIREMENTS

Hydraulic structures are often the features that cause the greatest local changes in water levels along the watercourse. It is therefore very important to obtain all the necessary details of any structure that has the potential to impact water levels. It is important to note that not only do the hydraulic opening, inlet, and outlet characteristics need to be clearly represented, but the overflow features need to be noted in detail as well. Extreme flow paths and extents can be quite different from average flows, where roadway overtopping, separation of flow paths, or failure of structures are quite common during extreme events. It is therefore important to keep this in mind when collecting information related to hydraulic structures.

Survey requirements:

- The hydraulic opening geometry is to be measured in detail, such that the width, height, and total area of opening is accurately represented in the model. If the bottom of the structure is the natural channel, the number of points to measure is the same as for the cross-sections (See Table 3.2).
- Depending on the hydraulic structure, the roadway or overflow surface needs to be accurately measured. For a roadway surface, Lidar data will be sufficient to extract the roadway top elevation along a distance that exceeds the maximum potential flood width of any scenario modelled. Other structures (e.g., low head dams, spillways, weirs, etc.) need to have their surface surveyed on the site to ensure the details of the overflow geometry are very clearly defined. The accuracy of those measurements is to follow the same requirements as the topographic survey requirements for ground surveyed cross-sections.

If *Record Drawings* of structures are available, these may be used instead of a site survey to collect the necessary information. However, it is recommended that site visits be conducted to confirm that the drawings match current conditions, and that they be documented in the modelling report. *Design Drawings* or *Issued for Construction Drawings* will not be considered acceptable, as the actual built structure may differ from the original design.

4.1 Inlet and Outlet Characteristics

Inlet and outlet characteristics can greatly impact the hydraulic efficiency of the structures. For example, a culvert with a projecting inlet will have a notable reduction in capacity compared to a tapered inlet, even if the culvert diameters are the same.

The specific inlet and outlet characteristics need to be obtained for each hydraulic structure and should be collected during the site survey. If possible, the ground survey should measure inlet characteristics (e.g., length of inlet projection, angle of headwalls, radius of curvature of taper, etc.), to ensure the accuracy of the information.

In addition, the inlet approach and outlet expansion areas need to be measured. Site photographs are needed on both sides of the structure, facing both from and towards the structure. This is very important to evaluate contraction and expansion losses for each structure. Suitable sources for inlet and outlet loss coefficients include the FHWA-HDS05 Hydraulic Design of Highway Culverts, 2005 and FHWA-HDS07: Hydraulic Design of Safe Bridges, 2012.

4.2 Location of Cross-Sections Around Structure

It is important to locate upstream and downstream cross-sections in a specific manner to allow the valid calculation of expansion and contraction mechanisms to adequately evaluate energy losses.

Four cross-section locations are needed around the structure. The following sketch is extracted from the HEC-RAS manual and denotes the locations of the four sections in a sketch for a bridge or culvert. This is applicable to any hydraulic structure that creates contraction and expansion of the flow.

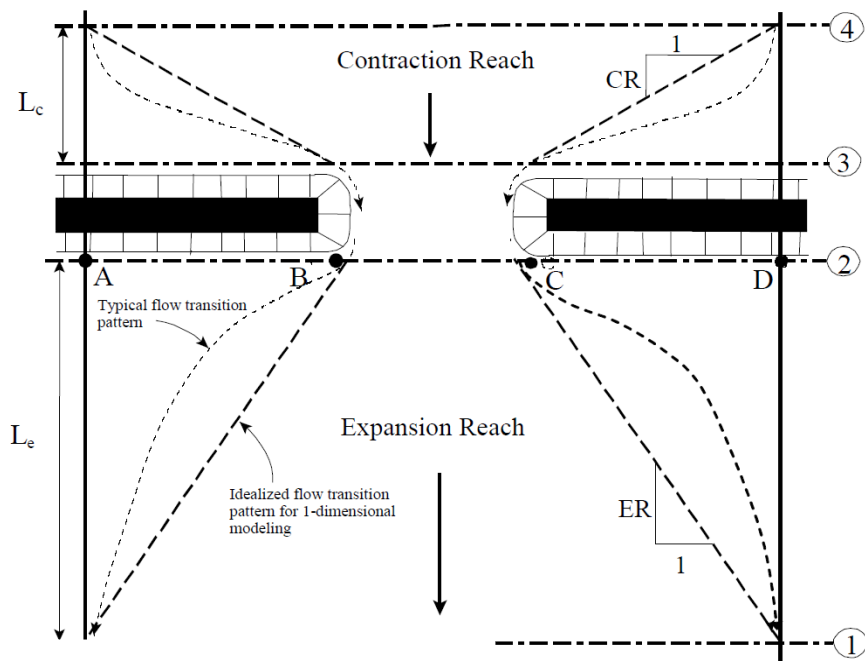


Figure 4.2 - Cross Section Locations at a Bridge or Culvert (Table 5.1 from the HEC-RAS Hydraulic Reference Manual)³

Cross section 1 is to be located sufficiently downstream from the structure so that the flow is not affected by the structure, and any local turbulence has dissipated. The field visit should attempt to locate the best location for this cross-section location. A rough first estimate is to use a distance from the structure that is equal to twice its average obstruction length (average of the distance A-B and C-D). Additional guidance is found in the HEC-RAS Hydraulic Reference Manual, 2008 that will consider degrees of constriction, different slopes, and different ratios of the overbank roughness to main

³ <https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%205.0%20Reference%20Manual.pdf>

channel, to identify an expansion ratio to multiply the obstruction length with to set the location of Cross-Section 1.

Cross-Section 2 is located a short distance downstream from the Bridge or Culvert. It is not located immediately downstream of the structure, but rather just after the outlet loss of the structure. It is meant to capture the section after the outlet loss of the structure but before the channel expansion.

Cross-Section 3, similarly, should be placed just before the structure's contraction losses, but at the end of the channel contraction.

Cross-Section 4 should be located just upstream of the channel contraction losses. A rough estimate can be made using a distance equal to the average obstruction length (average of the distance A-B and C-D). Additional guidance is found in the HEC-RAS Hydraulic Reference Manual, 2008.

The cross-sections do not necessarily need to be surveyed on foot or by boat. If the water was sufficiently shallow during the Lidar survey, the cross-sections can be directly extracted from there.

4.3 Strategy for Minimal Data Availability

If conditions are such that it is not possible, due to access, safety, or budget constraints, to obtain the data to the level of detail required, discussions will need to be held with the municipality to identify where a reduction in data collection is acceptable, but in general, hydraulic structures are essential factors that influence water levels in a drainage system. If the areas in question are deemed of significant importance for flood mapping by the municipality, it may be necessary to omit those specific areas from the project scope until such time that the issues can be overcome.

CONSIDERATION OF COLLECTION SYSTEM INTERACTIONS WITH WATERCOURSE

When water levels in a watercourse are high, any associated stormwater drainage system would not be able to drain out to the river or the coast. This will cause the drainage system to back up, producing localised flooding outside of the main watercourse floodplain. Similarly, combined sewer overflows into a watercourse with high water levels can prevent drainage of the wastewater and cause upstream flooding of wastewater within the serviced areas.

Interactions between a watercourse and stormwater/sanitary systems are often the subject of much debate. As a standard, the stormwater and sanitary systems are not included in flood mapping projects. The assessment of localised flooding occurring within the stormwater and combined system networks is the focus of Stormwater and Sanitary Master Plans or Stormwater and Sanitary Management Plans.

Stormwater Management Plans are typically best suited to occur after a flood mapping study has been completed. A flood study will provide the downstream water level boundary (in the watercourse) to the stormwater drainage system. The scope of a Stormwater Management Plan will typically include the drainage system of urbanized areas, including ditches, driveway culverts, catch basins, manholes and piped systems, which must be surveyed manually. Such systems can be quite sophisticated, such as combined stormwater/wastewater systems with combined sewer overflow chambers, and pumping stations. The focus of Stormwater Management Plans is the study of potential existing or future localized flooding, and the identification of mitigation and upgrade measures to service future development safely and cost effectively. It is important in such studies to include the downstream water levels, since there can often exist backwater effects that allow the watercourse or tide to flow back up through the system and cause flooding, or reduce the drainage capacity. The general approach to model set up and calibration is similar to a flood mapping study, where a representative geometrical description of the ground features is created within a model, and boundary conditions (meteorological and downstream water levels) are set in a representative manner. Calibration against measured extreme flood events also forms the basis for establishing the ability of the model to represent the impact of design storm events.

It is therefore to be assumed that the stormwater and sanitary collection system (and potential associated studies on water quality impacts) is not to be included in the Flood Mapping scope, unless specifically requested by the municipality.

HYDROLOGIC AND HYDRAULIC MODELLING REQUIREMENTS

The methods used for flood analysis need to be capable of resolving the mechanisms that influence flooding risks. Hydrologic and hydraulic considerations are presented here, including various approaches for the assessment, as well as modelling requirements.

Hydrologic and Hydraulic Modelling Requirements	Hydrology	Hydraulic Modelling
	Regional Flood Frequency	Approved Modelling Platforms
	Single Station Flood Frequency Analysis	Modelling Dykes or Berms
	Hydrologic Modelling	Modelling Blockages at Structures
		Ice Jam Assessment

6.1 Hydrology

A hydrologic analysis allows the estimation of runoff flows from a watershed into a watercourse. It is not intended to produce water levels, only flows. A hydrologic analysis can be conducted at a single point, or at many points. The Regional Flood Frequency and Single Station Flood Frequency analyses are typically conducted for one point, while hydrologic modelling is conducted to build on available data using localized hydrologic characteristics to infer flows at many locations within the watershed. Typical approaches include using the single point calculation as an upstream boundary to a short (less than 20 km) hydraulic model, or as calibration data to a hydrologic model. The Rational Method or Modified Rational Method are not acceptable approaches as they are developed for very small areas only (up to 20 ha). Where applicable, a flood frequency analysis (especially if based on a single station within the study area watershed) can produce the most representative flow estimates. However, such conditions seldom occur and alternative approaches, such as modelling, typically need to be used.

6.1.1 Flood Frequency Analysis

In a potentially changing environment, which may be caused by land-use changes or climate change, the suitability of hydrometric data may be uncertain. The Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation state in Section 6.3.1 (Key Assumptions of Flood Frequency Analysis) “Use of FFA [Flood Frequency Analysis] assumes that the record of observed floods can be treated as independent random variables drawn from a homogeneous and representative population that remains unchanged over time. A variety of statistical tests exist to help qualified professionals determine how well a peak flow record meets each of these pre-requisite assumptions for FFA”. Therefore, it is imperative to assess hydrometric data for change-points (e.g., deforestation), serial correlation (e.g., each subsequent observation is dependent on the one that preceded it), and trend (e.g., land-use change or climate change). If data are found to be homogeneous, constant over time, and display no serial correlational, standard flood frequency analysis techniques can be applied. Otherwise,

determining peak flood magnitudes (i.e., quantiles) is more complex. For example, if over time, an increasing temporal trend is identified in peak streamflow data, a standard statistical frequency analysis will underestimate the true flood quantiles.

The Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation state in Section 6.3.2 (Record Length) that FFA can be undertaken on periods of record greater than 10 years, however, it was cautioned that this is likely to result in unreliable results. A common rule is to avoid extrapolating annual exceedance probabilities (AEP) to more than double the length of available record. For example, one would need 50 years of data, to estimate the 1% AEP event. This number of station years is still considered low given that, in a stationary environment, one would expect to see one 2% AEP event in 50 years of data and an event greater than that is unlikely. Certain jurisdictions have required less data, but these are mostly generalized regional studies. It is therefore recommended that the period of record be extended through the suggested methodologies provided in the Federal Guidelines or a regional FFA be carried out as a comparative basis for the FFA on limited periods of record.

The Federal Guidelines do not recommend data transfer from other gauged locations to ascertain peak quantile estimates. However due to limited coverage, data transfer may be required in instances of limited data availability. Ideally, a strong correlation exists between the data of the candidate site and the study site, which can be assessed through overlapping periods of record. If data exhibit statistically significant correlation, then the watersheds are likely to be hydrologically similar. It is therefore recommended, in agreement with the Federal Guidelines, that regional FFA be used for peak quantile estimate in ungauged sites. It is recognized that regionalization may be somewhat more challenging in Nova Scotia, but even short periods of record can be included in a regional FFA analysis. Also, numerous hydrometric stations in the Province have long and accurate periods of record (some have over a hundred station years of data) and may facilitate the creation of homogenous regions.

The Canada-Nova Scotia Flood Damage Reduction Program published a document in 1980 that outlines a specific process for Nova Scotia, however, this approach can only be used in the following instances:

- ▶ Watersheds with drainage areas within the range of those of the 33 stations used in developing the equations (26.9 km² to 1450 km²).
- ▶ Not in areas of mainland Nova Scotia where few hydrometric stations used in their development are located (western Cumberland and Colchester counties, interior portions of Shelburne, Yarmouth and Digby counties, and significant portions of Annapolis and Hants counties)
- ▶ Not in the Cape Breton Island watersheds.

If regional flood frequency analysis is deemed inappropriate for the study area, it is suggested that a prescriptive methodology be developed for data transfer between stations that does not rely on a subjective assessment of catchment similarity.

6.1.1.1 SINGLE STATION APPROACH

This can be applied where existing flow gauging stations are located either in the target watershed, or in a watershed with similar hydrologic characteristics. This approach is not suitable if the study area watershed is less than 20 km² (since there are so few of them), unless the existing local gauging station also has a drainage area less than 20 km², in which case the target watershed should have a drainage area within

20% of the gauging station drainage area. If no suitable gauging station exists, hydrologic modelling should be conducted to estimate flows. In the case of a watershed with similar hydrologic characteristics, a review of the following hydrologic characteristics must be made, and good consistency between them must be ensured:

- ▶ Period of record (should be a minimum of 20 years to produce meaningful statistics)
- ▶ Watershed Drainage area
- ▶ Percent of watershed area covered by lakes
- ▶ Average slope of watershed
- ▶ Percentage of development
- ▶ Percentages of other types of land cover (Low density to High density forest, grass, wetlands, brush, etc.)
- ▶ Whether flow regulation (e.g. dams) exist within the watershed
- ▶ Proximity of gauged watershed to target watershed
- ▶ Geographic similarity (coastline the watersheds drains to, the mountain or hill the watersheds initiate at, the maximum rainfall amount for the relevant duration of event - following the time of concentration of the watershed - to be obtained from the Rainfall Frequency Atlas for Canada, the orientation of the watershed).

It is recommended that several (3-4) gauged watershed characteristics be quantitatively compared to the characteristics of the study area. If little similarity is found between the study area watershed and the gauged watershed, the Single Station Flood Frequency Analysis may not be suitable. If the Regional Flood Frequency Analysis is not applicable either, a discussion must be held with the Municipality to document the lack of flow data. A decision may be jointly made to select a representative watershed, or to install a new flow gauge, but the data limitations must be made very clear in the analysis report.

6.1.1.2 STATISTICAL ANALYSIS

Once the flow data has been collected and prorated, the peak annual instantaneous maxima need to be organised and a statistical extremal value analysis conducted. According to the Federal Flood Mapping Guidelines, 2019, the Generalised Extreme Value (GEV) analysis is the most suitable probability distribution function and is to be included. Other types are also accepted, including Gumbel, Frechet, Weibull (which are within the GEV family of distributions), Normal, Log-Normal, 3-parameter Log-Normal, Log Pearson III, or Method of Moments. Naturally, it is necessary to include a range of statistical tests to evaluate the suitability of the various functions to identify the most representative. Confidence Intervals (95%) need to be included in the graphing of the selected function. Other approaches presented in the Federal Flood Mapping Guidelines (2019) document are also acceptable.

6.1.2 Hydrologic Modelling

Hydrologic models are to be used where:

- ▶ The watershed area is less than 20 km² (unless specific characteristics discussed for the single station approach apply)
- ▶ The length of the hydraulic model study area is more than 20 km (representative changes in flows may not be well represented with a flood frequency analysis), or

- ▶ The hydrologic characteristics between watersheds are too diversified to be represented by a single gauging station. Occasionally, it may be possible to break down the study area watershed into several components, each with their respective hydrologic calculation, but this is mostly applicable to very large watersheds (> 1000 km²)
- ▶ Additional processes were identified as important contributors to flooding in certain parts of the watershed (e.g., snow melt, groundwater inflow).

6.1.2.1 MODELLING PLATFORMS

Acceptable hydrologic models are the following:

- ▶ HEC-HMS
- ▶ SWMM5

Other software may be used, but they must be open-source, non-proprietary, and be able to conduct an event as well as long term models to the same as or more advanced level of detail than the software listed above. Any alternative software proposed must be clearly documented, justified, and submitted to the Nova Scotia Department of Municipal Affairs & Housing for acceptance before it can be used⁴.

6.1.2.2 MINIMUM DATA INPUT REQUIREMENTS:

The rainfall input to the model, for the design events, shall follow the closest Environment Canada climate station with Intensity-Duration-Frequency (IDF) curve data available. The distribution of the rainfall shall follow the IDF data, meaning that the 5-minute peak intensity of the rainfall event will match that of the IDF curve, as well as the 15-minute, 30-minute, etc., up to and including 24 hours. For this, the A and B coefficients derived by Environment Canada in the IDF relationship ($I = A \cdot t^B$) may be used to assemble the rainfall distribution. For reference, *Applied Hydrology* (Chow, 1988 p. 446-7) includes a detailed methodology for the Alternating Block rainfall distribution method. However, software exists using other relationships that are more accurate and as easy to implement. It will be up to the consultant to use best professional judgement when choosing the methodology and ensure it is clearly explained and rationalized in the report. Any software and methodology should be non-proprietary and accessible for reviewers and future modelling.

Regardless of the method, the input data shall include delineation of the following land cover surface type to account for the specific surface roughness, infiltration, or surface storage characteristics of each surface type:

- | | |
|---|---|
| <ul style="list-style-type: none"> • Light forest • Medium density forest | <ul style="list-style-type: none"> • Dense forest • Light brush |
|---|---|

⁴ Rather than Identifying a robust set of requirements that detail model capabilities that would be very difficult to check an individual model against, specific modelling software was chosen. Descriptions of model internal workings are not standardized and not typically explicitly stated or are hidden for intellectual property reasons. US FEMA has created a list of models that looks for third party test results and the ability to reproduce results from other accepted models before approving new models. Any alternative software proposed should refer to software on this list. https://www.fema.gov/sites/default/files/2020-03/Model_Acceptance_Checklist_Feb_2018.pdf

- Heavy brush
- Grass
- Wetland
- Rocky outcrops

- Lakes
- Low density development
- Medium density development
- High density development

Delineation of soil type shall be conducted if more than one soil type is present in the watersheds. Soil infiltration characteristics shall be obtained from the Canada Department of Agriculture soil database, 1972, which includes soil information. Soil characteristics can then be obtained using Rawls et al., 1983.

Where possible, soil infiltration calculations shall be conducted using measured soil characteristics, that are available from the Canada Department of Agriculture soil database. The Green-Ampt formulation is such an example⁵. This approach is meant to be a simple but robust method for assessing infiltration and runoff, which is based on actual soil characteristics, and a method that is also closer to actual soil infiltration behaviour. The use of Curve Numbers for soil infiltration calculations is not considered an acceptable method: it is not based on Canadian soils, is overly simplified, and does not have sufficiently specific characteristics (based on one of a total of four possible soil groups).

It is understood that there is a natural variability to soil conditions and runoff amounts within any watershed at any given time. It is therefore expected that long term simulations will have greatly varying runoff coefficients (the ratio of runoff volume to rainfall volume) for any given rainfall event. For example, the runoff coefficient will be very different after a dry summer period compared to frozen ground conditions.

For the purposes of extreme event flood modelling, it is expected that runoff coefficients will be greater than average values. In order to ensure some consistency and a minimum acceptable level of safety with respect to runoff calculations, the resulting runoff coefficients are to reach at a minimum the following values (the maximum values would be 1, for frozen ground conditions, or higher if snowmelt is included):

Average Land Cover	Minimum Runoff Coefficient
Majority of Dense Forest / Heavy Brush	0.5
Majority of Light Forest / Light Brush	0.6
Majority of Grass	0.65
Majority of Light Development	0.7
Majority of Medium Density Development	0.8
Majority of Dense Development / Wetlands / Lakes / Rocky outcrops	0.9

⁵ The Green-Ampt method was suggested because the data are already available for all of Canada, so additional measurement are not necessary. Soil types are available from Agriculture and Agri-food Canada in shape files (<http://sis.agr.gc.ca/cansis/publications/surveys/ns/index.html>), and Green-Ampt parameters are found from the following source, which is a reference in the industry. Source: Rawls, W.J. et al., (1983). J. Hyd. Engr., 109:1316.

The runoff coefficients need to be calculated for each watershed and need to meet the above criteria. If they do not, adjustments to the model (infiltration characteristics for example) need to be made to bring the calculated runoff coefficient to the required values.

The hydrologic model extents need to cover the entire tributary area and be broken down into sub-watersheds (by similarity of hydrologic characteristics) as necessary to represent the gradually changing flows along the watercourse.

6.2 Hydraulic Modelling

Hydraulic modelling is the assessment of water levels in a hydraulic conveyance system that are reached when flows are entered into this system. Water levels will be dependent on factors such as channel shape, slope, roughness, bends, constructions, storage, structures, etc. Water level calculations need to take into consideration the various mechanisms that affect water levels. Coastal modelling naturally requires at least a 2D modelling platform; a steady state model for example, will not adequately assess water levels in an area that is tidal. However, storage areas or dendritic networks with no specific constriction could be suitably assessed with a one-dimensional steady-state model. The following criteria is therefore to be used for model selection, combined with professional judgement:

One Dimensional Steady State Models:

- Only for dendritic networks with little storage (such as lakes), few constrictions, and no hydraulic structures.

One Dimensional Unsteady Flow (hydrodynamic) Models:

- Suitable where clearly defined channels follow clear pathways.
- Tidal effects, storage, constrictions, or hydraulic structures are present.
- Can include multiple paths, but those must be clearly defined and constant (such as an overflow into a ditch system or pond).

Two Dimensional Hydrodynamic Models:

- Needed where there are unclear flow paths that can vary depending on the flows.
- Potential of overflows into large floodplain areas with multiple pathways.
- Localized effects of structures or bends, creating different water levels along the watercourse cross-section, are needed for the study.

Three-Dimensional Hydrodynamic Models:

- Needed where vertical effects impact water levels, such as local structure effects such as uneven weirs, or around scour holes in fast flows.
- Where the bed level changes during the event, and subsequently alters water levels, the model can include erosion and sedimentation to update the riverbed shape during the simulation. This is needed where such simulations identify safety risks, or significant cost savings.
- The cost of using this type of model and its greater data requirements needs to be balanced with the accuracy needed for the area being studied.

6.2.1 Approved Modelling Platforms

The acceptable hydraulic models in each of the above categories are listed below:

River Modelling - One Dimensional Steady State Models:

- HEC-RAS
- SWMM5
- MIKE-11 by DHI

River Modelling - One Dimensional Unsteady Flow (hydrodynamic) Models:

- HEC-RAS (ver. 4.0 and up)
- SWMM5
- MIKE-11 by DHI

River Modelling - Two Dimensional Hydrodynamic Models:

- HEC-RAS (ver. 5.0 and up)
- PCSWMM2D (Quasi-2D flow)
- Delft3D by Deltares
- MIKE Flood by DHI
- Telemac2D

Coastal Modelling - Two Dimensional Hydrodynamic Models:

- Delft3D by Deltares
- MIKE-21 by DHI
- Telemac2D

River and Coastal Modelling - Three-Dimensional Hydrodynamic Models:

- MIKE 3 by DHI
- Delft3D by Deltares
- Telemac3D

The reference manuals for each model should be followed carefully, as each model has a slightly different approach to calculating water levels. For example, hydraulic structure loss coefficients in one model may not produce the same results as in another model.

Other software may be used, but they must be open-source, non-proprietary, and be able to conduct an event as well as long term models to the same as or more advanced level of detail than the software listed above. Any alternative software proposed must be clearly documented, justified, and submitted to the Nova Scotia Department of Municipal Affairs & Housing for acceptance before it can be used⁶.

⁶ Rather than identifying a robust set of requirements that detail model capabilities that would be very difficult to check an individual model against, specific modelling software was chosen. Descriptions of model internal workings are usually not standardized or explicitly stated or are hidden for intellectual property reasons. US FEMA has created a list of models that looks for third party test results and the ability to reproduce results from other accepted models before approving new models. Any alternative software proposed should refer to software on this list. https://www.fema.gov/sites/default/files/2020-03/Model_Acceptance_Checklist_Feb_2018.pdf

The following requirements apply to all models:

- Cross-sections used in the model (for One Dimensional models), or the domain extents of the model (for Two and Three-Dimensional models) need to be sufficiently wide to include the highest potential flood to be modelled. If this is not the case, loss of water, artificial constriction, or artificial surcharging will occur, resulting in invalid results.
- Sufficient cross-sections need to be included to allow the generation of a representative set of water level results (see Topographic Requirements above).
- Roughness coefficients need to follow the Chow, 1959 guidance.
- Hydraulic model extents need to include the upstream and downstream end of the development that the study area is within, plus 5 km upstream and 5 km downstream, to ensure any potential impact on flows or water levels are included in the model.

6.2.2 Modelling Dykes or Berms

Dykes and berms are designed to encroach on the floodplain, and as such, need to be carefully modelled. If the hydraulic model does not have a specific dyke or berm modelling routine, the cross-sections need to be terminated at the dyke, and a weir connection needs to be added to link the main channel to the floodplain behind the dyke. If the dykes can be overtopped by a significant depth (greater than 300mm), failure of the dyke needs to be considered. The hydraulic model selected therefore needs to either have a dyke failure routine or be able to represent dyke failure using available modelling components (make modifications at given thresholds during the simulation to the geometry of the modelled dyke, as a representation of dyke failure).

6.2.3 Modelling Blockages at Structures

Blockages can be common in some structures, which restrict the natural cross-section of the channel, and where a large amount of debris can be generated in the upstream watershed, typically in forested areas. If anecdotal evidence has pointed to such an occurrence, debris jams will need to be included as a scenario in the model and discussed in the results. For this assessment, as much information as possible on the types of debris, the frequency, the mechanisms of the debris jam formation, and debris jam size and extents need to be collected. An estimate of the 5% AEP and 1% AEP debris jam will need to be made and the model will need to include some combination of weirs, orifices, restricted cross-sections, and hydraulic losses to represent the blockage present at the structure.

6.2.4 Ice Jam Assessment

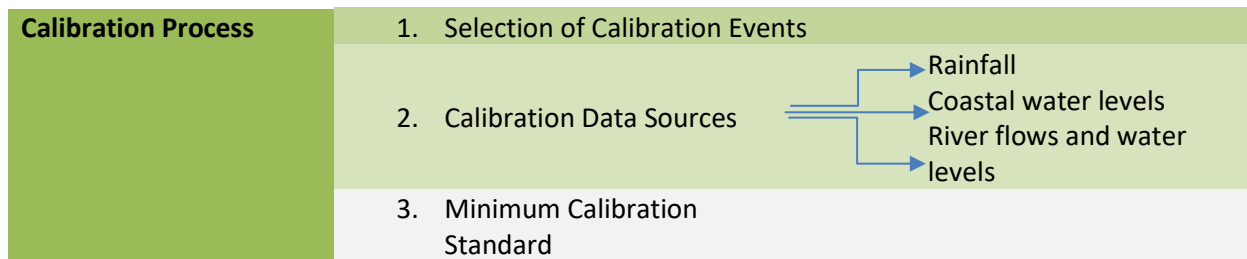
Ice thickness measurements should be obtained from a location as close as possible to the study area site (assemble local ice thickness data if available). If sufficient data is available, the procedure described in the Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation, 2019, should be followed.

If there is insufficient data, the Environment Canada Ice Thickness Program Collection can be an additional source of data. With this information, the US Army Corps of Engineer's Cold Regions Research

and Engineering Laboratory's methodology ("Method to Estimate River Ice Thickness Based on Meteorological Data") of extending the data using a local climate station should be followed. A statistical analysis to obtain a 1% AEP value for ice thickness should be conducted. From there, a suitable model should be used to evaluate the risks of ice jams forming in various locations in the watercourse. Any available ice jam thickness or water level information during ice jams should be used to calibrate the model.

In Nova Scotia very little exists in terms of consistent ice thickness measurement programs or ice jam thickness measurement programs. This lack of initial conditions and calibration data makes it very difficult to produce reliable assessments of expected ice jam thicknesses with a specific return period. For this reason, ice jam modelling results are not typically used to generate flood maps. Rather, longitudinal river profiles are generated, and comments are made to identify areas that are most at risk. It will be up to the consultant to decide whether the analysis is sufficiently representative of actual risks to generate a flood map or to generate a profile with some comments.

Model calibration is the process of reproducing measured flows and water levels using only climate data (and tidal water levels if needed) as input for a model run. The objective is to adjust the hydrologic and hydraulic models to be representative of the watershed and drainage system, so that it can produce realistic estimates of peak water levels during extreme events.



7.1 Calibration Process

Calibration is conducted by first identifying the most representative measured flood events, which are typically those closest to the design events (the 5% AEP and 1% AEP events). Rainfall, flow, and when possible, water level data are collected, and the model is run to see if the model results match the recorded flows and water levels (including the accreting and receding limbs). If this is not the case, the model parameters must be adjusted to allow the model to match the measured curves closely as possible. The adjustment process, however, is the core of the calibration effort. Careful judgement, thought, and discussions with experienced professionals and local individuals familiar with the natural variation of the hydrologic and hydraulic characteristics are needed to judiciously adjust the parameters within their representative range and arrive at a combination that matches the observations, while still including a representative set of parameters.

Validation events (the confirmation of the suitable calibration of the model using a different event) are considered standard modelling practice and is required by Section 6.5.5 of the Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation. However, it is also considered effective to include the validation events within the calibration as it will result in a more representative model reflective of additional conditions (Shamsi & Koran, 2017). Long time series gauge data may be compared to the modelled flows to see if they are in the expected range of observed values. However, even 30 years of data may not be sufficient to support statements that undermine the modelling results. If the methods used are well supported, then the model results are the best estimate that can be provided, especially if the long-term flow gauging data is used to calibrate the model.

The idea of independent testing does not apply well to those models due to the level of uncertainty, variability of parameters, and general lack of available data. In practice, using everything that is available to support the model calibration is typically the best use of the data. Regardless of methodology, a

discussion on the main events available for calibration is required and the rationale for selecting specific events must be explained.

7.2 Selection of Calibration Events

Model calibration is often considered to be the most important part of any modelling effort. It is the main source of evidence that the model is representative of the conditions during the calibration events, and by inference, of the design events. It is very important that the calibration events attempt to be representative of the conditions of the 5% AEP and 1% AEP events. Those may be created by a combination of various mechanisms, such as tidal events, winter events, or operational events. Therefore, calibrations events must attempt to include the relevant mechanisms at play that combine to create the highest water levels.

7.3 Calibration Data Sources

7.3.1 Rainfall

The closest and most reliable climate information must be sought for rainfall to be used in calibration. This is typically the Environment Canada climate stations, although if more than one type of gauge is available, the data must be compared to identify the most representative set, since some gauges are covered during the winter. Some rainfall gauged data may need to be quality controlled. One example is tipping bucket rain gauges which can underestimate precipitation intensity during extreme storms.

Available data may be supplemented by private rain gauge data if gathered closer to the study area watersheds, have similar annual averages, and reliability can be demonstrated (set up characteristics meet similar standards to the Environment Canada stations). If no locally reliable data are available, or if the watershed areas are very large, it may be necessary to obtain radar-rainfall data from Environment Canada over a large area, calibrate it on available rain gauges, and then calculate the specific rainfall for the individual watersheds of the study area. Relevant climate information will include not only rainfall, but also maximum and minimum temperature⁷, snow on the ground, wind speed and solar radiation, which all affect the type of event that occurred.

7.3.2 Coastal water levels

If the study area is affected by the tide, the most reliable tidal information must be obtained. The tide prediction model WebTide is available from the Department of Fisheries and Oceans, which could be used in areas with insufficient observations. DFO also publishes tidal heights for select sites in the annual publication “Canadian Tide and Current Tables”. The heights were derived from a network of historical tide gauge stations, however some of them recorded for no longer than one month which does not allow the development of storm surge estimates. The historical time-series observations are available online. It is recommended to examine the original record, check for potential adjustments in vertical datum, and compare with adjacent sites. Long-term observations for deriving reliable storm

⁷ The min/max daily temperature data is readily available from any climate station under “daily data” from ECCC. The value of this information is primarily to identify if snow fall or snowmelt was involved in the event, which would result in very different mechanisms for generating runoff than simply looking at total precipitation.

surge statistics along NS coastal waters are only available for the 4 permanent tide gauges at Halifax, Yarmouth, North Sydney, and Charlottetown. For any other site, estimates should be derived from modelling, such as past and current research projects by Environment Canada⁸ (James, T.S., Henton, J.A., Robin C., & Craymer, M. 2021) and Richards and Daigle (2011).

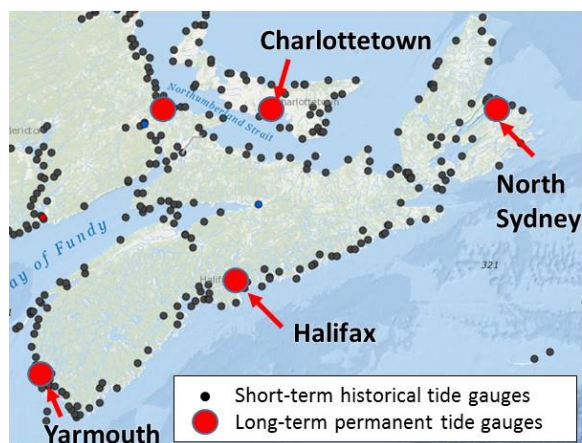


Fig. 1 DFO Tide Stations

7.3.3 River flows and water levels

In addition to this, measured river flow and water level data need to be identified, against which to calibrate the model. This is the data that the model will need to be able to simulate in a representative manner. This should include as many of the following sources as possible:

- Environment Canada gauged flows and if possible, measured water levels.
- Prorated data from a representative nearby gauged watershed, if the above is not available.
- Measured flows and/or water levels using private instruments. In this case, the quality of the set up needs to be carefully documented and needs to adhere to standards close to the Environment Canada standards.
- Water level data in reservoirs such as dam or water supply storage reservoirs, where water levels are recorded daily.
- Anecdotal information from area residents on peak water levels during given events. This will ideally include photos or identify high water marks that can be surveyed.
- Satellite data can sometimes capture peak water level events. In such cases, care must be taken since the photos will likely not represent the peak water levels at all points in the watercourse at one point in time.
- News articles.
- Flood databases from the local EMO or provincial databases.

7.4 Minimum Calibration Standard

It is extremely important to collect as much calibration data as possible since it will directly reflect on the quality of the resulting model. As a minimum, at least one reliable source of data for flows must be used (Environment Canada) and several locations with water levels must be available, to allow the

⁸ More research available at www.climatedata.ca

model to be representative of water levels throughout its extents. As much measured data as possible must be used, but if the only available water level information is anecdotal, this must be carefully recorded and documented in the report.

In addition, it is necessary that the data be sufficiently representative of the design events, i.e. at least one (flow or water level) event must have at least a 5% AEP. Since statistics on long term data should only be relied upon if at least 20 years of data are available, the associated return period of the peak event with this time range will be close to the 5% AEP. Alternatively, rainfall events can be compared to the Intensity-Duration-Frequency curves to estimate their return periods, and then the flows during those events can be roughly inferred to be similar (since return periods of rainfall and flow events are related).

7.5 Documenting the Calibration Results

The available data, its quality, and relation to the design events, must be carefully documented and graphed. The model results must be compared with the calibration data both graphically and through statistical error and correlation testing. The following error functions must be calculated and tabulated:

- Nash-Sutcliffe efficiency (NSE)
- Coefficient of determination (R^2)
- Simple least squares (LSE)
- Root mean square error (RMS E)

At a minimum, the pre-event water levels and flows, their accreting and receding limbs, as well as their peak values must be reproduced in a representative manner.

7.6 Sensitivity Analysis

When the calibration is deemed satisfactory, a sensitivity analysis must be conducted by varying the parameters that influence flows and water levels within their realistic ranges and tabulating or graphing their influence on peak water levels. This information will be very helpful for the Municipality to understand the main factors that influence peak water levels and allow initial insights into potential flood mitigation approaches. A discussion of the results of the sensitivity analysis shall be included in the report, to relate the behaviour of the watershed and hydraulic system under varying input conditions.

Maps are the main deliverable of the analysis described above. They need to be as clear and easy to interpret and understand as possible. With this goal in mind, the following criteria are set for production and delivery of mapping information. Included within the maps to be produced is hazard mapping. This is considered a valuable tool to protect public safety. It is a measure of hazard (in this case, depth of water multiplied by the velocity) and can be categorized into 3 different classes:

Table 10.1 Hazard classification according to depth and velocity

Class	Values in Depth (m) x Velocity (m/s)	Level of danger
Class 1	0.5 to 1.5	Danger to some
Class 2	1.5 to 2.5	Danger to most
Class 3	Above 2.5	Danger to all

The maps are provided to support the goal of protecting public safety. The maps will provide a clear visual tool for the Municipality to use as a guide for protection of public safety.

Criteria for production and delivery of mapping information:

- The mapping products need to be made available in both PDF and GIS formats (details for GIS data are provided in the next Chapter), so that they can be easily printed and shared, and the visualization of the information can be customized as needed by the Client.
- The colour schemes of the PDF maps must be consistent. As a standard, the 5% AEP event flood lines should be depicted in blue, and the 1% AEP event depicted as red. Climate Change flood lines should be depicted in purple and pink, respectively. A clear legend and labelling system should be noted on the map.
- A map displaying the locations of the various cross-sections used (if using a One-Dimensional model) or the model domain and mesh resolution (if using a Two or Three-Dimensional model) used.
- In addition to layers showing water extents, layers showing **water depth** at the resolution of the Lidar data, as well as layers showing **water velocity** (at the resolution of the model), and layers showing **Hazard** (Depth x Velocity) must be produced to help with efforts to protect public safety.
- PDF maps are to be produced to show, for the entire study area extents:
 - the 5% AEP and 1% AEP events,
 - for existing climate and future climate conditions (2050 and 2100),
 - for flood extents and hazard

NOTE: More detailed mapping can be produced by the Consultant if requested by the Municipality. The Municipality should also be able to make maps as needed using the GIS data they are provided upon completion of the project.

- The main roadways should be labelled to help the public understand the maps better.

- On the Flood Hazard maps, the main public safety infrastructure (main roads, ambulance centre, hospital, power corridors, treatment plants, etc.) should be labeled, as well as the most vulnerable areas (schools, senior homes, community buildings, etc.).
- The background of the maps should show an orthophoto to visualize information on the topography, land cover and land uses.

Final validation of flood extents:

Once the maps with flood extents have been produced, a final walkthrough of the study area should be made with the municipality to ensure there are no anomalies in the estimated flood extents. This step is required in areas of high risk and areas that are currently developed or are designated for future development in municipal planning documents.

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9.1 Reporting deliverables

The maps are to be accompanied by a report. This report should include, at a minimum:

- Background of the study, purpose of the investigation and objectives.
- Hydrologic and hydraulic setting.
- Previous history of flooding (that is known).
- Data availability, and for each set available quality and span. Data gaps and QA/QC to be documented.
- Survey summary maps.
- Cross-section surveys.
- Hydrologic assessment approach, with supporting rationale.
- Details of hydrologic assessment.
- Hydrologic assessment results, calibration results if modelling was undertaken.
- Hydraulic assessment approach, with supporting rationale.
- Details of hydraulic assessment.
- Hydraulic assessment results, calibration results, sensitivity testing and associated discussion.
- Calibrated model parameters to support review by the municipality or their client engineer.
- A table listing the structures that either surcharge or are overtopped, noting the peak flow to each structure and the overtopped flow, for each of the four flood events.
- Discussion on the estimated level of quality of the study, and the main limitations/sources of uncertainty (these should be explained based on availability and quality of data, assessment approach, modelling challenges, etc.).
- Recommendations for further efforts to improve the next flood mapping study, including potential additional data collection.

9.2 Mapping Deliverables

In addition to the report, the maps should be delivered both in pdf format and in a GIS Geodatabase (flood outlines) as a minimum. All maps (e.g. extents, velocity, depth, and hazard) should also be delivered in GIS raster file format, to the municipality and to the Department of Municipal Affairs and Housing. Data must follow the Nova Scotia Geographic Metadata Standard” (2021).

Model files for the requested scenarios should be included in the deliverables, with the necessary data to allow the user to run the models for the various scenarios investigated with the GIS data files. A Map Package is also to be created to allow the mapping layouts to conserve the data links. +

The GIS maps shall include the following types with corresponding layers:

Map Type	Layer	Name assigned to layer
Flood Extents	1% AEP Current Climate	Floodline_1_AEP_Existing
	5% AEP Current Climate	Floodline_5_AEP_Existing

	1% AEP Current Climate	Floodline_1_AEP_CC
	5% AEP Current Climate	Floodline_5_AEP_CC
Depth Maps	1% AEP Current Climate	Depth_1_AEP_Existing
	5% AEP Current Climate	Depth_5_AEP_Existing
	1% AEP Current Climate	Depth_1_AEP_CC
	5% AEP Current Climate	Depth_5_AEP_CC
Velocity Maps	1% AEP Current Climate	Velocity_1_AEP_Existing
	5% AEP Current Climate	Velocity_5_AEP_Existing
	1% AEP Current Climate	Velocity_1_AEP_CC
	5% AEP Current Climate	Velocity_5_AEP_CC
Hazard Maps	1% AEP Current Climate	Hazard_1_AEP_Existing
	5% AEP Current Climate	Hazard_5_AEP_Existing
	1% AEP Current Climate	Hazard_1_AEP_CC
	5% AEP Current Climate	Hazard_5_AEP_CC

The municipality can also request the preparation of other forms of data presentation, such as more focused maps at specific scales with specific information (e.g., property boundaries), but also 3D renderings or animations of specific flood scenarios showing the water levels rising, following the model output.

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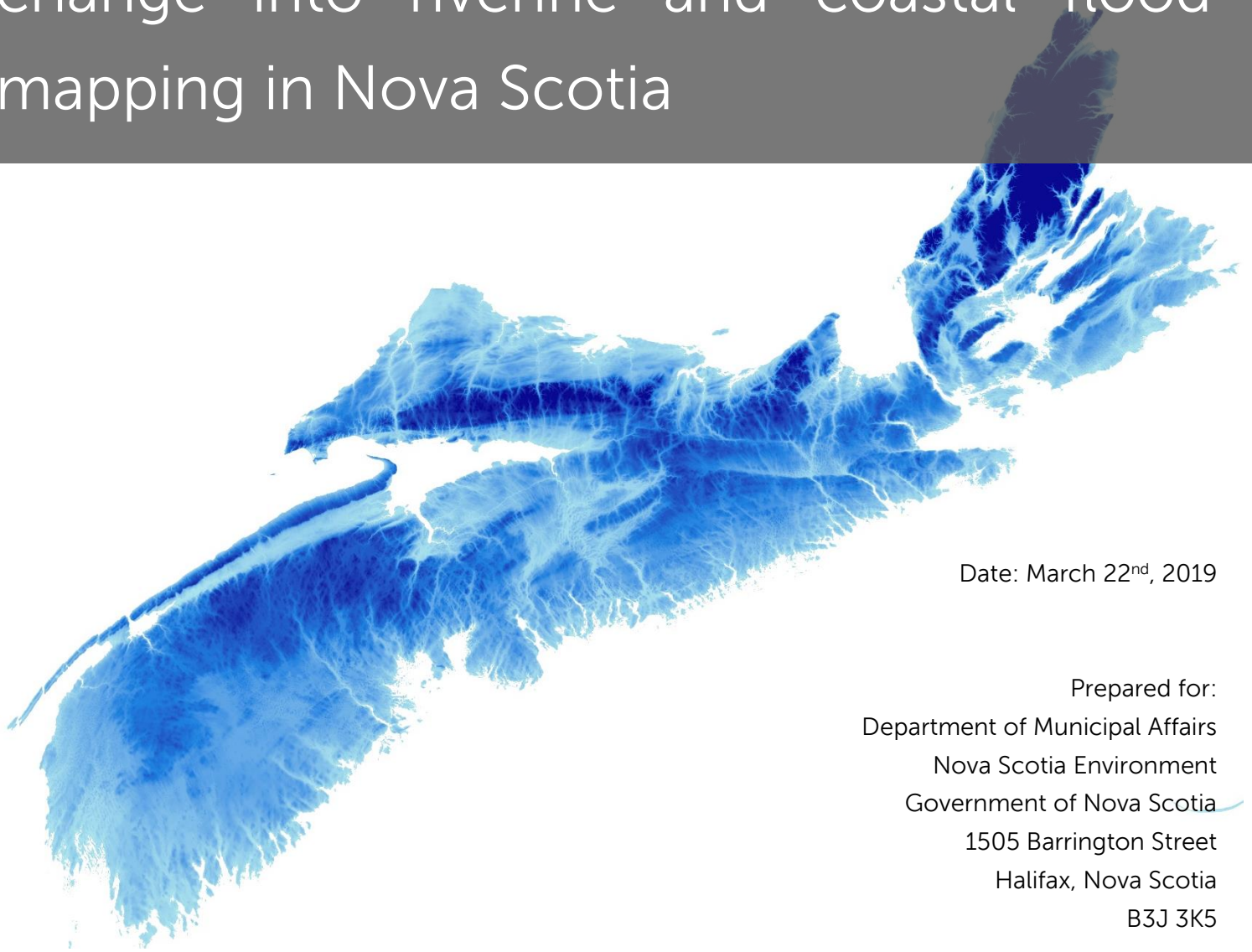
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Standard for the incorporation of climate change into riverine and coastal flood mapping in Nova Scotia



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Prepared for:
Department of Municipal Affairs
Nova Scotia Environment
Government of Nova Scotia
1505 Barrington Street
Halifax, Nova Scotia
B3J 3K5

This report was prepared collaboratively by researchers from Dalhousie University, St. Mary's University and St. Francis Xavier University.



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List of Abbreviations

°C	Degree Celsius
AR6	Sixth Assessment Report of the IPCC
C-C	Clausius-Clapeyron
CGS	Canadian Geodetic Survey
CGVD80	Canadian Geodetic Reference System 1980
CHS	Canadian Hydrographic Service
cm	Centimetre
CORDEX	Coordinated Regional Climate Downscaled Experiment
CSRS	Canadian Spatial Reference System
ECCC	Environment and Climate Change Canada
Eq.	Equation
GCM	Global Climate Model
GPS	Global Positioning System
HHWLT	Higher High Water Large Tide
HyVSEPS	Hydrographic Vertical Separation Surface
ICLR	Institute for Catastrophic Loss Reduction
IDF	Intensity-Duration-Frequency
IDF_CC	Intensity-Duration-Frequency Climate Change Tool
IPCC	Intergovernmental Panel on Climate Change
m	Metre
m ²	Metre Squared
n	Sample size
NAD83	North American Datum 1983

NRCAN	Natural Resources Canada
PCIC	Pacific Climate Impacts Consortium
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RCP8.5	Representative Concentration Pathway at radiative forcing of 8.5 watts per squared metre
RSLR	Relative Sea-Level Rise
W	Watt
W.Ant	Western Antarctic

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1 Introduction

1.1 Objective of the Standard

The objective of the standard is to develop a standardized framework for the incorporation of future climate changes into municipal riverine and coastal flood mapping in Nova Scotia.

The proposed framework was developed with the intention of providing a scientifically defensible, consensus-based approach that is practical to implement.

1.2 Scope of the Standard

Climate change is expected to impact several variables that influence the development of riverine and coastal flood maps. These include rainfall characteristics, relative sea level rise and storm surge. This standard focuses on how these variables should be adjusted in municipal riverine and coastal flood mapping to account for future climate change.

This standard only considers the technical aspects of how climate change projections should be incorporated into municipal riverine and coastal flood mapping in the province of Nova Scotia. Other elements of municipal riverine and coastal flood mapping, such as the selection of hydrologic/hydraulic models, calibration/validation practices and mapping standards, are to be developed through a companion initiative.

1.3 Limitations of the Standard

This standard is limited by the scientific knowledge and tools available at the time of this standard formation. Due to the rapidly evolving nature of climate science this standard should be periodically updated with new information and tools as they become available. Currently, there are significant uncertainties in climate change projections. Throughout, the precautionary principle was applied to address these uncertainties.

1.4 Expert Working Group Appointment

The Government of Nova Scotia consulted with multiple academic institutions in recognition of the need to obtain expert consultation. An interdisciplinary working group comprised of researchers in various fields was formed. These fields included: municipal planning, water resources engineering, coastal hydraulics and climatology.

This working group was formed in August 2018 and consisted of the technical advisors outlined in Table 1.

Table 1. Qualifications of the technical advisor panel.

Group Member	Organization	Bio
Dr. Eric Rapaport	Dalhousie University School of Planning and Architecture	Dr. Rapaport is an Associate Professor and Registered Professional Planner with expertise in municipal planning. His expertise areas include physical infrastructure and social vulnerability assessments. He also studies land use changes over time with GIS-based analysis.
Dr. Patricia Manuel	Dalhousie University School of Planning and Architecture	Dr. Manuel is a Full Professor and Registered Professional Planner and is an expert in environmental planning with a focus on climate change. She investigates adaptation planning and the management of wetlands and watersheds from a planning perspective. She is an expert in using land use planning as a tool for climate change adaptations. Her recent work has focused on climate change impacts along the coast and the vulnerability of coastal populations and communities to sea level rise and coastal flooding.
Dr. Rob Jamieson	Dalhousie University Department of Civil & Resource Engineering	Dr. Jamieson is a Full Professor and the Associate Director of the Centre for Water Resources Studies. He is a Professional Engineer and holds a Tier II Canada Research Chair in Cold Regions Ecological Engineering. He has expertise in hydrological modeling and incorporating climate change projections into water resources engineering applications.

Group Member	Organization	Bio
Dr. Barret Kurylyk	Dalhousie University Department of Civil & Resource Engineering	Dr. Kurylyk is an Assistant Professor and Professional Engineer in the Centre for Water Resources Studies and holds a Tier II Canada Research Chair in Coastal Water Resources. His research expertise areas include physical hydrology and hydrogeology. His research is interdisciplinary with a focus on environmental change and climatology aspects related to water resource management.
Dr. Danika Van Proosdij	Saint Mary's University Department of Geography and Environmental Studies	Dr. van Proosdij is a Full Professor and Chair of the Department of Geography and Environmental Studies. She is an expert in coastal systems, coastal vulnerability assessments and nature-based climate change adaptation. Her research focuses on the response of coastal ecosystems to natural and anthropogenic drivers of change.
Dr. Hugo Beltrami	Saint Francis Xavier University Department of Earth Sciences	Dr. Beltrami is a Full Professor and a Tier I Canada Research Chair in Climate Dynamics at the Climate & Atmospheric Sciences Institute. His expertise areas are climate change, downscaling methods for climate projections, paleoclimatology, inverse theory, and the integration of climate models and palaeoclimatological data, land surface processes and improvement of land surface model components of global climate models.

1.5 Working Group Activities

Upon formation of the expert working group, members were allocated the task of conducting literature reviews on topics within their expertise areas and relevant to the climate change standard. Four primary topic areas were identified, which are listed below along with the topic leader(s). The individual literature reviews are provided in Appendices A-D.

- Planning Horizons and Considerations (Rapaport and Manuel)
- Global Climate Models and Downscaling Approaches (Beltrami)
- Sea Level Rise and Storm Surge Projections (van Proosdij)
- Future Climate Intensity-Duration-Frequency Relationships (Jamieson and Kurylyk)

The working group convened for an in-person workshop to deliver preliminary presentations on their respective literature reviews on January 15th, 2019 in Halifax, Nova Scotia. Group members then finalized draft reports detailing the findings and recommendations from their review, and these drafts were distributed to the working group. A second in-person workshop was held on February 22nd, 2019 in Halifax, Nova Scotia. The objective of the second workshop was to develop consensus-based decisions on the content and justification for the standard specifications based on the literature reviews. Both meetings were facilitated by the Government of Nova Scotia's Department of Municipal Affairs and Nova Scotia Environment.

The standard and justifications provided herein are the final product of the working group efforts and represent a collaborative effort of the technical advisors and their research teams.

2 Climate Change Standard Specifications

2.1 General

The 1:20 and 1:100 year flood scenarios, incorporating the expected impacts of climate change on rainfall characteristics and coastal flooding, shall be produced using a calibrated and validated hydrologic-hydraulic model. The specifications for model inputs shall be incorporated according to the following directives.

The justification for directives herein is provided in Section 3.

2.2 Emissions Scenarios

The representative concentration pathway of 8.5 W/m² (RCP8.5) shall be used for all climate change projections used in riverine and coastal flood mapping studies.

2.3 Time Horizon

The future time horizon for mapping riverine and coastal flood boundaries shall extend until 2100.

An interim flood boundary should be produced with a time horizon extending to 2050 for interim municipal planning purposes.

2.4 Intensity-Duration-Frequency Curves

Inputs to the hydrologic model shall include 1:20 and 1:100 rainfall events derived from a future climate IDF relationship. A dual-method approach consisting of estimates from both the statistical IDF_CC tool (Institute for Catastrophic Loss Reduction (ICLR), Western University) and the semi-physical Clausius-Clapeyron scaling method (C-C) shall be used as per the following specifications.

The IDF-CC tool specifications are as follows:

- a) The complete "Bias Corrected Ensemble" shall be used to generate future IDF relationships for the time horizon of 2050-2100.
- b) The outputs shall be used to determine the 95th percentile rainfall totals/intensities for the storm durations of interest.

The C-C scaling method specifications are as follows:

- c) Statistically downscaled and/or dynamically downscaled daily maximum temperature projections shall be used. Either or both datasets should be obtained from the following sources:

- The Environment and Climate Change Canada (ECCC) Climate Data Extraction Tool should be used to obtain an ensemble of statistically downscaled daily maximum temperature projections.
 - Dynamically downscaled daily maximum temperature ensemble projections should be obtained from the Coordinated Regional Climate Downscaling Experiment (Mearns et al., 2017).
- d) The future projection period shall be 2070-2100, and the historical period shall be determined by a qualified professional given the available observational data for the site of closest interest.
- e) The IDF relationship based on observational climate data shall be scaled using the difference in the 95th percentile of average daily maximum temperature between modeled historical and future time periods. Scaling factors shall be used for the C-C scaling calculation, where:
- A scaling factor of 7% per 1-degree Celsius rise in temperature shall be used to scale historical IDF relationships for rainfall durations greater than 6 hours.
 - A scaling factor of 14% per 1-degree Celsius rise in temperature shall be used to scale historical IDF relationships for rainfall durations of less than or equal to 6 hours.
- f) The 1:20 and 1:100 rainfall totals to be used in flood mapping shall be the higher of the rainfall values yielded from both methods (i.e., IDF_CC and C-C).

2.5 Coastal Flood and Downstream Riverine Boundary Conditions

The total sea level to be used in riverine and coastal flood mapping shall be computed as per Equation 1.

$$\text{Total Sea Level (m)} = \left[\begin{array}{l} \text{Higher High Water Large Tide (HHWLT) (m)} \\ + \text{Relative Sea Level Rise (climate change + subsidence) (m)} \\ + \text{storm surge (1:20 and 1:100 year values) (m)} \end{array} \right] \quad \text{Eq.[1]}$$

Where:

- a) The HHWLT grid from the *Hydrographic Vertical Separation Surfaces* (HyVSEPS) from the Canadian Hydrographic Service (CHS) and the Canadian Geodetic Survey (CGS) shall be used to determine the HHWLT.

- b) The 95th percentile of the James et al. (2014) projected global relative sea level rise (RSLR) shall be used, for RCP8.5 and projected to year 2100 for the location nearest to the area of interest. Local effects, such as tidal expansion in the upper Bay of Fundy region, should also be considered.
- c) An additional 65 cm shall be added to the RSLR projection to account for the possibility of the melting of the West Antarctic Ice Sheet.
- d) The 1:20 and 1:100 year historical storm surge shall be included. The methodology used for the estimation of this term shall be determined by a qualified professional given the available historical data or model projections.

3 Justification and Recommendations

3.1 General

This section of the standard provides justification for the specifications as per Section 2. Some recommendations are provided herein to supplement the standard specifications. For further details on each aspect of the standard the reader is encouraged to consult the Appendices which present detailed literature reviews upon which this standard was based.

3.2 Emissions Scenarios

The RCP8.5 scenario represents when radiative forcing reaches 8.5 W/m² at the end of year 2100. This corresponds to a global mean annual surface temperature increase of between 4 and 6°C above pre-industrial levels. This scenario assumes the highest emissions among the standard RCPs. Which represents the business as usual scenario with high energy demand and no mitigation policies.

The RCP8.5 represents the most likely radiative forcing for GCMs given our current emissions trajectory. RCP8.5 is currently representative of the most probable future scenario given the political decisions recently made by countries with the highest emissions levels, and the response of the Earth's system to the expected greenhouse gas concentrations. Further details for this specification are provided in Appendix A.

3.3 Time Horizons

The time horizon with which to extend climate projections was specified as the year 2100. The justification for using the projections up to the year 2100 was that many municipal infrastructure components, or commercial/industrial and residential structures, will likely still be in use in 80 years.

Climate change adaptation from a municipal planning perspective requires both a long-term outlook that anticipates future climate conditions, and a short-term outlook that facilitates the implementation of adaptive strategies. In recognition of the potential value of a short-term planning horizon, an interim time horizon up until the year 2050 should also be produced. This short-term horizon would provide a 30-year planning horizon that may be used by municipal planners to reach incremental planning objectives on short-term time horizons. Further details supporting this specification are provided in Appendix B.

3.4 Intensity-Duration-Frequency Curves

The IDF_CC tool and the C-C scaling method were identified as two practical options for projecting how IDF relationships may change under future climate scenarios. Both methods were viewed as possessing comparable limitations, thus it was recommended that both be applied in parallel. Both methods are driven by GCM projections, and therefore a multi-model ensemble was recommended for application of both methods, as this is a widely recommended practice for utilizing GCM projections (IPCC, 2013).

The 95th percentile of temperature and rainfall projections were recommended for use given the level of uncertainty in the estimates; this approach is also widely recommended for applying the results of multi-model ensembles. The use of the 95th percentile projection represents a conservative approach yet mitigates the risk of selecting an individual outlier from the multi-model ensemble.

A detailed discussion of these methods is provided in Appendix C.

3.4.1 IDF_CC Tool

The IDF_CC tool is an online statistical tool developed by the ICLR at Western University to estimate changing climate impacts on IDF relationships in Canada. The IDF_CC tool is currently being used in engineering applications across Canada for updating IDF relationships.

Advantages of the IDF-CC tool are that sub-daily rainfall projections are achievable, and the software tool is user friendly and accessible. Some disadvantages of the tool include inflexibility in the output format and processing interface. There are also uncertainties with the long-term maintenance of the tool as new GCM projections become available. Utilization of only statistically downscaled GCMs available in IDF-CC was recommended due to the concern with using projections that had not been bias corrected.

3.4.2 Clausius-Clapeyron Method

The Clausius-Clapeyron scaling method represents the moisture-holding capacity of air and its dependence on temperature. Some climate scientists have used this relationship to suggest that extreme precipitation will increase by approximately 7% per degree Celsius in the future

(Trenberth et al., 2003). This scaling method was specified to be used in parallel with the IDF_CC tool due to the supporting body of academic literature concerning the physical principles involved. The method also only requires daily temperature projections, and could be practically applied by professional water resource consultants in the absence of more sophisticated statistical tools, such as IDF-CC.

A 14% per degree Celsius super C-C scaling factor was recommended for rainfall durations less than or equal to 6 hours. This was selected given the considerable uncertainty in predicting the impact of temperature increases on short duration convective storms. A historical and future 30-year period of reference was deemed appropriate for assessing temperature changes, based on justifications found in WMO (2017) for computing climate normals. Also, the results across GCMs are more consistent for temperature than precipitation (Schardong et al., 2018).

The historical period will vary with respect to the observational climate data available at the location of interest (See Appendix C for details). For this reason, it was specified that professional judgement be used on a case-by-case basis for determining the historical period.

3.5 Coastal Flood Mapping

A comprehensive justification for the coastal flood mapping specifications is available in the literature review provided in Appendix D.

3.5.1 HHWLT

The HHWLT is the average of the yearly highest highs of tides predicted over a 19-year astronomical cycle. It is recommended that the HyVSEPS grid surface from the CHS and CGS be used to determine the HHWLT. This model is based on oceanographic models, observed water levels, GPS observations, sea level trends, satellite altimetry and a geoid model, and is a significant advancement in flood modeling from the traditional station based analysis (Robin et al., 2016). The spatial resolution of this information also enables application throughout all regions of Nova Scotia.

Specification of the datum, geoid model and epoch, will need to be consistent with the companion flood mapping standard that the province is currently developing. However, as outlined in Appendix D, this working group recommends that future flood mapping use the CGVD2013 datum and the GRS80 ellipsoid in the NAD83(CSRS)2010 reference frame.

3.5.2 Relative Sea Level Rise

Relative sea level is the difference in elevation between the sea surface and the land (Horton et al., 2018). Uncertainty in the estimates for sea level rise due to climate change supports the adoption of values based on the best available science from many recent studies as reviewed

by Horton et al. (2018). For this component, it was recommended that the James et al. (2014) projections be used to estimate RSLR, based on the comprehensive accounting for vertical crustal motion and incorporation of contributions from Antarctica.

These sea level rise projections have also recently been interpolated into a national RSLR surface raster with a grid resolution of 0.5×0.5 degrees. This new raster product is anticipated to be released publicly in the Spring of 2019. See Appendix D for an example of this data product.

The 95th confidence interval of the RCP8.5 scenario was recommended to address the uncertainty in the projections used to reach the RSLR estimates.

The most important component of sea level rise for Nova Scotia is the accuracy of the vertical land motion component from isostatic rebound. The sea level rise projections presented in James et al. (2014) was adopted in this standard because this resource incorporates the most comprehensive distribution of GPS stations in Canada available from the CGS.

3.5.2.1 Western Antarctic Ice Sheet

Global sea level rise has contributions from a variety of components. These include thermal expansion of the upper layer of the ocean (often termed steric effect), mountain glaciers and ice caps, the Greenland and Antarctic ice sheets and land water storage (Church et al., 2013). An important, but poorly constrained factor in projections of global sea level rise is the stability of the West Antarctic Ice Sheet (W.Ant) (Church et al., 2013). The primary concern is that most of the W.Ant is based below sea level, hence in direct contact with warming oceans. Therefore, it is sensitive to thermal erosion and subsequent destabilization (Daigle, 2016).

The Intergovernmental Panel on Climate Change (IPCC) stated that if the W.Ant were to melt, it would likely lead to a substantial rise in global sea level within this century (IPCC, 2013). There was medium confidence that the additional contribution would not exceed several tenths of a metre in this century.

To address this uncertainty, James et al. (2014) have suggested that an additional scenario be generated in which the RCP8.5/2100 scenario (RCP8.5 + W.Ant) is augmented by 65 cm of sea level rise assumed to be sourced from the West Antarctic ice sheet. Further confidence is placed in this RCP8.5 + W.Ant. estimate as it is consistent with the 95th percentile of most sea level projections ($n = 54$) reviewed by Horton et al. (2018).

3.5.3 Storm Surge

The committee reached a consensus that historical 1:20 and 1:100 year storm surge heights should be added to the HHWLT, and projected relative sea level rise, to obtain total sea level values for riverine and coastal flood mapping. Historical storm surge values were

recommended due to the level of uncertainty in future storm surge projections at this time. The use of the HHWLT value in combination with extreme storm surge values also provides a factor of safety.

The committee did not prescribe a specific approach for storm surge predictions, as the most appropriate method would depend on the availability of data and tools, and should be assessed on a case-by-case basis by a qualified professional.

Some guidance is provided on the estimation of storm surge in Appendix D. There are a few methods that may be used to estimate the storm surge component which include but are not limited to:

- DalCoast Atlantic Canadian storm surge predictions from ECCC (Bernier & Thompson, 2006).
- Use of tide gauge data to estimate potential storm surge levels based on historical storms.

4 Research and Resource Gaps

There are many uncertainties inherent in climate change in relation to riverine and coastal flood mapping. In recognition of this, some strategic areas should be prioritized for future research to reduce these uncertainties. These include:

- i) Validation of the models and techniques specified in the standard with empirical data.
 - This includes additional tide gauges, climate stations and river hydrometric stations.
 - The Bay of Fundy coastal region was identified as a key area where additional empirical measurements are required.
- ii) Coordination with other organizations to identify and access relevant data and tools.
 - Assess what complimentary data collection programs exist which may be relevant for improving climate change projections and coastal water level estimates in Nova Scotia.
 - Coordinate with other organizations (e.g., ECCC, Pacific Climate Impacts Consortium (PCIC), ICLR) that are producing climate projections and tools to ensure that the most up-to-date information is being used for riverine and coastal flood modeling.
- iii) Develop mechanisms to support high-resolution dynamical downscaling to inform flood mapping in Nova Scotia.

5 Review of the Standard

Due to the changing nature of climate change science it is recommended that the standard herein be reviewed one year after the release of the latest IPCC reports (e.g., approximate 5 to 10-year frequency). This will enable the continuation of the incorporation of the best available science into best practices for riverine and coastal flood mapping in Nova Scotia.

The next IPCC report (AR6) is anticipated to be released in 2020. The science recommendations herein are based on research likely to be reviewed and summarized within AR6. It is recommended that the standard be verified against AR6 findings and projections.

It is also recommended that the panel or another appointed expert panel with adequate multi-disciplinary expertise be formed to revise the standard as needed based on the state-of-the-science.

In the case of an extreme storm event—with extensive flood impacts—it is recommended that this appointed expert panel reconvene to review the robustness of the standard herein.

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APPENDIX A –

Global Climate Models &
Downscaling Approaches

APPENDIX B –

Planning Horizons & Considerations

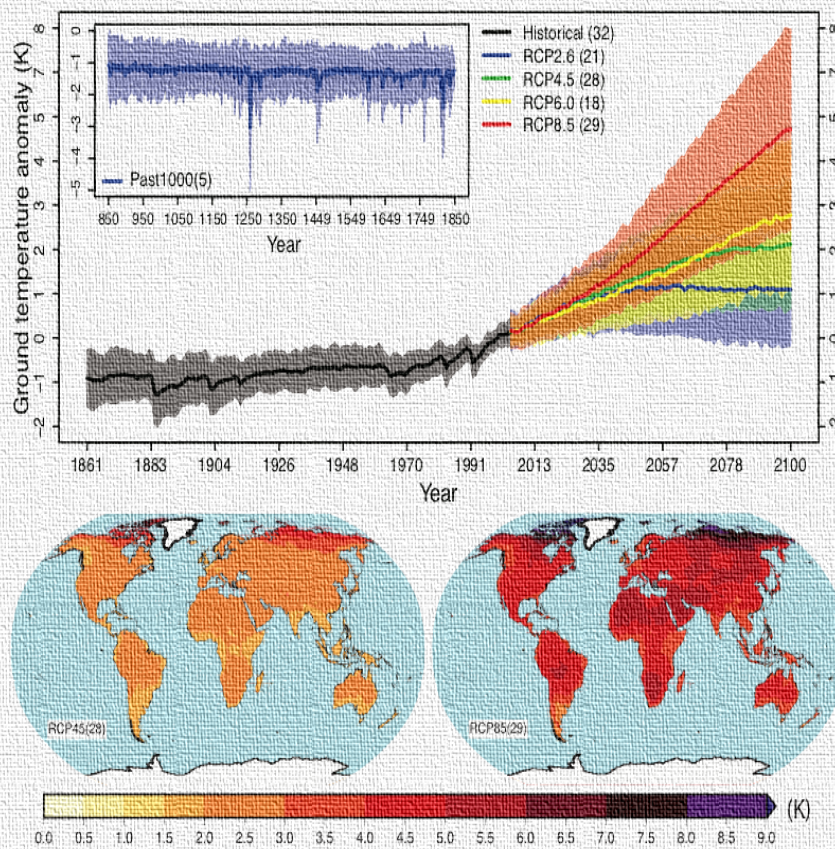
APPENDIX C –

Future Climate Intensity-Duration-Frequency Relationships

APPENDIX D –

Sea Level Rise and Storm Surge
Projections

CLIMATOLOGY GROUP REPORT ON STATE OF THE ART CLIMATE DATA AND SIMULATIONS AVAILABLE FOR FLOODLINE MAPPING IN ATLANTIC CANADA



ALMUDENA GARCÍA-GARCÍA, FRANCISCO JOSÉ CUESTA-VALERO & HUGO BELTRAMI

Climate & Atmospheric Sciences Institute - St Francis Xavier University - Canada

March 15th, 2019

A report of the Climate & Atmospheric Sciences Institute and St. Francis Xavier University

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1 Introduction

The fifth Assessment Report on Climate Change of the Intergovernmental Panel on Climate Change (IPCC) forecasts a change in climate variables such as temperature, precipitation, sea ice extension and volume, and atmospheric circulation patterns during the 21st century (IPCC, 2013b). This change in climatic conditions is not expected to be homogeneous but with marked regional differences. Such regional behavior of climate change requires specific studies at regional and local scales, since key variables relevant to the sustainability of societies, particularly temperature and precipitation, are anticipated to change. Shifts in precipitation patterns may alter the probability distribution of extreme events, causing floods and droughts in zones that have not previously experienced such phenomena. As in the case of precipitation, increases in surface air temperatures will probably multiply the number of temperature extreme events globally.

Meteorological measurements of surface air temperature show an increase of around 1.5 °C over Canada since 1950, with stronger trends at high latitudes and at the western part of the country, and with weaker trends over the maritime provinces (Warren et al., 2014). This warming trend is particularly marked in the Arctic region, displaying a temperature increase twice as large as the global mean (Bekryaev et al., 2010; Collins et al., 2013; Pithan et al., 2014). Daily minimum temperatures present a higher warming trend than daily maximum temperatures and mean temperatures, in agreement with the global trend (Hartmann et al., 2013), while winter temperatures also present higher temperature increases than summer temperatures. Despite this spatial and temporal discrepancies, surface air temperatures over Canada display a general warming for all zones and for all seasons. The general temperature increase over Canada is expected to affect potential evaporation and the capacity of the atmosphere to transport moisture. Projected global precipitation patterns are enhanced at higher latitudes and diminished in tropical areas (IPCC, 2013b), thus changes in precipitation intensity, frequency and duration are expected in Canada. Indeed, meteorological observations show a 16% increase in annual precipitation over Canada since 1950, specially in spring and fall with a decrease in winter precipitation (Warren et al., 2014). Rainfall has increased by 13%, while snowfall has increased by 4%.

Such changes in temperature and precipitation regimes are expected to affect the frequency, intensity and duration of extreme events (Jeong et al., 2016). Meteorological station records indicate less frequent cold events since 1950 in Canada, specially in winter, along with an increase in warm events, specially in summer (Warren et al., 2014). Although changes in precipitation extreme events are harder to characterize, observations tend to reflect a general increase in the number of extreme precipitation events over Canada. Drought episodes are also expected to change along with temperature and precipitation regimes. Canada has not sustained drought episodes during the second part of the 20th century, although there is an increasing risk for southern and western regions of the country, particularly for the prairies (Masud et al., 2017).

In a regional perspective, Atlantic Canada presents the least surface air temperature increase of all Canada, with a change of 0.7 °C since 1950 (Palko et al., 2017; Warren et al., 2014). Additionally, no clear trend is evident in annual precipitation over the region, although both summer and fall show precipitation increases. It is observed, nonetheless, an increase in heavy precipitation events due to storms at certain locations of the region (Palko et al., 2017; Warren et al., 2014), and more intense hurricanes have been occurring since the 1980s (IPCC, 2013b). These observed changes in temperature and precipitation over Canada and particularly over Atlantic Canada indicate that current climate change is affecting Nova Scotia. However, as far as we know there is no comprehensive assessment of future climate conditions and climate change for this province, and therefore studies about the evolution of temperature, precipitation and their associated extreme events are highly desirable in order to develop adaptation and mitigation strategies to protect infrastructures, communities and humans in the province.

Currently, our best tools to obtain information about future climate under different possible scenarios are climate models. Climate models are mathematical tools used to computationally resolve the main equations driving the Earth's climate, for instance the energy, water and momentum conservation. The scientific community has been working on the development of climate models since the last century, providing with a new generation of climate models much more complete and complex than those used in previous decades (Bryan et al., 1975; Manabe et al., 1975). This new generation of global climate models, named GCMs, includes model components to simulate each climate subsystem, atmosphere, ocean, soil and cryosphere in addition to various biogeochemical cycles, such as the carbon cycle, the sulphur cycle, or ozone (Flato et al., 2013).

GCMs have shown useful skills to simulate past, present and future climate at continental scales. However, due to the complexity of the physical processes described within the models, the set of external forcings considered, the need of large ensembles of long simulations and the limited computational resources, the resolution employed can be considerably coarse. The coarse resolution employed within GCMs (around 200 km) often constrains the representation of important features at regional and local scales. The use of finer spatial resolutions to perform climate simulations is expected to enhance regional climate information provided by models, through improvements in the representation of climate and weather phenomena associated with a more detailed description of orography, coastal lines, inland water bodies, islands and cities. This regional and local climate information is needed for climate change assessments and impact studies on agriculture, aquaculture, water resources, pollution, terrestrial ecosystems and other environmental features (Leung et al., 2003).

Regional climate information can be obtained from different sources, for instance from high-resolution Atmospheric General Circulation Models, statistical downscaling techniques and dynamical downscaling techniques (Flato et al., 2013). High-resolution Atmospheric General Circulation Models are used to simulate the global climate with higher resolution than using GCMs, but omit-

ting interactions between the atmosphere and the ocean, and including some uncertainties arising from physical parameterizations used to represent regional processes. Statistical and dynamical downscaling techniques are applied over selected regions of the planet using information from re-analyses or global climate models as boundary conditions (Vaittinada Ayar et al., 2016a). Statistical downscaling techniques derive empirical relationships between large-scale and regional/local variables of interest, that are applied to equivalent variables in global climate simulations. Dynamical downscaling techniques resolve the physical processes at a high horizontal and vertical resolution to scale down the coarse-resolution climate information.

This report summarizes different sources of climate information currently available for developing climate change mitigation and adaptation analyses over Atlantic Canada, particularly addressing flood risks. Hence, we compile a list of the available climate datasets that provide information about changes in rainfall regimes and extreme events over Nova Scotia. This report is organized as follows: Section 2 briefly explains what is a General Circulation Model and the requirements for simulating past, present and future climate conditions, including a description of the freely available GCM simulations covering Nova Scotia and Canada; Section 3 illustrates dynamical downscaling methods and the available databases; Section 4 describes statistical downscaling practices and summarizes the available datasets; Section 5 discusses the possible approaches to obtain projections of regional climate change and the evaluation requirements to reinforce the reliability of the obtained products using observational data; Section 6 summarizes the key points and recommendations of this report.

2 GCMs and Future Scenarios

General Circulation Models are numerical tools attempting to reproduce the state and evolution of the global climate system. These tools represent all relevant Earth's systems, including the atmosphere, the oceans, the continental subsurface, the cryosphere and the biosphere (Flato et al., 2013). Thus, mathematics, physics, chemistry, biology, geology and computational sciences are combined to build a model of the climate system as accurate as possible. That is, GCMs solve differential equations governing the evolution of natural processes, from the Navier-Stokes equations describing the motion of fluids in the atmosphere and the ocean to the chemical reactions of the carbon cycle. Solving those differential equations, nevertheless, is not a trivial task and, for this purpose, the Earth needs to be described as a set of three-dimensional cells, where the set of equations are solved in the center ("node") of these cells. Something similar needs to be done with the time variable. Time is also discretized in GCMs by time steps of approximately twenty minutes to balance the number of iterations and the temporal extent of the simulation.

The discretization of space and time in GCMs imposes limitations to the simulation of certain phenomena, which need to be included in models as parameterizations. That is, processes occurring at smaller spatial and temporal scales than the resolution (cell size) simulated by a certain GCM

cannot be solved by the algorithms constituting the model. Parameterizations, therefore, refer to the approximation of unsolvable processes within climate models assuming the existence of certain relationships between resolved and unresolved processes, which allows to incorporate the effects of the unresolved processes in climate simulations (McFarlane, 2011). Turbulent transfer processes, moist convection and drag processes due to the inhomogeneous orography are some of the most relevant phenomena that need to be parameterized. Such three processes deeply affect the representation of precipitation regimes within GCMs, causing discrepancies between simulations and observations (Flato et al., 2013). Indeed, although GCM simulations are able to reproduce large-scale features of the global precipitation (Flato et al., 2013; Mehran et al., 2014), the same simulations present poor regional results in comparison with observations, overestimating precipitation in mountainous zones and underestimating it in arid zones. Additionally, there is a tendency for the models to precipitate too frequently in light amounts, and too rarely in heavy amounts. The intensity of daily precipitation events is consistently underestimated, with models being able to reproduce the length of dry spells and overestimating the length of wet spells (Sillmann et al., 2013). There is also a marked effect of the employed resolution on the representation of precipitation, since high-resolution models tend to simulate larger total annual precipitation amounts as well as greater daily precipitation intensities than GCMs employing coarser grids. Cumulus convection is of special importance for representing heavy rainfall events. Although deficiencies in the parameterization of convective precipitation lead to discrepancies between simulations and observations (Rosa et al., 2013), other factors related to microphysical processes also need to be improved within GCMs. Furthermore, the simulated hydrological cycle presents severe physical inconsistencies that have been not addressed in the current generation of GCMs (Liepert et al., 2013).

Although GCMs represent the most important natural processes that govern the evolution of climate, there are relevant processes for the evolution of climate that cannot be predicted by models. This is the case of the injection of greenhouse gases and aerosols from volcanic eruptions, which need to be prescribed to the model from observations and estimates of past volcanic events. Other factors that alter the climate state and evolution following no natural laws are anthropogenic activities. Anthropogenic activities have been the main cause of the observed climate change during the last two centuries (Flato et al., 2013), and since they are not natural processes, these activities cannot be directly simulated by GCMs. Therefore, both anthropogenic activities and unpredictable natural phenomena such as volcanic eruptions and variations in the emitted energy by the Sun are prescribed to the models as boundary conditions or radiative forcings. Radiative forcings modify the amount of solar radiation trapped in the Earth's system and generate an energy imbalance that can result in an energy gain by the system, as in the case of increasing the atmospheric concentration of greenhouse gases, or in an energy loss, as in the case of increasing the amount of aerosols in the atmosphere. Correspondingly, models yield better results when simulating recent periods than when simulating periods in the remote past, since there is a larger degree of uncertainty in the estimates of past radiative forcings, among other factors. Radiative forcings are also necessary for simulating future climate, which is of special relevance for developing adaptation and mitigation

strategies at global, regional and local scales. Hence, modelling groups explore hypotheses about how population, technology, energy demand and generation, land use and emissions of greenhouse gasses and aerosols may change over future decades and centuries. That is, scientists develop plausible future socioeconomic scenarios from which to estimate the future radiative forcings, which are then employed to generate future climate projections. The first consistent and broadly adopted collection of future scenarios was prepared for the Special Report on Emission Scenarios (SRES, Nakicenovic et al., 2000) by the IPCC and was later employed to inform the IPCC Third and Fourth Assessment Reports on Climate Change. That is, the SRES scenarios were the boundary conditions of the GCMs participating in the third phase of the CMIP and the resulting simulations were assessed, compared and analyzed to draw conclusions about climate modelling and climate change, which were then summarized and explained by the IPCC assessment report. Two type of scenarios, the A1 and A2, are of special interest. The A1 scenarios consider a world with very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Meanwhile, the A2 scenarios consider a continuously growing global population, but the regional economic development is slower than in the A1 scenario.

Thus, GCMs generate useful and comprehensive information about the possible changes in future climate conditions in both the near-term and long-term. Such information can be used to design adequate adaptation and mitigation strategies. For this purpose, several projects and databases are described below, all of them based on advanced GCMs and historical and future scenarios.

2.1 The CMIP5 Project

The Coupled Model Intercomparison Project (CMIP) is a project established to study and compare climate simulations made with coupled ocean-atmosphere-cryosphere-land GCMs under the auspices of the World Climate Research Programme (WCRP). The project is currently in its fifth phase (CMIP5, Taylor et al., 2011), consisting in a coordinated suite of climate model experiments attempting to analyze and understand major knowledge gaps in past, present and future climate. The methodology is simple: a number of different models from independent modelling groups around the world perform the same experiments -that is, different GCMs are run using the same external forcings, and publicly release their results to assess the generated climate trajectories. This multimodel ensemble approach allows to study the uncertainty in model simulations by employing several structurally different models (Collins et al., 2011; Knutti et al., 2010). That is, the ensemble explores the range of uncertainty due to factors such as the different methods to solve processes or the different processes included in each model. The wide range of structural options for building a GCM should impact the model errors, feedbacks and response to forcings, generating a variety of climate trajectories consistent with the current knowledge about the climate system.

Two periods of time are of special interest for the modelling community and are highly studied in the different CMIP phases, the historical period, usually defined from the Industrial Revolution

(1850) to present, and the 21st century. Historical simulations (Hurtt et al., 2011; Mieville et al., 2010), therefore, attempt to reproduce the observed evolution of climate, and its realism has increased with the different CMIP phases as more numerous and comprehensive estimates of the historical radiative forcings have been produced. In the case of the 21st century projections, the radiative forcings need to be estimated by hypothesizing how factors such as the world population, the energy consumption and the gross primary product of each country will evolve in the future. As the evolution of those factors is impossible to predict accurately, several scenarios need to be developed to account for all plausible trajectories of each relevant factor. Despite the considerable success of the SRES family of scenarios to inform the IPCC Third and Fourth Assessment Reports on Climate Change, the new generation of models requires quite more detailed scenarios. These new scenarios also include the effect of mitigation and adaptation policies on regional and global climate conditions for the first time. This new set of climate scenarios is composed by the four Representative Concentration Pathways (RCPs, Vuuren et al., 2011) that were used to run the GCMs participating in the fifth phase of the CMIP, and the final simulations were employed to inform the IPCC Fifth Assessment Report on Climate Change. The RCPs are considered to be representative of the scientific literature about scenarios, which is the reason for the *representative* word in their names. The *pathway* term reinforces the idea that the trajectory to reach the final atmospheric concentration of greenhouse gases is also important when those scenarios (Moss et al., 2010). Additionally, the RCPs are named in agreement with the radiative forcing level at the year 2100, and they are briefly described below:

- The RCP2.6 scenario reaches 2.6 W/m² at the end of 2100, which approximately corresponds to a global surface temperature increase of between 1.3 and 1.9 °C above preindustrial levels. This scenario considers a strong mitigation in emissions of greenhouse gases, reaching a peak in concentrations by the middle of the century and a concentration decrease from that point.
- The RCP4.5 scenario reaches 4.5 W/m² at the end of 2100, which approximately corresponds to a global surface temperature increase of between 2 and 3 °C above preindustrial levels. This scenario considers a stable concentration of greenhouse gases by the end of the century.
- The RCP6.0 scenario reaches 6.0 W/m² at the end of 2100, which approximately corresponds to a global surface temperature increase of between 2.6 and 3.7 °C above preindustrial levels. The scenario considers a delayed start in reducing emissions of greenhouse gases, starting after 2060.
- The RCP8.5 scenario reaches 8.5 W/m² at the end of 2100, which approximately corresponds to a global surface temperature increase of between 4 and 6 °C above preindustrial levels. This scenario considers the highest emissions, with high energy demand and no mitigation policies.

A major question for adaptation and risk studies is which of the four RCPs will resemble the

future evolution of climate. However, those scenarios do not attempt to predict the future, but to explore the uncertainties regarding anthropogenic practices and policy decisions in the short and long terms (Moss et al., 2010; Vuuren et al., 2011). An option for the selection of a RCP is to discuss which RCP could be closer to observations now that a number of years have passed since the release of the CMIP5 archive. Nevertheless, the four scenarios present similar radiative forcings until 2035 (Moss et al., 2010), which makes impossible to distinguish which RCP is more accurate in comparison with observations. RCP2.6 can be deemed as unlikely, since the world will probably warm beyond the 2°C temperature target set in the Paris Agreement (Larkin et al., 2018), and the RCP2.6 does not surpass such temperature target (Collins et al., 2013). Three RCP scenarios remain as possible future climate realizations, but it is difficult to select one. Fyke et al., 2015 assessed the probable future climate evolution assuming a decrease in the price of non-fossil energy sources with time. They considered all possible policy decisions, estimating the likely CO₂ emissions and their associated temperature changes for the 21st century and beyond, producing a large ensemble of possible scenarios. The median of such myriad of plausible scenarios resembles the trajectory of the RCP6.0, with a significant number of realizations yielding emission trends similar to those of the RCP4.5 scenario. This study does not include the effect of short-live warming agents (Rogelj et al., 2015) nor the effect of the permafrost carbon feedback (MacDougall et al., 2015), which may lead to the conclusion that the most probable scenario would be one between the RCP6.0 and RCP8.5.

2.2 The CMIP6 Project

While writing this report, the sixth phase of the CMIP project (Eyring et al., 2016) is already ongoing, with the first simulations already published at the servers of some modelling groups. CMIP6 activities were motivated by the Grand Science Challenges of the WCRP, which attempt to address specific gaps in knowledge that have hindered progress in understanding key aspects of climate dynamics. As a modelling effort, the contribution of the CMIP6 is focused on studying the response of the Earth's system to forcing, systematic model biases and future projections of climate change given the uncertainties in model simulations (e.g., internal variability or tuning practices, among others). The CMIP6 simulations and scientific achievements are expected to support the IPCC Sixth Assessment Report on Climate Change as well as other national and international climate assessments or special reports.

As in previous versions of the CMIP project, the CMIP6 protocol demands to perform a set of experiments by each modelling group in order to participate in the different endorsed Model Intercomparison Projects (MIPs). These experiments consist in: a long-term preindustrial control simulation (piControl simulation) of at least 500 years to assess the represented internal variability of the Earth's system and the presence of drifts due to an incomplete initialization of the model; an atmosphere-only simulation (AMIP) forced by observations of sea surface temperature and sea ice concentration to evaluate the ability of the atmosphere model components; two idealized experi-

ments with prescribed CO₂ concentrations (abrupt4×CO₂ and 1pctCO₂) to study the represented climate sensitivity and feedbacks by each GCM; and a simulation of the historical period (Historical simulation, 1850-2014) for evaluating the performance of GCMs against observations. Such set of experiments allows to characterize fundamental forcing and feedback responses in models, as well as critical biases, in a simple manner. GCMs successfully performing these five simulations will have a robust base for trusting the results of the rest of experiments.

Beyond the core experiments described above, twenty-one endorsed MIPs explore the scientific questions considered by CMIP6 activities. Certain number of new MIPs have arisen directly from knowledge gaps identified in analyses based on the CMIP5 archive, being the most relevant the Radiative Forcing MIP (RFMIP) to study the different responses to forcing in GCMs, the Flux-Anomaly-Forced MIP (FAFMIP) to better understand ocean heat uptake and sea-level rise, the Volcanic MIP (VolMIP) to characterize the response of the Earth's system to volcanic eruptions, or the Aerosols and Atmospheric Chemistry MIP (AerChemMIP) to quantifying forcings and feedbacks from aerosols. CMIP6 also includes previously successful MIPs, such as the Paleoclimate Modelling Intercomparison Project (PMIP) for simulating climate conditions in relevant periods of the past. Of special importance for adaptation and mitigation studies are the new version of the Coordinated Regional Climate Downscaling Experiment (CORDEX), to produce relevant regional climate information through downscaling techniques, and the High-Resolution MIP (HighResMIP), which is the first coordinated activity on high-resolution modelling. The complete list of endorsed MIPs can be consulted in Eyring et al., 2016 and in the special issue of *Geoscientific Model Development* (https://www.geosci-model-dev.net/special_issue590.html, last access February 2019).

Emission pathways for the CMIP6 future climate projections (Gidden et al., 2018) employ 14 different emission species from 13 emission sectors to update the four RCP scenarios from the CMIP5 project and to fill the gaps that have not previously been studied by the RCPs. The methodology for constructing these future scenarios is the same that was previously employed for generating RCP scenarios, considering a range of possible futures of green or fossil-fueled economic growth as well as high inequality between or within countries. Such framework is called Shared Socioeconomic Pathways (SSPs) and was introduced by Moss et al., 2010.

Four high-priority (tier-1) future scenarios are produced, designed to provide forcing targets similar in both magnitude and distribution to the RCPs. Tier-1 scenarios include the SSP1-2.6, the SSP2-4.5, the SSP3-7.0 and the SSP5-8.5. Each scenario's name is related to the radiative forcing achieved at the end of the century (2.6, 4.5, 7.0 and 8.5 W/m²) and to a specific SSP that represents the characteristic emission pathway followed by the scenario. Five additional future scenarios (tier-2) are provided for studying activities affecting climate evolution separately, namely the SSP1-1.9, the SSP3-Low Near-Term Climate Forcing (NTCF), the SSP4-3.4, the SSP4-6.0 and the SSP5-3.4-Overshoot (OS). All nine scenarios are interesting to explore uncertainties in future emission pathways and land use, and are also required for specific endorsed MIPs, such as those

described above.

The described scenarios, therefore, provide continuity between the CMIP5 and CMIP6 projects (tier-1 scenarios), and expand the range of applications relative to RCPs (tier-2 scenarios). Efforts to reach the temperature targets set by the Paris Agreement can be assessed using the SSP1-1.9 (1.4°C) and SSP1-2.6 (1.7°C) scenarios. The SSP3-LowNTCF and the SSP3-7.0 scenarios allow to evaluate the effect of near-term climate forcings (such as CH₄) on the climate evolution. An important note should be made regarding NTCFs, since these CMIP6 scenarios do not consider greenhouse gas emissions from the permafrost carbon feedback, which was an issue in CMIP5 RCPs. It has been shown that emissions from microbial decomposition of organic matter in previously frozen soils at high latitudes will have a non-negligible effect on future climate evolution (e.g., MacDougall et al., 2012) and on the emission budgets for keeping future temperatures under the terms of the Paris Agreement (MacDougall et al., 2015). That is, only GCMs reproducing the permafrost carbon feedback would be able to simulate the effect of this process on climate, but since the CMIP6 scenarios prescribe the atmospheric concentration of greenhouse gases such effect will not appear in the resulting climate trajectory. Interestingly, SSP3-7.0 is considered as the CMIP6 counterpart of the RCP6.0, but both scenarios present a markedly different radiative forcing at the end of the 21st century. Nonetheless, the SSP4-6.0 reaches the same radiative forcing than the RCP6.0 at the end of the century, but it was designed as a tier-2 scenario. This distinction between the SSP3-7.0 and the SSP4-6.0 has an impact on our final recommendations for the most suitable scenario to assess future flood risks over Nova Scotia (see Section 5). Finally, the SSP5-3.4OS and the SSP5-8.5 present high emissions and no mitigation policies until mid-century, followed by the implementation of substantive mitigation efforts in the case of the SSP5-3.4OS scenario. Thereby, this pair of scenarios allows to evaluate the impacts of delayed climate action on climate evolution.

2.3 AdaptWest: Current and Projected Climate Data for North America

Due to the coarse spatial resolution employed by global climate models, several groups have worked on downscaling simulations from the CMIP5 archive, interpolating the original data into a finer grid. The Conservation Biology Institute has developed the AdaptWest platform to provide with a database from which users may get regional information over North America for climate adaptation planning (Wang et al., 2016). The database includes variables averaged over two historical periods (1961-1990 and 1981-2010) from the Parameter Regression of Independent Slopes Model and WorldClim observational databases, as well as variables averaged over three future periods (2011-2040, 2041-2070 and 2071-2100) from the CMIP5 archive under the RCP4.5 and RCP8.5 emission scenarios. The datasets were generated using the ClimateNA software to interpolate climate simulations into a 1 km grid, taking into account the elevation of the terrain.

The AdaptWest database contains climate information derived from the multi-model mean of 15 CMIP5 models and data from 8 individual GCMs, also included in the CMIP5 archive (see the

AdaptWest website for a list of the models, <https://adaptwest.databasin.org/pages/adaptwest-climatena>, last access November 2018). The database provides with temporal averages of minimum, maximum and mean temperature for a given month (°C), and total precipitation for a given month (mm). There are other many variables in this database related to temperature and precipitation extreme events as well as biologically relevant variables that may be useful for climate change reports. The data is available on the AdaptWest website without registration.

2.4 CCAFS-Climate Data Portal

The collaboration between the International Centre for Tropical Agriculture and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) also provides with a database for high resolution climate information over North America by interpolating future simulations from the CMIP5 archive to a finer grid (Ramirez-Villegas et al., 2010). The interpolation method employed to generate this database is based on the spline spatial interpolation of anomalies of original data into a grid with a resolution of approximately 30 arc-seconds. The dataset includes temporal averages of the anomalies relative to the period 1961-1990 for four future periods (2020-2049, 2040-2069, 2060-2089, and 2070-2099) under the four RCP scenarios (RCP2.6, RCP4.5, RCP6.0, and RCP8.5), with the availability of future simulations depending on the model. Data from 24 different CMIP5 GCMs have been interpolated and included in the database, containing variables of maximum, minimum and mean surface air temperature (°C) and accumulated rainfall (mm/month). This database can be retrieved from the CCAFS-Climate data portal after registration (http://www.ccafs-climate.org/data_spatial_downscaling/, last access December 2018).

3 Dynamical Downscaling

Dynamical downscaling studies employ Regional Climate Models (RCMs) to represent climate variability and climate change over a specific region including the physical description of fundamental climate dynamic processes as in global climate models. The limited spatial extend and the associated reduction in computational cost allow the use of fine spatial and vertical resolutions within models, which improves the representation of complex orography, land uses and land-sea and other surface contrasts (Leung et al., 2003; Rummukainen, 2010). RCMs are used to simulate high-resolution physical processes consistent with a prescribed large-scale climate dynamics from a global climate model, which make them useful tools for future climate change studies at regional and local scales.

RCMs have been developed since the late 1980s, evolving from limited-area mesoscale and weather forecast models as well as from regional configurations of global climate models. These models are applied to limited-area domains requiring information about all meteorological variables over the whole domain for the model initialization and at their lateral boundaries along the simula-

tion. RCMs are the most common tools used for dynamical downscaling studies with a diverse set of applications at different temporal scales from regional processes and sensitivity studies to paleoclimate and future climate simulations (Wang et al., 2004). Due to the extensive use of these models, there is a large amount of boundary data potentially available for downscaling, although the computational space needed to store the output data may present a limitation for small modelling groups. The use of RCMs has grown in the last decades leading to improvements in dynamical downscaling studies, for instance by employing finer horizontal and vertical resolution, by the incorporation of new model components for simulating the ocean, sea-ice and vegetation dynamics-ecosystem biogeochemistry, and by the formation of new coordinate experiments providing long regional climate simulations at high resolution over all land regions of the world (Giorgi et al., 2015; Rummukainen, 2010).

The use of higher spatial resolutions requires high temporal resolution within RCMs, with time steps four times shorter than those employed by GCMs (5 min or less in RCMs in comparison with 20 min or more in GCMs), to maintain numerical stability. The higher temporal and spatial resolutions in Regional Climate Models improve the representation of physical and dynamical processes, including detailed descriptions of important regional atmospheric and surface feedbacks, which are absent in GCMs (Prein et al., 2016). Despite the enhanced representation of certain processes, RCMs are still too coarse to capture subgrid-scale processes, and therefore need to be parameterized. Some of those processes are radiation, convection, cloud microphysics and land-surface processes (Dirmeyer et al., 2012). Specifically, precipitation is simulated in a RCM by combining the large-scale precipitation resulting from the clouds and precipitation that are actually resolved by the model, and the subgrid-scale convective precipitation, which is parameterized at scales larger than 4 km (Prein et al., 2015). Although precipitation is a variable deeply affected by parameterizations and the represented feedbacks in RCMs, this type of models have shown a general improvement in the simulated daily distribution of precipitation and extreme events in comparison with GCMs. Another advantage of RCMs is their ability to reproduce the fine-scale details of the orography, which lead them to produce more reliable precipitation distributions over areas with complex topography (Buonomo et al., 2007). Nevertheless, the use of finer resolutions within Regional Climate Models do not guarantee better performance in simulating precipitation. Such improvement may depend on the physical parameterizations employed, as well as on the region, season, intensity and duration of the considered precipitation event (Knist et al., 2018).

In addition to the uncertainties arising from the use of different parameterizations within RCMs, dynamical downscaling simulations include uncertainties from the GCM simulation employed as boundary conditions and from the chosen emission scenario. Furthermore, Regional Climate Model simulations acknowledge that global conditions drive local and regional conditions, but they neglect the influence of local and regional conditions on global circulation patterns (one-way vs two way nesting) (Maraun et al., 2010). The uncertainties arising from the quality and treatment of boundary conditions may be reduced with the use of anomalies for the impact analyses or by the use of

bias-corrected boundary conditions. Despite the discussed uncertainties, RCMs are able to provide simulations for multiple variables that are physically coherent and consistent with the large-scale patterns from the used boundary conditions.

There are a number of RCM simulations publicly available for the community, but just a small part is suitable for climate studies over Atlantic Canada. Those datasets that provide information about future climate conditions over eastern Canada are briefly described below.

3.1 North America Coordinated Regional Downscaling Experiment (NA-CORDEX)

North America Coordinated Regional Downscaling Experiment (NA-CORDEX) is the North American component of the global coordinated project on regional climate modelling named Coordinated Regional Downscaling Experiment (CORDEX) (Mearns et al., 2017). The CORDEX program was sponsored by the World Climate Research Programme as a tool to answer its Grand Scientific Challenges. The NA-CORDEX database provides with regional climate simulations over North America with spatial resolution of approximately 50 km and 25 km from 1950 to 2100. Although using spatial resolutions of 50 km and 25 km represents a significant improvement in climate simulations comparing with resolutions employed by GCMs (around 200 km), this spatial resolution is still too coarse to simulate explicitly convective processes within RCMs. This is one of the main limitations of using the CORDEX projections for flood planning reports, since the parameterization of convective processes introduces uncertainties in the simulation of extreme events, particularly those related to precipitation.

The NA-CORDEX includes present and future simulations from seven different RCMs using boundary conditions from the ERA-int reanalysis, and from six GCMs, which were included in the CMIP5 project (see the NA-CORDEX website for a list of the RCMs and GCMs employed for the simulations at <https://na-cordex.org/simulation-matrix>, last access November, 2018). The NA-CORDEX database provides with one simulation from a pair of RCM-GCM models under the RCP2.6 emission scenario, seven simulations from six pairs of RCM-GCM models under the RCP4.5 emission scenario and twenty-six simulations from sixteen pairs of RCM-GCM models under the RCP8.5 emission scenario. Note that the number of pair of models and the number of simulations do not fit because the same pair of models can be used with the two different resolutions indicated above.

CORDEX outputs are provided at daily timescale, but the database also includes monthly, seasonal, and annual averages of each variable. Additionally, some of the simulations include outputs of precipitation at sub-daily scales. The CORDEX archive provides variables of daily precipitation ($\text{kg m}^{-2} \text{s}^{-1}$), daily near-surface air temperature (K), daily maximum near-surface air temperature (K), and daily minimum near-surface air temperature (K) among others. These data are freely available at the National Center for Atmospheric Research gateway (<https://www.earthsystemgrid.org/search/cordexsearch.html>, last access November, 2018), in the website of the Cana-

dian government (http://climate-modelling.canada.ca/climatemodeldata/canrcm/CanRCM4/index_cordex.shtml, last access November, 2018) or by contacting the different modelling groups.

3.2 Phase 2 of the CORDEX Program in the Context of the CMIP6 Project

A new phase of the CORDEX program has been developed as part of the diagnostic model intercomparison project in the CMIP6 (Gutowski Jr et al., 2016), to provide regional information and inform the IPCC Sixth Assessment Report on Climate Change. This new phase of the CORDEX project is focused on addressing the challenges and scientific issues identified by the results of its predecessor, providing statistical and dynamical downscaling of the CMIP6 historical simulations and future experiments under new emission scenarios. The second phase of the CORDEX will cover the period 1950-2100, or 1900-2100 if possible, using the CMIP6 model outputs at a 6-hour resolution. The project will contain data for a number of RCMs using boundary conditions from different GCMs, covering all continents with a spatial resolution from 10 to 20 km, increasing the standard resolution employed by the first phase of the CORDEX project. The use of different RCM-GCM pairs will help to determinate uncertainties arising from the use of different models as well as the performance of a number of realizations with the same RCM-GCM pair will help to characterize the effect of internal variability in the downscaled data. Additionally, the new phase of the CORDEX program will provide with a new framework for the simulation of smaller domains at a range of resolutions, that allows the use of convective-permitting models. Thus, the second phase of CORDEX will ideally produce large ensembles of downscaling simulations for the study of specific regional processes, feedbacks and circulations.

3.3 Canada Climate Change Data Portal

The University of Regina provides with regional dynamically-downscaled climate projections over Canada at a resolution of 50 km through the Canada Climate Change Data Portal (CCDP) website (<http://canadaccdp.ca>), last access November 2018). They use 2 different Regional Climate Models (the RegCM and the PRECIS) with boundary conditions from the HadGEM2-ES GCM simulations under the RCP4.5 and RCP8.5 emission scenarios (see Huang et al. 2016; Zhou et al. 2018 for more information about the employed models and simulations). The CCDP program will release new regional simulations using the PRECIS and the WRF RCMs driven by several GCMs simulations shortly. The use of two RCMs with boundary conditions from the same GCM, allows the evaluation of uncertainties arising from the internal differences between RCMs. However, using boundary conditions from a single GCM prevents us from recommending this database for climate change impact studies. Each GCM simulation provides a possible representation of future climate, and the CMIP5 archive provides with outputs from more than 30 GCMs, being all of them in agreement with the scientific knowledge. Thus, using simulations from just one GCM as boundary conditions can be a limiting factor for characterizing uncertainties in the evolution of climate. Another disadvantage of

this database is the employed spatial resolution, which is too coarse to resolve convective processes.

This dataset provides with daily time series and temporal averages for a present period (from 1986 to 2005) and three future periods (from 2020 to 2039, from 2040 to 2069, and from 2070 to 2099). Daily maximum, minimum and mean temperature (°C) as well as daily accumulated precipitation (mm/day) can be retrieved from the CCDP website after registering.

4 Statistical Downscaling

Another method to obtain regional climate information at high spatial resolution from relatively coarse global or regional climate model simulations is statistical downscaling (IPCC, 2007). Statistical downscaling techniques derive statistical relationships between observed large-scale climate conditions (predictors, such as pressure fields) and observed local or regional climate variables (predictands such as surface air temperature or precipitation). Thus, statistical downscaling studies require high-quality surface observations to establish the statistical relationships between large-scale and local-scale climate conditions as well as for the calibration of the statistical model (Lucio-Eceiza et al., 2018a). Establishing robust statistical models requires the meticulous selection of informative predictors that depend on the variable of interest (predictands). For example, various predictors describing the atmospheric circulation can be used to statistically downscale precipitation, such as humidity and temperature, but their efficiency depends on the selected region and season (Gooré Bi et al., 2017; Timbal et al., 2008).

Once the relationships are well defined and the statistical model is calibrated, they are applied to the outputs of future simulations from GCMs, obtaining local/regional climate conditions in the future under different scenarios (Gutiérrez et al., 2013). The selection of predictors is more complicated in a climate change context, since only predictors affected by global warming can be employed in statistical downscaling models, and the selected predictors need also to be reasonably well simulated by the GCM. There are different techniques to perform statistical downscaling analyses, but they are generally divided into three categories: transfer functions (linear and non-linear), clustering (weather typing and analogs) and weather generators (stochastic methods). The statistical downscaled method should be chosen according to the variable of interest, because variables have different characteristics that made suitable different downscaling techniques (Benestad, 2010). Nonetheless, an important limitation of statistical downscaling models is that most of the available techniques assume that the statistical relationships are maintained in time, which may not be realistic in a changing climate (Wilby et al., 2004).

Statistical downscaling techniques are less computationally demanding than RCMs, and are usually easier to apply (Vaittinada Ayar et al., 2016b). However, as in the case of dynamical downscaling studies, statistical downscaling experiments depend on the quality of the boundary conditions from

GCMs and the assumptions of the selected climate scenario. Although statistical downscaling methods have received more attention from statisticians than from the climate community, their use in combination with GCMs and particularly with RCMs may be very useful for downscaling studies at local scales as well as to address the needs of impact model's users.

Several scientific groups in Canada use statistical downscaling models to provide future climate informations under different scenarios. A list of public databases containing regional statistically downscaled data is provided below.

4.1 Pacific Climate Impacts Consortium

The Pacific Climate Impacts Consortium (PCIC) regional climate service centre at the University of Victoria offers a set of statistical downscaled simulations over Canada under three different RCP scenarios (the RCP2.6, the RCP4.5 and the RCP8.5). The database contains daily variables of precipitation (mm/day), and maximum and minimum near-surface air temperatures (°C), at a gridded resolution of approximately 10 km for the simulated period of 1950-2100. Global climate model simulations from the CMIP5 archive are statistically downscaled using two different methods; the Bias Correction Spatial Disaggregation (Wood et al., 2004) and the Bias Correction/Constructed Analogues with Quantile mapping reordering (Gudmundsson et al., 2012) for five different domains across North America. The employed statistical downscaling models were defined and calibrated using the gridded observational database provided by Hopkinson et al. (2011) and McKenney et al. (2011) from 1950 to 2005. This gridded observational database represents an approximation of the historical climate, thus gridded values may differ from the climate stations including some biases at high elevations and in areas with low density of meteorological stations.

The PCIC product contains statistically downscaled data from a realization of 12 different GCMs from the CMIP5 archive. The use of just a realization from each GCM ensemble as well as the use of only 12 models out of more than 30 GCMs available in the CMIP5 project limit the analysis of uncertainties arising from the employed driving conditions. Additionally, it would be highly valuable if PCIC provides statistical downscaled data from the combination of statistical and dynamical downscaling models, for example using the already available regional simulations from the CORDEX program.

The entire dataset can be retrieved at <https://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios> (last access December, 2018). To our knowledge, there is no plan for updating the PCIC database with the simulations that will be released as part of the CMIP6 project or the CORDEX project.

4.2 Environment and Climate Change Canada Downscaled Scenarios

Environment and Climate Change Canada (ECCC) also provides with a statistical downscaled database, using the Bias Correction/Constructed Analogues with Quantile mapping version 2 procedure and global climate model projections from the CMIP5 archive (Cannon et al., 2015). The statistical model is based on the gridded daily datasets of minimum temperature, maximum temperature and precipitation over Canada provided by McKenney et al. (2011), also employed by the PCIC downscaled database. Once the statistical model was built, it was calibrated using the period 1950-2010 as reference, applying the calibration techniques to each variable separately.

The ECCC dataset consists of downscaled output data from an ensemble of 24 individual GCM simulations, as well as the corresponding multimodel median, of the Historical experiment and three future scenarios (the RCP2.6, the RCP4.5, and the RCP8.5). However, this dataset does not include downscaled data from any regional climate model, and only one realization of each GCM was employed for the statistical downscaling database to give equal model weighting, which may limit the assessment of uncertainties arising from the internal variability of the models. Thus, the database provides downscaled data at daily, monthly, annual and multiyear scales of maximum and minimum temperature (°C) and total precipitation (mm/day) covering from 1950 to 2100 at a gridded resolution of approximately 10 km. The statistical downscaled original data and anomalies relative to the period 1986-2005 for the individual models can be retrieved at <http://climate-scenarios.canada.ca/?page=bccaqv2-data> (last access November, 2018), while similar data for the multimodel ensemble percentiles can be retrieved at <https://climate-change.canada.ca/climate-data/#/downscaled-data> (last access November, 2018).

5 Discussion

In this report, we have summarized the available sources of climate data over Canada, particularly mentioning the regional databases from dynamical and statistical downscaling projects, which are the most adequate for impact studies focused on Atlantic Canada. However, an important limitation is present in these databases. All the GCMs whose data are employed for dynamical and statistical downscaling, as well as all the RCMs included in this report, do not resolve convective processes in their simulations. The resolution of convective processes is crucial for the representation of precipitation evolution and extreme precipitation events, which are essential for climate change impact studies focused on flood risks at the local scale. Convective processes can be resolved only at spatial resolutions finer than 4 km, which prevents GCMs from solving convection, and thus such models need to approximate its effect on climate evolution. That is, only RCMs are able to dynamically solve the physics of convective processes. A popular convective-permitting RCM among research groups is the Weather Research and Forecasting (WRF) model. As an example, Knist et al., 2018 have shown the improvement of the simulated diurnal cycle and the hourly intensity

distribution of precipitation using the WRF model in a convective-permitting simulation over Europe. This convective-permitting simulation also yields a more realistic representation of the observed increase in the temperature-extreme precipitation ratio from the Clausius-Clapeyron scaling, in comparison with a coarser simulation using parameterized convection.

There are some studies evaluating results from convective-permitting models in North America, particularly focused on the US (Liu et al., 2017; Romine et al., 2013), however none of these studies analyze the convective-permitting simulations over Atlantic Canada or Nova Scotia. Therefore, it would be highly desirable to perform a dynamical downscaling experiment over Atlantic Canada employing a convective-permitting RCM (< 4 km resolution) and the most adequate driving conditions and parameterizations. Additionally, the design and development of a downscaling experiment using a dynamical model or the combination of both, dynamical and statistical downscaling techniques, allow the selection of the most suitable spatial and temporal resolution for your region of interest, as for Nova Scotia. In the case of a dynamical downscaling study, choosing the RCM and boundary conditions that the literature recommends for the region of interest can reduce the biases and increase the reliability of the final product. However, there are not many climate studies focused on Nova Scotia and several tests are required before performing a RCM simulation to ensure that the generated climate information will improve the original, coarser boundary conditions. All the required tests previous to run a simulation, the computational cost of running a long simulation with a fine resolution, and the cost of performing an ensemble of simulations using different downscaling models driven by several GCM simulations needed to evaluate the uncertainties arising from the structurally different RCMs and from the boundary conditions, may make the design and performance of a downscaling study resource intensive.

As we have noted above, there are different approaches to obtain local climate information using statistical and dynamical downscaling techniques (summarized in Figure 1). These techniques have several variants that can alter the final downscaled product. Thus, downscaling experiments may add value to the boundary conditions from reanalyses and from global climate models, depending on the experiment design. For this reason, the evaluation of downscaled data against observations of the variables to be used, over the selected region and at the desired temporal scales, is crucial for developing climate change mitigation and adaptations measures, applying bias-correction techniques if necessary and determining the uncertainties from the employed simulations.

The lack of observations in the region of interest and the potential instrumental and methodological errors in the observational data may also bias the evaluation of the downscaling experiment (Bernhardt et al., 2018; Brohan et al., 2006; Lucio-Eceiza et al., 2018b,c; Tapiador et al., 2017). For this reason, it is important to evaluate the downscaling technique using different observational databases, and comparing with the driving boundary conditions from both reanalyses and global climate models. Thereby, the downscaling products can be evaluated in the present (observations) and in the future (boundary conditions). For the evaluation of downscaling experiments in Canada,

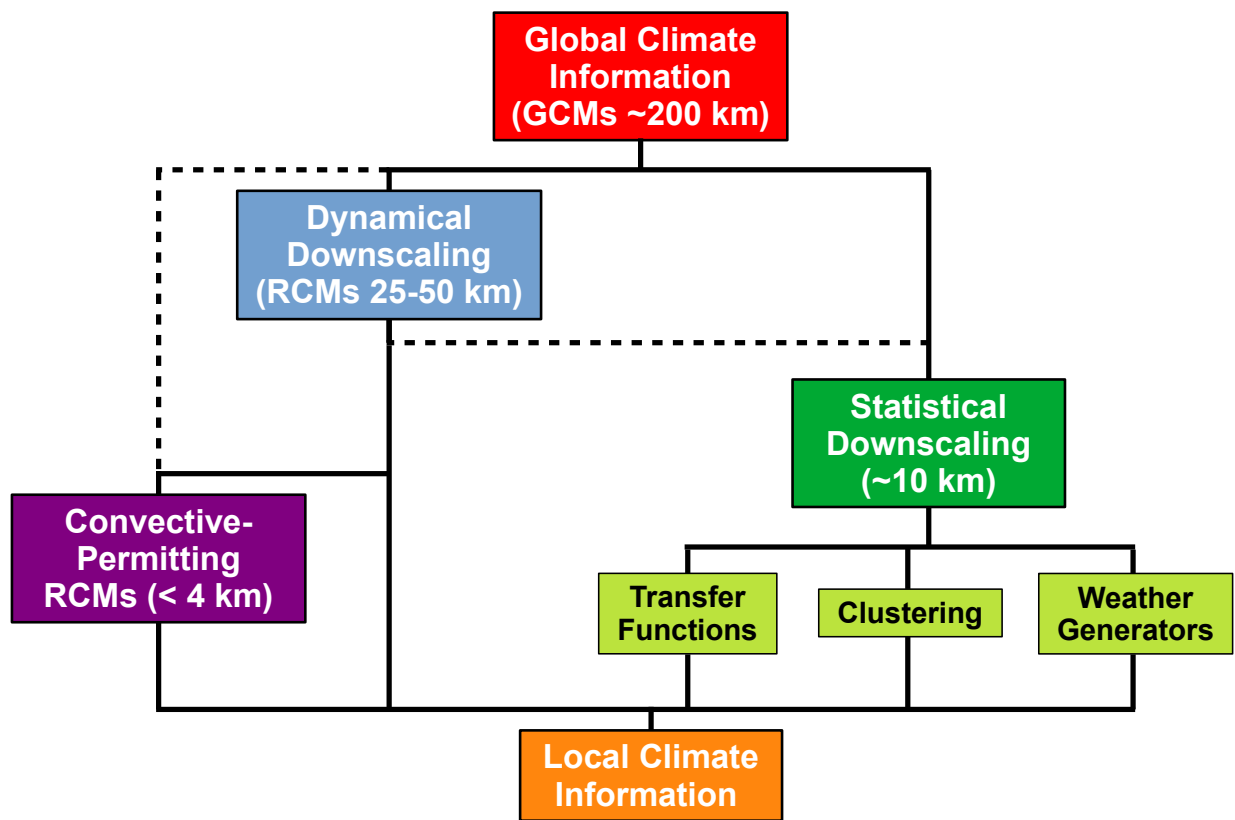


Figure 1: Summary of the possible downscaling approaches to obtain local climate information from GCM global climate information.

there are different datasets that can be used depending on the region, the time scales and the variables of interest:

- **Daymet: Daily Surface Weather and Climatological Summaries.** Among the NASA projects dedicated to observe the Earth system, the Oak Ridge National Laboratory Distributed Active Archive Center provides with a database of daily surface observations on a 1 km grid for North America (Thornton et al., 2012). This database was published in 2018 and is available at https://daac.ornl.gov/DAYMET/guides/Daymet_mosaics.html#Daymet_m_citation (last access December, 2018). The Daymet product is derived from observations at meteorological stations using different interpolation and extrapolation algorithms, covering from 1980 to 2015. This dataset includes observations of the maximum and minimum 2-meter air temperature (°C), and total precipitation (mm/day) among other variables. The Daymet product is available after registration on the previously indicated website.
- **ECCC: Adjusted and Homogenized Canadian Climate Data.** ECCC provides with several observational databases useful for the evaluation of regional climate studies over the Canadian domain. Among these databases, we find the Adjusted and Homogenized Canadian Climate Data, which includes climate station datasets with adjustments derived from statistical procedures (Mekis et al., 2011). Observational data are provided for minimum, maximum and mean temperature (°C), and total precipitation (mm) among other variables at 41 locations over Nova Scotia and 1057 over Canada (mostly southern Canada). The dataset provides seasonal averages, monthly averages, annual averages and trends of the desired period within the 1840-2017 period. The data is available without registration and can be retrieved at <https://climate-change.canada.ca/climate-data/#/adjusted-station-data> (last access December, 2018).
- **ECCC: Daily Climate Observations.** Environment and Climate Change Canada also provides with a daily database from meteorological stations at 8 locations in Nova Scotia and 325 over Canada (mostly southern Canada). This dataset includes one or two observations per day of temperature (°C), precipitation (mm) and series of hourly observations at some stations that typically produce more weather variables, such as humidity, snow rain etc.. The observational period of this dataset covers from 1969 to 2018, being available without previous registration in the ECCC website <https://climate-change.canada.ca/climate-data/#/daily-climate-data> (last access November 2018).
- **ECCC: Climate Normals.** For bias correction and evaluation purposes, observational climatologies and normals can be useful. Environment and Climate Change Canada provides with a database containing climate normals and averages per decade at 4 locations in Nova Scotia and for 214 stations over Canada (mostly southern Canada). This database includes climate normals, averages and extremes from 1981 to 2010 based on Canadian climate stations with at least 15 years of data in the period. Information about the number of observations is included

in the database, as well as, the climate information of temperature (°C) and precipitation (mm) among other variables. The data can be retrieved at <https://climate-change.canada.ca/climate-data/#/climate-normals> (last access December, 2018) without registration.

- **ECCC: Regional Deterministic Precipitation Analysis.** A recent database containing estimates of the total precipitation from in situ precipitation gauge measurements, weather radar and numerical weather prediction models can be retrieved from Environment and Climate Change Canada servers at <https://climate-change.canada.ca/climate-data/#/regional-deterministic-precipitation-analysis> (last access December, 2018) without previous registration. The precipitation results are estimated at 6 h intervals or daily over North America covering from 2012 to today. There are two different spatial resolutions, 10 km and 15 km, using three different projections, World Geodetic System 1984, Canada Atlas Lambert and Pseudo-Mercator.
- **ECCC: Gridded Historical Climate Data.** Another gridded database is available among the Environment and Climate Change Canada data, the Canadian Gridded Data. This dataset contains historical temperature and precipitation anomalies interpolated from adjusted and homogenized observations using a spatial resolution of 50 km across Canada. The database contains mean, minimum and maximum temperature (°C) and total precipitation (%) anomalies relative to a mean reference period (1961-1990) covering from 1948 to 2017, including monthly averages, seasonal averages and annual averages. More information about this database can be found at http://data.ec.gc.ca/data/climate/scientificknowledge/canadian-gridded-temperature-and-precipitation-anomalies-cangrd/Canadian_Gridded_Data_-_READ_ME_Technical_doc_EN.pdf (last access December, 2018) and the data can be retrieved at <https://climate-change.canada.ca/climate-data/#/regional-deterministic-precipitation-analysis> (last access December, 2018).
- **The CRU Dataset.** One of the observational databases most commonly employed across the world, is the Climatic Research Unit (CRU) dataset (Harris et al., 2014). The CRU database is continuously updated, improved and maintained, providing with several gridded weather variables covering global land areas, excluding Antarctica, at different spatial resolutions and for different periods. For example, the CRU CL v. 2.0 dataset provides a monthly database at 10 minute resolution from 1961 to 1990, including variables such as precipitation (mm/month), wet-day frequency (days), temperature (°C), diurnal temperature range (°C), relative humidity (%), sunshine duration (%), ground frost frequency (days) and windspeed (m/s). The CRU TS database offers monthly time series from 1901 to 2017 over all land area at 0.5° resolution, containing different variables (mean temperature, diurnal temperature range, precipitation, wet-day frequency, vapour pressure and cloud cover). All the CRU databases can be freely retrieved from the CRU website <https://crudata.uea.ac.uk/cru/data/hrg/> (last access December 2018).

Once the dynamical and/or statistical downscaling models are evaluated and calibrated over the region of interest in the present against observations and their driving simulations, the downscaling models can be used to perform future climate simulations under different emission scenarios. Driving conditions from GCMs represent different climate trajectories, since each GCM uses different algorithms and relies on slightly different assumptions. That is, GCMs generate a range of possible climate projections that are in agreement with the scientific knowledge of the Earth's system. Thus, it is important to use as many GCMs as possible as driving conditions in downscaling experiments to account for the uncertainties arising from the structural differences between General Circulation Models. The median, the 5th and the 95th percentiles of a large ensemble of simulations from different GCMs allow the characterization of possible future scenarios considering their intrinsic uncertainties. However, a number of GCMs share an undisclosed amount of code, which potentially biases the behavior of the multimodel ensemble. Although this limitation of the ensemble approach should be considered in regional downscaling studies, there is not standard methodology for addressing these biases. Another important factor to take into account in downscaling studies is the internal variability of climate models due to the stochastic character of the Earth's climate. The best approach to evaluate the uncertainties arising from the internal variability of GCMs and RCMs is to perform several realizations exclusively modifying the initial conditions of each model.

Another relevant factor that should be considered when selecting a database for climate risk assessments is the sustainability of the project. All the databases compiled in this report are provided by institutions located outside Atlantic Canada, which means that updates on the datasets as well as their dates of release would be imposed by these institutions and their funding, and may not correspond with the interests of the Atlantic provinces. The development of a climate services center in Atlantic Canada would fill the gap of climate knowledge in these provinces, providing continuity and quality to the regional climate data available over Nova Scotia to address requirements from users of impact models.

Regional climate data provided by downscaling experiments can be directly analyzed and employed for flood planning reports. The temporal resolution of the output data from a dynamical downscaling can be set to the users necessities, in contrast to climate databases provided by external institutions which typically contain outputs at daily scales, with very few outputs at sub-daily resolutions. This temporal resolution is not adequate for developing climate change impact studies. Thus, these climate databases are generally used to feed independent statistical tools and algorithms, which are able to generate useful information for flood risk reports. Two of the most commonly employed techniques among flood management reports are the rainfall Intensity-Duration-Frequency (IDF) curves and the Clausius-Clapeyron scaling.

The rainfall IDF curves relate the intensity of extreme precipitation events with their duration and frequency of occurrence, based on relationships retrieved from observational data. Thus, IDF curves that relied on observational data assume that the relationships between the intensity, duration

and frequency of extreme precipitation events remain stable in time, which may be unreal under a climate change scenario (Sugahara et al., 2009). In this context, the Western University has developed a web based tool to estimate Intensity-Duration-Frequency (IDF) curves under changing climatic conditions using precipitation gauge observations at 700 meteorological stations in Canada, reanalysis products, future climate simulations from 24 state-of-the-art GCMs from the CMIP5 archive, and 9 statistically downscaled simulations from the PCIC archive (see Section 4.1). Using all these databases, the IDF tool provides with IDF data at a gridded resolution of approximately 10 km from 1950 to 2100 under various RCPs (see <https://www.idf-cc-uwo.ca/Manuals> for more information about the employed data and methods, last access December, 2018). The use of the IDF tool and the available IDF data can be retrieved after registration at <https://www.idf-cc-uwo.ca/home> (last access December, 2018).

The Clausius-Clapeyron scaling has been also used for developing strategies of flood risk management. This technique is based on the relationship between the atmospheric temperature and the water-holding capacity of the atmosphere, which determines that for an increase of 1 °C in the atmospheric temperature, the moisture-holding capacity of the atmosphere increases by 7%. This ratio is then applied to heavy precipitation events assuming that the Clausius-Clapeyron scaling is valid for extreme events in the present and in the future. Nevertheless, some studies have shown limitations in the application of this scaling ratio at local scales (Wasko et al., 2016) and at certain atmospheric temperatures (Singleton et al., 2013; Wasko et al., 2017).

The use of the previously described statistical methods for the analysis of precipitation extreme events requires regional climate data from downscaling experiments. The use of those statistical algorithms adds uncertainties to the climate information retrieved from downscaling experiments, due to their internal assumptions. For this reason, it is recommendable to use the original outputs of downscaling experiments for climate change impact reports if the frequency of the data outputs is adequate. At this stage, the development of a climate services center may also help providing output data from downscaling experiments at the desired temporal scales.

6 Conclusions

Flood risk assessments over Nova Scotia require regional climate information retrieved from dynamical or statistical downscaling experiments or the combination of both tools. However, all downscaling studies require global climate information in the present and in the future under emission scenarios, which can only be provided by General Circulation Model simulations. The current generation of GCM simulations included in the CMIP5 archive, that was employed to inform the last IPCC Assessment Report on Climate Change, provides valuable information for all types of downscaling studies. At this stage, we recommend considering the maximum number of GCM simulations performed under the RCP6.0 and under the RCP8.5 emission scenarios, since the retirement of the US from

the Paris Agreement will likely lead to more severe changes in the Earth's system during the 21st century. Nevertheless, the continuity of the RCP6.0 is not directly guaranteed by the CMIP6 project, which makes the RCP8.5 most sustainable scenario in the long-term. Additionally, a higher number of RCP8.5 simulations are available (IPCC, 2013a), deeming this scenario as the most suitable for ensemble approaches. Therefore, we conclude that the RCP8.5 is the most recommendable scenario for performing an assessment of future flood risks in Nova Scotia.

The best approach to select a database for developing climate change studies based on currently available data in Nova Scotia would be to assess the performance of the datasets proposed in this report against observational products as those discussed in Section 5. The products from downscaling experiments with the best performance in the region are then selected for flood risk studies. The PCIC and the ECCC statistically downscaling products appear to be the best candidates to develop a flood line mapping in the province of Nova Scotia, although a comprehensive evaluation is required before employing the data, taking into account their associated limitations (Sections 4.1 and 4.2). These two databases provide daily outputs at a resolution of 10 km, making them the databases with the finest spatial resolution included in this report. Nevertheless, it is also highly desirable to use data from dynamical downscaling experiments, since none of the techniques have been proven to perform better than the other one over Nova Scotia. The most suitable dynamical downscaling product is the NA-CORDEX archive (Section 3.1). The NA-CORDEX ensemble at 25 km resolution contains at least 16 simulations under the RCP8.5, using different RCMs and GCMs. The combination of this product and the two previously indicated statistical downscaling products is recommendable for developing climate studies. These three databases can then be employed to develop studies on the management of flood risks in Nova Scotia using the bias corrected outputs to directly analyze changes in the intensity, frequency and duration of extreme events or to feed the desired algorithms or statistical techniques, such as the IDF curves or the Clausius-Clapeyron scaling.

For the near future, the most promising and sustainable approach would be to use a large ensemble of global climate simulations as driving conditions for regional downscaling experiments. Among the available downscaling techniques, convective-permitting Regional Climate Models are the most appropriate tools to generate reliable climate change information for impact studies focused on flood risks. However, there is no database for Nova Scotia fulfilling the requirements discussed in this report. The establishment of a Climate Services Center dedicated to Atlantic Canada, like the one emerging at St. Francis Xavier University, would be the optimal approach to address the needs of climate change researches, as well as to ensure the sustainability and quality of future regional risk assessments.

Acronyms

CCDP Canada Climate Change Data Portal

CMIP Coupled Model Intercomparison Project

CORDEX Coordinated Regional Downscaling Experiment

CRU Climatic Research Unit

ECCC Environment and Climate Change Canada

GCM General Circulation Model

IDF Intensity-Duration-Frequency

IPCC Intergovernmental Panel on Climate Change

MIP Model Intercomparison Project

NA-CORDEX North America Coordinated Regional Downscaling Experiment

NTCF Near-Term Climate Forcing

OS Overshoot

PCIC Pacific Climate Impacts Consortium

RCM Regional Climate Model

RCP Representative Concentration Pathway

SRES Special Report on Emission Scenarios

SSP Shared Socioeconomic Pathway

WCRP World Climate Research Programme

WRF Weather Research and Forecasting

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School of Planning, Dalhousie University
Faculty of Architecture and Planning
5410 Spring Garden Road
Halifax NS

Municipal Flood Line Mapping: Planning Horizons and Considerations

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Kate Clark, MPlan, Research Analyst
kate.clark@dal.ca

Claire Tusz, Research Assistant
claire.tusz@dal.ca

Patricia Manuel, Professor
patricia.manuel@dal.ca
(902) 494-6597

Eric Rapaport, Associate Professor
eric.rapaport@dal.ca
(902) 494-7801

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Municipal Flood Line Mapping: Planning Horizons and Considerations

School of Planning, Faculty of Architecture and Planning, Dalhousie University

Executive Summary

This report summarizes planning horizons and considerations relevant to climate change scenario building for municipal flood line mapping in Nova Scotia.

Flood line mapping is a valuable tool for guiding planning policy decisions for development, environmental protection, provisions for public health and wellbeing, and many other planning aims. Across Canada, municipalities are in need of up-to-date flood maps that address and predict the impacts of climate change on flood events into the future. Through this report, our team was asked to inform the selection of an appropriate planning horizon for municipal flood line mapping projections in Nova Scotia and offer planning considerations for flood mapping policy and scenario building, as found in planning literature and practice across Canada.

Our research looked at both short-term and long-term planning horizons used or recommended for different areas of planning where flood mapping is commonly employed or considered. These areas of planning are land use, population growth, conservation and climate adaptation, economic development, infrastructure resiliency, and vulnerable population planning. By summarizing horizons found through planning literature, federal guidelines, and a selection of roughly 130 plans from flood-sensitive Canadian communities, this report finds that planners in Canada are applying long-term visions (10-50 years) for land use, population forecasting, conservation, and infrastructure planning that typically look 30 years or more into the future, while also using incremental, short-term horizons (1-10 years) to review and update data and planning strategies.

Planning Areas	Short-term	Long-term
Land Use Planning	1-10 years	10-50 years
Population Forecasting	10 years	30 years
Vulnerable Populations	5 years	-----
Conservation/Climate Adaptation	2-10 years	30+ years
Infrastructure Resiliency	5 years	30-35 years
Economic Planning	1-2 years	3+ years

Planning considerations for climate change flood line mapping were collected by looking at the uncertainty of planning using projections, the reception of projections, and policy approaches to planning for flood impacts. For Nova Scotia, these considerations will influence the adoption of the selected climate change scenario by municipalities. Considerations discussed herein include whether to use a single climate scenario or multiple scenarios when predicting climate change impacts, whether a hazard-based or risk-based policy framework is most appropriate for flood policy, how to be more transparent about assumptions, process and sources for flood mapping, and how best to balance using expert-driven versus participatory approaches to scenario building for climate change. Little consistency was found between municipalities in Canada on the above considerations. Sample flood mapping studies were selected to elaborate on existing approaches from the communities of Waterford River Area, NFLD; the City of Surrey, BC; the City of Edmonton, AB; and, the Halifax Harbour of Halifax Regional Municipality, NS.

This report finds that a minimum time horizon appropriate for climate change flood line mapping to inform planning is 30 to 35 years, with 5-year updates of flood modelling.

When developing a climate change scenario and framework for flood mapping, the Province of Nova Scotia should consider:

- encouraging municipalities to incorporate participatory planning when building on or updating the selected provincial climate change scenario;
- whether producing multiple climate change scenarios might aid interested municipalities with planning policy that addresses a greater range of potential outcomes beyond the minimum recommended scenario;
- how to be explicit about the data sources, variables, and projection strategies used so that they are available to those assessing the provided scenarios; and,
- defining and encouraging municipalities to adopt a risk framework for flood mapping that is consistent with the Federal Flood and Mapping Framework, where municipalities may wish to exceed the minimum standards provided by the Province to assist with the development of responsive planning strategies that address both the probability of flood hazard and the social, economic, and environmental impacts of flood events.

More work can be done to determine the best course of action for Nova Scotia regarding the planning considerations discussed in this report. A greater understanding of flood mapping decisions and processes in Canada may be achieved from engaging with municipalities and speaking with planning professionals. Doing so may help us to better understand what similar conversations are being had about flood hazard and climate change across Canada and how decisions for scenario building and planning response are being approached by governments and decision-makers.

Final Report

Purpose

This report summarizes planning considerations relevant to climate change scenario building for municipal flood line mapping in Nova Scotia, as collected through academic articles, existing plans, and reports of Canadian communities.

The goal of this report is to inform the selection of appropriate planning horizons for municipal flood line mapping projections in Nova Scotia and offer sample approaches to flood mapping policy and process based on considerations found in literature and in practice.

In partnership with the province, this report contributes to Nova Scotia's Municipal Flood Line Mapping Project begun in August 2018. Herein we contribute justification for planning horizons and strategies to help "develop a recommended climate change scenario to be used in developing Municipal Flood Line Mapping (MFLM) conducted in Nova Scotia".



Summary of Recommendations

This report finds that a minimum time horizon appropriate for climate change flood line mapping to inform planning is 30 to 35 years, with 5-year updates of flood modelling.

When developing a climate change scenario and framework for flood line mapping, the Province of Nova Scotia should consider:

- encouraging municipalities to incorporate participatory planning when building on or updating the selected provincial climate change scenario;
- whether producing multiple climate change scenarios might aid interested municipalities with planning policy that addresses a greater range of potential outcomes beyond the minimum recommended scenario;
- how to be explicit about the data sources, variables, and projection strategies used so that they are available to those assessing the provided scenarios. Doing so can assist with maintaining consistent projection techniques, which can also make updates and alterations more easily comparable;
- defining and encouraging municipalities to adopt a risk framework for flood mapping that is consistent with the Federal Flood and Mapping Framework, where municipalities may wish to exceed the minimum standards provided by the Province to assist with the development of responsive planning strategies that address both the probability of flood hazard and the social, economic, and environmental impacts of flood events.



1.0 Introduction

Flood mapping is a valuable tool for guiding planning policy decisions for development, environmental protection, infrastructure adaptation, provisions for public health and wellbeing, as well as a number of other planning aims. This year, the Government of Canada released several documents as part of its Federal Flood Mapping Guidelines Series, including a *Federal Flood Mapping Framework* (Version 2.0, 2018) and *Case Studies on Climate Change in Floodplain Mapping* (Volume 1.0, 2018). Preparation of additional documents are underway in this series to assist provincial, municipal, and related authorities with the development and implementation of flood mapping strategies. These materials respond to a recognized need for further guidance and consistent practices for flood mapping in Canadian communities.

Nova Scotia's Second Statement of Provincial Interest on Flood Risk Areas, set out in Schedule B of the Municipal Government Act (1999), addresses five floodplains identified through the Canada-Nova Scotia Flood Damage Reduction Program (FDRP), undertaken in the 1980s. In addition to detailing regulation for these FDRP areas, this Statement also acknowledges a need for further identification of floodplains in Nova Scotia and encourages municipalities to investigate flood areas and flood events for their communities. This policy makes municipalities responsible for identifying locally known floodplains, which in this case refer only to those recognized using historical information, not modelled projections. Establishing a recommended climate change scenario for municipal flood line mapping will remove barriers for Nova Scotian communities by identifying the possible extent of flooding within their jurisdiction and guiding appropriate planning action to mitigate flood impacts.

With the help of a technical committee from Nova Scotian universities, industry, and government, the Province of Nova Scotia will develop a recommended climate change scenario for municipal flood line mapping conducted in Nova Scotia. In order to inform the selection of an appropriate horizon for the minimum climate change scenario, researchers from Dalhousie University's School of Planning investigated time horizons for forecasting and visioning in planning, and the utility of municipal flood mapping in planning, to offer insight into appropriate planning horizons and considerations when selecting a climate change scenario.



The following questions guided this research:

- What time horizons are used for planning?
- Why are these time horizons used?
- What are the planning considerations when using flood scenarios?
- How has climate change flood mapping been approached in Canada?

Our research found that flood mapping is used to assist policy and decision-making for many areas of planning. The time horizons used for flood mapping are largely influenced by its intended utility. In this report, time horizons are defined as the maximum period of time for which the goals and policies of a plan or strategy are intended to apply. Herein we discuss horizons used to plan for land use, population growth, conservation and climate adaptation, economic development, infrastructure resiliency, and vulnerable population planning, so that they may be taken into consideration when developing a climate change scenario for mapping. This report finds that a minimum time horizon appropriate for climate change flood line mapping to inform planning is 30 to 35 years, with 5-year updates of flood modelling. We also provide four recommendations for the scenario building process that may help guide decisions regarding the use of short-term versus long-term horizons, regional and stakeholder input, and addressing uncertainty. Four municipal flood mapping projects from communities across Canada have also been selected to illustrate planning approaches to climate change scenario building in Canadian municipalities. These are:

Waterford River Area, Newfoundland and Labrador;
The Town of Surrey, British Columbia;
EPCOR, City of Edmonton, Alberta; and,
Halifax Harbour, Halifax Regional Municipality, Nova Scotia.

An annotated bibliography of selected academic sources and planning reports concludes this document, offering further insight into the existing state of knowledge on scenario building and flood mapping for planning, as well as resources for the justification of scenario building approaches.

2.0 A Discussion of Planning Horizons

Planning responds to both short-term and long-term goals for community growth and development by looking at normative, predictive, and aspirational visions of the future. Some areas of planning use forecasting to predict future conditions, such as population growth or economic conditions, while others work towards visions of what a community wishes to look like in the future, using zoning and other policy to enable desired development or environmental protection outcomes.


The following planning areas and interests, including land use, population growth, vulnerable populations, conservation and climate adaptation, infrastructure resiliency, and economic development, use unique timescales that are considered the most reasonable for developing corresponding policy, or to maintain the most relevant information based on available data. Explanations are provided to briefly illustrate the complex nature of these planning timescales so that they may be considered when selecting horizons to frame municipal flood line mapping in Nova Scotia to incorporate climate change.

Table I: Summary of planning horizons

Planning Areas	Short-term	Long-term
Land Use Planning	1-10 years	10-50 years
Population Forecasting	10 years	30 years
Vulnerable Populations	5 years	-----
Conservation/Climate Adaptation	2-10 years	30+ years
Infrastructure Resiliency	5 years	30-35 years
Economic Planning	1-2 years	3+ years

2.1 Land Use

Policy for the development of land and land use is articulated through Municipal Planning Strategies (MPS), Official Plans, and other equivalent comprehensive municipal plans across Canadian provinces. A 20-year time period is a common horizon for land use planning in Canada (Seasons, 1991). Ontario, for instance, provincially legislates that Official Plans can plan for no less than 20 years into the future (Provincial Policy Statement, Policy 1.1.2). From our selection of 85 Canadian communities [Appendix




1], 20-year horizons appear most frequently for land use plans. The table seen in Appendix 1 also shows that few Nova Scotian municipalities articulate a planning horizon for their MPS. Those that do, vary from 5 to 50 years.

Land use decisions can impact the future of communities for hundreds of years when we consider the lifespan and permanency of some developments (Hallegatte, 2009; Woodruff, 2016). Short-term planning horizons for land use, those from 1 to 10 years (Policy Horizons Canada, n.d.; Seasons, 1991), can be beneficial for effective policy because they force more frequent policy review and adaptation to changing conditions, while long-term horizons, those beyond 10 years and up to 50 years, may be more successful at avoiding future challenges by addressing them proactively. Ontario offers an example where both long-term and short-term planning horizons are applied to land use planning through legislation for Official Plans. By legislating a minimum 20-year horizon for Official Plans, Ontario is requiring a long-term outlook for land use through its municipalities, as seen in The London Plan (20-year plan), Mississauga's Official Plan (35-year plan), and the City of Toronto's Official Plan (30-year plan), for example. Municipalities in Ontario are also required to update their Official Plans through plan reviews conducted every 5 years (The Planning Act 16 (11), 1990) in order to keep policy direction relevant (Ontario Ministry of Municipal Affairs and Housing, 2018). Similarly, the Province of Newfoundland and Labrador implements a mandatory 10-year cycle for Municipal Plan review, as legislated in the Urban and Rural Planning Act (2000) [13(2)(g)].

2.2 Population Growth

Population projection and forecasting is a common tool for planners when trying to assess development needs for future generations. For instance, a community with a greater total number of seniors than other age cohorts will have different short-term and long-term needs than one with a booming population of those 18 and younger. Understanding trends in population change can be particularly important when considering appropriate climate change adaptation or mitigation strategies and making decisions about what types of development meet the needs of present and future communities.

All forecasting requires making some assumptions about continuing trends or future conditions, which influences the projected outcome. The further into the future a projection looks, the more assumptions need to be made and the less certain its results become. Research performed by Smith



and Sincich (1991) determined that 10-year projections offer reliable short-term results for population forecasting, while 30-year horizons are ideal for long-term projections. Smith and Sincich (1991) also found that the precision of population forecasts declines when looking beyond the 30-year mark, as seen through their analysis of small area projections in the USA.


Our sample of Canadian municipalities found that a 20-year horizon was most common in the surveyed communities that used population forecasting. Some municipalities, such as the City of Surrey use roughly a 30-year population forecast (City of Surrey, 2019), while others use somewhat shorter horizons, such as Halifax Regional Municipality's original regional plan, based on a 25-year population forecast by Altus Group Economic Consulting (2009). Additionally, other smaller Nova Scotian communities only consider historic population information as part of their planning. Examples include Truro (MPS, 2010), West Hants (MPS, 2008), and East Hants (Socio-Economic Study, 2018).

2.3 Conservation and Climate Adaptation

In 2010, Natural Resources Canada published *Adapting to Climate Change: An Introduction for Canadian Municipalities*. In this document, the Government of Canada recognizes climate change as having a major impact on increased flood risk due to sea level rise and “projected higher frequency and intensity of rain storms” (Richardson, 2010, 3). The Canadian Climate Change Scenarios Network, through Environment Canada, provides climate change projections up to the year 2100 to assist policy advisors and decision-makers across Canada with the development of adaptation strategies.

Municipalities in Canada regularly plan for climate change action and adaptation, as well as strategies for ecological and historical conservation. Conservation and adaptation are by their nature far-reaching goals, intended to have lasting impacts into the future. These efforts are linked with goals for sustainability, which also looks to produce ongoing, long-term benefits.

Oftentimes a horizon is not stated for these planning intentions, as they are meant to have lasting results achieved through short-term action. Regulation often uses short-term horizons to establish conservation strategies and build resiliency over time in communities, making a long-term goal more tangible through short-term, incremental policies. For instance, Canada's National Advisory Panel recommends regular 2 to 5-year progress updates of conservation efforts in Canada, with 10-year goals often being proposed as part of visioning, such as Canada's 2010 commitment to protect at least 17%




of land and freshwater by the year 2020 (Aichi, 2010, Target 11; National Advisory Panel, 2018). Nova Scotia's Climate Change Action Plan *Towards a Greener Future* (2009) also uses 10-year goals for addressing climate change through actionable goals for 2020. In *Towards a Greener Future*, long-term goals are also defined as those 30 years beyond the short-term horizon (i.e. 2050). Our sample of Canada's municipal climate change plans and sustainability strategies found that horizons span anywhere from 5 to 100 years, with long-term goals often being considered those 30 years or further. The most frequently used horizon for Integrated Community Sustainability Plans was found to be 30 years, while Climate Change Plans most often were found to set short-term action-based goals using 5-year horizons [Appendix 1].

Conservation and adaptation planning depend greatly on the availability of geographic data. The most recent Canadian Geodetic Vertical Datum was updated in 2013 to replace the datum of 1928, a timespan of 85 years, as the new reference standard for height across Canada (Natural Resources Canada, 2017). Natural Resources Canada reports that over the last 20 years it has produced six geoid models using gravity surveys, digital elevation models, and space-based satellite observations as well as levelling observations. Vertical datums are used for cartography, therefore using outdated data for flood mapping or other planning activities adds to the uncertainty of scenarios, influencing planning decisions.

2.4 Economic Development

Economic forecasting can either try to determine the economic situation in future years, or plan for expenditures based on expected projects, investments, and other factors (A. Chute, Dec. 12, 2018). The Province of Nova Scotia uses short-term economic outlooks, defined as 1-2 years into the future, for expenditure planning and budgeting purposes, while long-term outlooks (those looking 3 or more years ahead) are considered less certain. Alexander Chute, an economist with the Nova Scotia Finance and Treasury Board, promotes using multiple economic scenarios to better understand potential outcomes (A. Chute, 2018).

Strategic plans are commonly used by municipalities to outline desired economic growth, goals, and direction. They are developed through collaboration with stakeholders and public consultation and typically plan for 3 to 5 years into the future (Kabir, 2007). There is growing support for strategic planning that looks forward to 10-year horizons (UNSM, 2013) or further, which is seen in the case of



Ottawa 20/20, released in 2003 with a 20-year horizon, as well as through our survey of municipal strategic plans in Canada [Appendix 1].

In Nova Scotia, the Financial Management Best Practice Committee identified multi-year capital planning as a best practice for municipalities. It is recommended that the appropriate horizon for a capital plan is at least 3 years, or preferably 5 or more. FMCBC also defines capital plans as typically 5 or 6 years long (FMCBC, 2013). Capital plans include an inventory of a municipality's assets, establish priorities for infrastructure and asset management according to current assessments, and identify future projects. FMCBC (2013) also suggests that capital budgets should be produced and updated annually, using the capital plan as their basis.

2.5 Infrastructure Resiliency

Planners make policy decisions using knowledge of both present conditions and future projections. Infrastructure planning looks at existing infrastructure assets and plans for the maintenance of those assets, as well as plans for the further development of systems and the implementation of adaptive technologies. In this case, assets include roads and bridges and associated infrastructure such as culverts. Nova Scotia's Department of Transportation and Infrastructure Renewal, for instance, uses a 5-year plan as its long-term guiding document for the development of roads and bridges across the province. However, other literature suggests that this is a relatively short-term horizon.

Hoornweg et al. (2018) demonstrate the use of cost curves in Toronto to evaluate the potential cost and longevity of proposed transportation infrastructure using a long-term horizon of 35 years. If properly and regularly maintained, infrastructure can be expected to remain in place for up to 200 years (Hallegatte, 2009; Hoornweg et al., 2018), allowing planners to make assumptions that incorporate established systems when planning far into the future. However, researchers like Reiner (2016) warn against the fallacy that infrastructure systems are reliable, suggesting that planning does not always adequately anticipate system failures or incorporate sufficient adaptive strategies in the case of hazards. Risk analysis, like that performed by Mamo (2015), can be performed to better understand deterioration factors and the likelihood of impacts from hazard events.



2.6 Vulnerable Populations


Information on demography and socioeconomic factors is made available through the Canadian Census Program, the profiles from which are released by Statistics Canada every 5 years. Using this data, planners can identify at-risk populations and communities by calculating social or place deprivation. For example, in Nova Scotia, a growing number of seniors means that most communities are addressing the needs of an aging population. Rapaport et al. (2015) looks at four coastal Nova Scotian municipalities as case studies of how to plan for seniors facing both social and place vulnerability due to climate change impacts. Armenakis and Nirupama (2014) similarly look at population vulnerabilities overlaid with spatial flooding risk to determine the unique challenges faced by vulnerable populations in the case of climate change flooding.

While this data is not used to perform projections, updating information on vulnerable populations with each census update is important to ensure that plans continue to address social needs appropriately.

2.7 Conclusions

Planners use flood mapping to assess if certain buildings, ecosystems, populations, or infrastructure systems are threatened by storm surge, future sea level rise, or increased precipitation. Flood maps help planners determine where development should be restricted to mitigate impacts going forward, or where adaptation is needed to retain existing assets through future conditions. There are nearly limitless ways in which planning might use and consider climate change flood maps, through both short-term and long-term lenses. Infrastructure is a predominant long-term consideration for climate change adaptation (See Sections 4.2 and 4.3 for cities of Edmonton and Surrey) and requires both a long-term outlook, that anticipates required investment, and a short-term outlook that allows for adaptive strategies informed by updated knowledge.

Short-term horizons, seen commonly through plan reviews or action plans, reflect an incremental approach to planning and may offer more accurate results due to the availability of updated data with fewer assumptions; however, short-term horizons also may not support the large investment necessary for effectively mitigating climate impacts. Long-term horizons can support more robust action to adapt to, and mitigate the impacts of, flooding due to climate change, but there is also



greater uncertainty attributed to long-term projections. This can make decision-makers and stakeholders reluctant to commit to responsive policy action. The following section details planning considerations that may impact the selection of a minimum time horizon and climate change scenario due to challenges to the uncertainty and reception of climate change scenarios.

Because plans are heavily driven by community need, population forecasting is a large driver. At a minimum, communities are tracking their historical population change from census to census period, which is a 5-year time horizon. Population forecasting for planning purposes stays within a 30-year time horizon from a baseline year. As guidance, an appropriate minimum time horizon for climate change scenarios for municipal planning would be 20 to 30 years. From the literature on climate change studies, 100 years from a baseline into the future appears as the maximum time horizon. All of this also happens to coincide with base climate change studies. For example, the PEI inland flooding risk mapping modelling study in Hillsborough River Basin looks at time intervals of every 25 years with a maximum time horizon of 2100 (AMEC 2014).

Our scan of Canadian municipal plans shows a mean long-term planning horizon of 20 years, with a 60-year time horizon as the maximum for policy and a 5-year minimum time horizon for plan review. Our sample of planning horizons has been restricted to those used in a policy context. Planners may consider conditions beyond the typical long-term planning horizons, such as projected climate conditions for 2100; however, we found that this is not often reflected through long-term planning policy which typically directs action for 20 to 30-year time horizons.



3.0 Considerations for Scenario Building


3.1 Expert-driven versus Participatory Approaches

Scenario building is the art and science of building plausible futures. This process can include following trajectories based on historic trends as well as those that are aspirational and directed by desired outcomes. Scenario building includes choosing from multiple possible futures, such as those found in IPCC scenarios of climate futures, each one determined using a certain set of assumptions based on factors such as level of energy consumption leading to greenhouse gas emissions.

Future flood scenarios, especially those that incorporate climate change projections, can be met with skepticism from decision-makers, stakeholders, and community members due to what Moser (2005) calls human-dimension uncertainties. There are often cultural, interpretive, or value-based barriers to motivating adaptive or mitigation strategies, or to bolstering political support for adopting climate change scenarios. One way to address these uncertainties, is by encouraging dialogue during the scenario building process (Cobb and Thompson, 2012).

Thistlethwaite et al. (2017)'s *Canadian Voices on Changing Flood Risk* found that flood risk is increased due to a lack of public awareness. Their study found that from a national survey of 2300 Canadians only 6% of those living in designated flood risk areas knew of the flood risk affecting their homes, and only 21% believed the risk of flooding would increase in the next 25 years. Both Star et al. (2016) and Thistlethwaite et al. (2017) and call for greater opportunity for collaboration and joint learning through participatory scenario building between practitioners and stakeholders in order to challenge uncertainties, identify solutions, and promote awareness of climate change flood risks. Star et al. (2016) concludes that mixed-method scenario building, where expert knowledge is combined with local input, is the most effective for decision-making as it adds to the credibility and transparency of information. For planners, it is important that community members and decision-makers feel confident that policy is reflecting the public interest and responding to legitimate issues for the community.

It is also worth noting the impact of the political cycle on planning time horizons. Municipal decision-makers in Nova Scotia are governed by a 4-year election cycle, posing challenges to consistent long-term action. Researchers like Cobb and Thompson (2012) acknowledge the short-term interests that



might influence flood policy decisions and encourage greater dialogue between science professionals and decision-makers to encourage more responsive, long-term adaptation and innovation.


3.2 Using Multiple Scenarios

Future projections become less certain the further into the future we try to look. Uncertainty in scenario building can influence how projects are received by policy-makers and the public, which in turn impacts what kind of policy is developed in response. Planners and decision-makers may take an adaptive approach to flood area policy by choosing to implement flexible strategies, where the uncertainty of future scenarios is mitigated by the ability to adapt policy and action going forward. Hallegatte (2009) outlines several such approaches including no-regret strategies, flexible or reversible actions, acquiring safety margins, promoting soft adaptation, or reducing time horizons for implementation. A no-net increase development policy, for instance, is an example of a no-regret policy where developers are required to implement the infrastructure necessary to maintain natural systems as they were pre-development. Ensuring that climate change flood scenarios are updated regularly and consistently would benefit flexible approaches to policy.

The question of uncertainty can be addressed through the scenario building process by providing multiple flood scenarios from which to base policy. Stevens and Hanschka (2014) recommend that flood hazard maps account for uncertainty by “...erring on the side of caution...” (p. 929) using less frequent flood events to calculate flood lines, such as 1 in 500 or 1 in 1000 year floods, or by incorporating and planning for a buffer that extends beyond the calculated flood line. This approach may be reflected through a two-zone approach to flood area policy.

A report prepared by AMEC Environment and Infrastructure for PEI’s Department of Transportation and Infrastructure summarizes three approaches to the delineation and management of flood areas as:

“One-zone Concept: Using this, planning authorities determine the flooding hazards limit, and prohibit all development or site alternation within those boundaries. This is the most effective way of minimizing threats to public health or safety or property damage. Where the one zone concept is applied, the entire flood plain or the entire flooding hazard limit defines the floodway.



Two-zone Concept: This concept identifies the floodway and the flood fringe. The floodway refers to that portion of the floodplain where development and site alteration would cause a threat to public health and safety and property damage. The flood fringe is the portion of the flood plain where development may be permitted subject to certain established standards and procedures.

Special Policy Areas: In some unique or exceptional situations, communities are allowed to continue uses in a flood plain if the area is officially designated as a Special Policy Area (SPA). The application of the SPA concept is really limited to those areas, which are essential for the continued viability of existing uses; e.g. historical sites or old neighbourhoods built before flood plain policies came into effect.” (AMEC, p. 65)

A one-zone approach involves drawing one line to represent the extent of the flood zone. Development is usually prohibited in this area due to the likelihood of hazard due to flood events and risk to health and public safety. For instance, Webster et al. (2014) conducts flood mapping for the LaHave River in Bridgewater, drawing a line that shows the maximum flood extent. A two-zone approach involves defining a second zone beyond the limit of the flood area. The extent of this second zone can be selected as a precautionary measure, such as the two-metre buffer suggested by Forbes et al. (2009) for Halifax harbour, or can reflect a second, less-likely, flood scenario. In Nova Scotia, this is seen through the use of floodway and flood fringe zones defined through FDRP flood mapping.

Finally, special policy areas (SPA) can be used when the continued use of the land is considered worthy of the risk presented by flooding. SPA’s are frequently used by Conservation Authorities in Ontario. Section 3.1.4 of Ontario’s Provincial Policy Statement (2014) under the Planning Act allows planning authorities to permit development and site alteration in areas associated with flood hazard in “...exceptional situations...” (p. 31). Appendix B of Toronto Region Conservation Authority (TRCA)’s *Living City Policies* (2014) lists 15 designated SPA’s in its jurisdiction. The City of Brampton’s downtown core, for example, was identified by TRCA as subject to flooding in the province’s Regulatory Flood event. In order to address risk to health and safety in a flood event for this area without disrupting the crucial economic and social function of Brampton’s downtown, unique technical provisions apply to the construction of new buildings or additions to existing buildings, and site-specific policy for land use, urban design, and open space are in place within the boundaries of four zones designated within the SPA (City of Brampton (2017), Section 5.6.3. *Downtown Brampton Secondary Plan*).



3.3 Transparent Assumptions, Process, and Sources

Our research into flood mapping in Canada looked at a range of reports and plans where sources for the climate data or horizons used were not explicitly stated or provided. We found that this posed challenges to the interpretation of the flood mapping provided. All modelling procedures make a series of assumptions that influence the projected scenario outcomes. Acknowledging these assumptions is part of responsible modelling practice (Henstra and Thistlethwaite, 2018) and can assist with improving scenarios going forward. For instance, the benefits of this practice are demonstrated by Policy Horizons Canada, with the Government of Canada, which uses a number of methods to conduct strategic foresight to improve public policy, drawing out assumptions that govern policy decisions in order to assess their legitimacy and plausibility over a 10-15 year horizon (Government of Canada, n.d.).

In a policy brief making recommendations for the future of flood risk mapping in Canada, Henstra and Thistlethwaite (2018) stress the importance of making flood risk maps publicly available. Our research found that maps were often not provided as public resources, making individual flood awareness and action less likely. When flood maps were publicly posted, oftentimes they did not clearly state what conditions or horizons were being illustrated, leading to ambiguous interpretation. Henstra and Thistlethwaite (2018) also recommend greater transparency of process and uncertainty by providing accessible information on terminology, data sources, and limitations to modelling and forecasting. For instance, maps should indicate and provide access to the vertical datum used as reference for presenting flood elevations. Stevens and Hanschka (2014) point out that reference points determined through survey work can vary significantly between datasets, making it important for interpretation and for comparison to past or future projections, that the data sources be transparent. Daigle's report, *Sea-level rise and coastal flooding estimates for Hantsport* (2016) demonstrates how data for climate change factors like oceanographic effects, tidal range, and vertical land movement may or may not be applied to climate change scenarios. Users of municipal flood line maps can benefit from knowing which variables are being considered through the selected scenario.

3.4 Risk-Based versus Hazard-Based Policy Approaches

The Federal Flood Mapping Framework defines hazard as a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and




economic disruption or environmental degradation (Government of Canada, 2018). Risk is the combination of the likelihood and the adverse consequences of a specified hazard being realized, including potential economic, social/cultural, environmental and human impacts. Canadian municipalities are currently employing both risk-based and hazard-based flood policy strategies, with hazard-based approaches being historically predominant (Thistlethwaite and Henstra, 2017). In an article published by the Canadian Water Resources Association in the Summer 2014 edition of *WaterNews*, Murray and Francois describe the hazard-based methods for flood prediction employed by municipalities and recommend the adoption of a risk-based framework.

Hazard-based approaches involve a return-period standard, using a selected historical flood event as the statistical representation of a potential flood occurrence, with a frequency analysis to quantify the likelihood of a similar occurrence. This method offers a basis for design standards that are likely to protect against historically extreme conditions. Municipalities also respond to events that exceed this standard by offering emergency flood relief funding for repairing damages (Henstra and Thistlethwaite, 2017; Murray and Francois, 2014). A risk-based approach considers the likelihood of events that exceed the recorded standards, as well as incorporates regional risk factors posed by exposure, such as the location and density of population, and vulnerability, including the condition of infrastructure or the potential economic or social cost of flood consequences. In Europe, flood risk mapping most often identifies potential flood losses from economic damages, with few illustrating damages to people or the environment (Mertz et al., 2007). Both Mertz et al. (2007) and Woodruff (2016) show that there are conflicting definitions and approaches to assessing risk that pose challenges to flood mapping.

3.5 Conclusions

Scientific and human-dimension uncertainty is a major factor in the development and reception of flood line mapping standards. This report makes recommendations [pg. 2] informed by the considerations discussed in this section that recognize some challenges of climate change scenario building and implementation due to uncertainty, and direct further research or action. Here, we also note Nova Scotia's existing precautionary principle, appearing in the province's Environment Act (1994), to address uncertainty:



“the precautionary principle will be used in decision-making so that where there are threats of serious or irreversible damage, the lack of full scientific certainty shall not be used as a reason for postponing measures to prevent environmental degradation” [Section 2(b)(ii)].

The precautionary principle may be similarly appropriate for use in policy resulting from flood line mapping for climate change. As Woodruff (2016) recommends, acknowledging uncertainty explicitly through the planning process and in policy can make assumptions about climate change more transparent, encouraging discussion and breaking down barriers between experts and decision-makers. It also promotes a proactive approach to policy that is not restricted by the potential for change to scientific knowledge or community understanding, and instead adapts as further information becomes available.




4.0 Canadian Approaches to Flood Mapping

In Nova Scotia, the Municipal Government Act (MGA)'s Second Statement of Provincial Interest on Flood Risk Areas provides some insight as to the existing regulation of floodplains across the province. Under this legislation, there are five provincially designated floodplains that were identified through the Canada-Nova Scotia Flood Damage Reduction Program (FDRP). As specified through this federal partnership, regulation of the FDRP floodplains uses a two-zone approach. The first zone, termed the "floodway", is defined as having the greatest risk of flooding, 1:20 years or a 5% annual chance of flooding, and the second zone, the "floodway fringe", acts as a buffer between the floodway and other zoning, and is defined as having a 1:100 years or 1% annual flood probability. Other than the regulations specified by this policy, Nova Scotian municipalities have little guidance for the identification and management of locally known flood areas.

Existing studies and literature overwhelmingly recommend the adoption of consistent flood mapping policies and guidelines. Work is underway at a federal level to address this need. *Canada's Federal Flood Mapping Guideline Series* "...aim[s] to provide advice to provinces and territories, whose responsibility it is to provide technical guidance to implementing bodies, as well as individuals and organizations in Canada that need to understand and manage flood risks and their consequences to communities...The present guidelines are intended as a basis for further specification as defined by a province or territory." (Federal Flood Mapping Framework Version 2.0, p. 4). As Canadian provinces move forward with developing more specific mapping guidance for municipalities, they can look to existing municipal strategies to better understand what is being done in other communities to assess flood hazard and incorporate climate change projections into flood modelling, as well as how these strategies are chosen. The following case studies were selected to illustrate existing approaches to flood mapping in Canadian communities.

4.1 Waterford River Area, Newfoundland and Labrador

Mapping for the Waterford River area was produced as part of the Newfoundland and Labrador's Climate Change Adaptation Initiative for the cities of St. John's, Mount Pearl, and Paradise, Newfoundland. This project represents one of 38 communities in Newfoundland and Labrador where



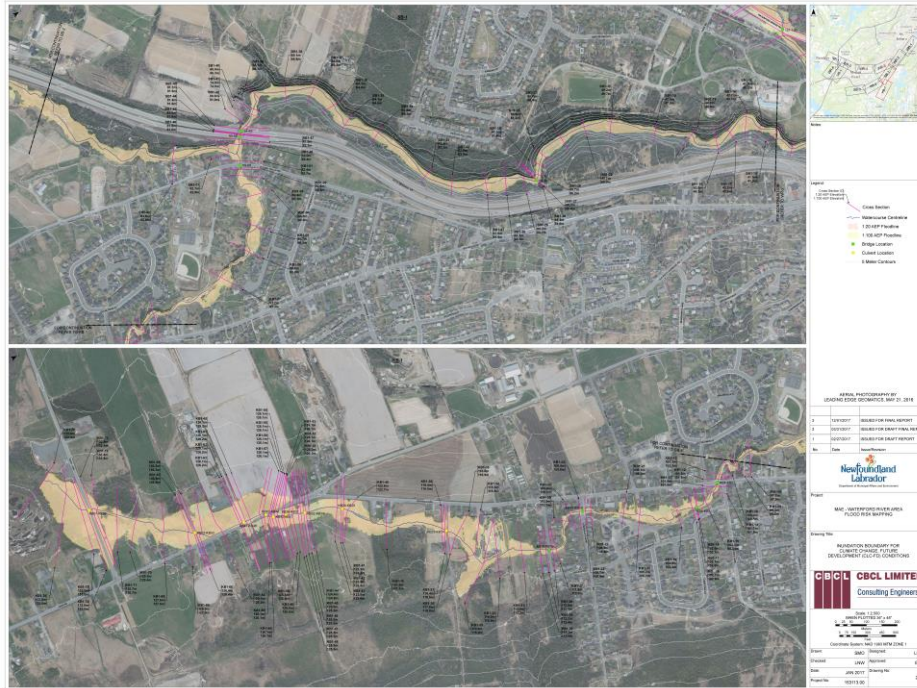
flood risk areas have been identified and mapped. Since 2009, these flood risk maps are in the process of being updated to include climate change projections.

The flood mapping study for the Waterford River Area offers a long-term projection of future flood zones for the purposes of public safety information, climate change adaptation, land use planning, and design standards. In conjunction with Policy 6.13 for Flood Plain Management, the province has made all flood maps and studies publicly available online.

Hydrologic and hydraulic modelling was undertaken for this study. The hydrologic model used was simulated with the 1:100 and 1:20 AEP flood flows at 6, 12, and 24-hour precipitation rates for both existing and climate change conditions. The hydraulic models translate the hydrologic model results onto the regional topography, determined using LiDAR and aerial photography. The Province of Newfoundland and Labrador has continued to use the policy standard set out by the FDRP program where a floodway, determined using a 1:20 storm scenario, is identified along with a floodway fringe, representing the extents of a 1:100 storm scenario. Additionally, Newfoundland and Labrador's policy for flood plain management defines Climate Change Flood Zones as "Based on extension of the floodway fringe, this is the area which is likely to be impacted due to the latest forecasted affects of climate change."¹ Policy 6.08 requires communities to incorporate the results of flood risk maps, when completed, to their Municipal Plan using the flood risk area zoning defined by the province (Policy 5.0).

IDF curves were produced with ranges of storm durations for the following return periods: 1:2, 1:5, 1:10, 1:25, 1:50, and 1:100. The CBCL Waterford Area report describes this set of return periods as "typically" used (p. 6). These projections use IDF values developed from the Ruby Line rain gauge, based on 16 years of data collected from 1997 to 2014. The impact of climate change was considered through the selection of an additional IDF curve, projecting anticipated rates of rainfall for the 2071-2100 time horizon. These projected precipitation rates were taken from Conestoga-Rovers and Associates report *IDF Curve Updates for Newfoundland and Labrador* (2015) completed for the Office of Climate Change and Energy Efficiency. Climate change IDF curves were also projected for 2011-2040, 2041-2070; however, the 2071-2100 curve was selected as the most conservative option (26% overall rainfall increase).


¹ https://www.mae.gov.nl.ca/waterres/regulations/policies/flood_plain.html



Page 3 of 1:20 and 1:100 Climate Change Floodlines for Waterford area. (2018). Provided at <https://www.mae.gov.nl.ca/waterres/flooding/frm.html>.

This study produced two maps, one illustrating flooding according to current climate conditions using an analysis of historical data, and one illustrating flooding where climate change precipitation is considered, both for 1:20 and 1:100 return periods. Sea level rise is not incorporated. Water structures and infrastructure, such as bridges and culverts within the floodway and flood fringe are identified. Zoning and property mapping was also provided by each municipality to compare the projected impact of flooding on current and future development conditions, as seen through each scenario.

The three municipalities recognize the new flood mapping but are at different stages of incorporating it into their municipal policies and by-laws. The city of Mount Pearl is preparing to adopt the flood risk maps under the City's municipal plan and development regulations through an amendment process (Howell, per comm). The town of Paradise adopted its new Municipal Plan before the flood mapping was completed. In anticipation of the updated flood mapping, however, the town included the following policy in the Plan: 6.4.1 (5) "When completed, incorporate the recommendations of a Waterford River Floodplain Study into the Municipal Plan and Development Regulations consistent



with provincial floodplain policy”. (Glenn, per comm.) The next step will be to amend the Municipal Plan to include the new floodplain. The City of St. John’s Council has not yet committed to updating municipal zoning maps to reflect the new flood mapping, but St. John’s acknowledges that there are new floodplain boundaries which will eventually override the previous floodplain boundaries still in use (O’Brien, per comm). Mechanisms for future incorporation could include new boundaries in the municipal floodplain maps under the St. John’s Development Regulations and an expansion of the Open Space (O) Zone in areas where the provincial mapping indicates an appreciable increase in the flood plain (O’Brien).

4.2 City of Surrey, British Columbia

The City of Surrey is a coastal community south of the Fraser River in British Columbia. It is a member of the Metro Vancouver Regional District, with over 500,000 people, the second highest population in the province. In recent years, flooding caused by precipitation, snow melt, and storm surge has increasingly affected areas across BC, with severe flooding occurring recently in Surrey due to rainfall (CBC News, Dec. 11, 2018).

In November 2013, the city’s Climate Adaptation Strategy was approved by Surrey council. Increased resilience to flood risk into the future is one aim of this strategy, which also informs an ongoing 3-year engagement project, the Coastal Flood Adaptation Strategy, to communicate climate impacts and adaptation strategies with residents and stakeholders. As part of this strategy, several engineering studies have been carried out for the City of Surrey to produce floodplain maps that illustrate future flood conditions across the region.

The City of Surrey is subject to both coastal and riverine flooding. Therefore, floodplain studies for this region look at the impacts of climate change through sea level rise, storm frequency and intensity, and precipitation rates. The province of British Columbia’s technical guidelines on sea level rise² recommends that municipalities assume a 1 metre rise in global mean sea level rise between 2000 and 2100, translating to a 10 cm rise in ocean levels per decade. This rate is translated into relative regional estimates of sea level rise by applying the effect of local ground movements, i.e. subsidence, to the 10 mm per year standard. Similarly, Surrey’s floodplain studies incorporate downscaled global climate model projections for rainfall, produced through the Pacific Climate Impacts Consortium. IDF curves

² http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/coastal_flooded_land_guidelines.pdf

were not considered suitable for Surrey’s interest in floodplains, stating that they are most beneficial for event-based analysis and thought to be less reliable for the changing conditions of a long-term, continuous projection method.

Flood protection through upgrades to, and the development of, lasting infrastructure is of priority to the City of Surrey. Studies are interested in climate change projections to guide land-use changes for 2040, 2070, 2100, and 2200 time horizons. To address this desired range, floodplain maps have been produced that illustrate a 200-year return period flood extent for present conditions and for projected conditions according to the years listed above.

Land use conditions and alterations are considered, as determined from Surrey’s Official Community Plan, in conjunction with projections to assess vulnerability of existing infrastructure, such as the region’s sea dams, dikes, and bridges, which were found to be at extensive risk to river flooding by the 2100. Analyses show that flooding for low-lying areas is most significantly impacted by coastal flooding caused by sea level rise. Modelling also determined that the return period of a 200-year flood would be reduced to less than 2 years by 2100, while in upper floodplain areas a 200-year storm would become a 5 to 10-year storm on average.

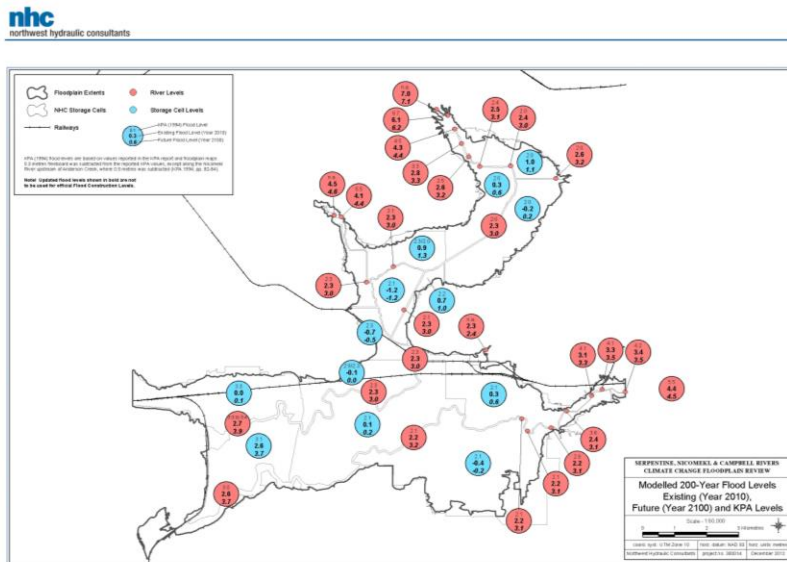



Figure 8.2. Modelled 200-year flood levels – existing (2010), future (2100) and KPA levels
 Serpentine, Nicomekl & Campbell Rivers – Climate Change Floodplain Review
 Final Report



Official floodplain maps have not yet been prepared from the above modelling and floodplain reviews. However, inundation maps have been produced for the present, 2100, and 2200 conditions along Surrey's Serpentine, Nicomekl, and Campbell Rivers (NHC, 2015) that offer a better understanding of present and future flood hazard and vulnerability. Reports recommend that monitoring and updates continue to be undertaken in addition to using long-term time horizons for policy (Natural Resources Canada, 2018).

4.3 EPCOR and the City of Edmonton, Alberta

The City of Edmonton is the provincial capital city of Alberta with a population of close to a million people. The North Saskatchewan River runs through Edmonton's urban centre, leaving much of the city's developed land vulnerable to riverine and pluvial flooding. EPCOR is the City of Edmonton's municipally owned electric and water utility. They hold an interest in providing safe, reliable, and sustainable water and energy services across the municipality.

In February 2018, EPCOR initiated its Stormwater Integrated Resource Planning (SIRP) approach, part of which includes the development of flood maps and a risk framework for mitigation priorities. This project responds to the City of Edmonton's Climate Change Resiliency and Adaptation initiative, and results are presented periodically to the Utilities Committee for review and consideration. EPCOR has been working closely with the Climate Change Adaptation team to align the SIRP recommendations with the Climate Change Action Plan.

In developing its Climate Change Strategy, the City of Edmonton produced climate models for 2050 and 2080. The year 2050 was selected as the time horizon for climate change planning action because it aligned with the horizons of other municipal plans, including economic and growth strategies. The models and projections produced during the development of this strategy have not been made publicly available (D. Koleyak, 2019).

In October of 2018, three scenario maps were released assessing flood risk across Edmonton's flood basins, each reflecting a different approach to risk assessment determined through public consultation. IDF curves were used for EPCOR's mapping process, combining 32 data sets (historical) to effectively consider the entire study area. Accelerated rates of precipitation due to climate change were modelled using IDF curves as well. EPCOR used global flood models purchased from insurance companies widely used across Canadian municipalities, including GBA Risk Assurance based in the UK, and Benfield Insurance. Insurance industry maps provide estimated overland and riverine flooding depths for 1:20,

1:50, 1:75, 1:100, 1:200, 1:500, and 1:1500 return periods. They are based on regional topography and applied global climate models. EPCOR incorporates projections from 1:20 through to 1:200 storm scenarios into their mapping.

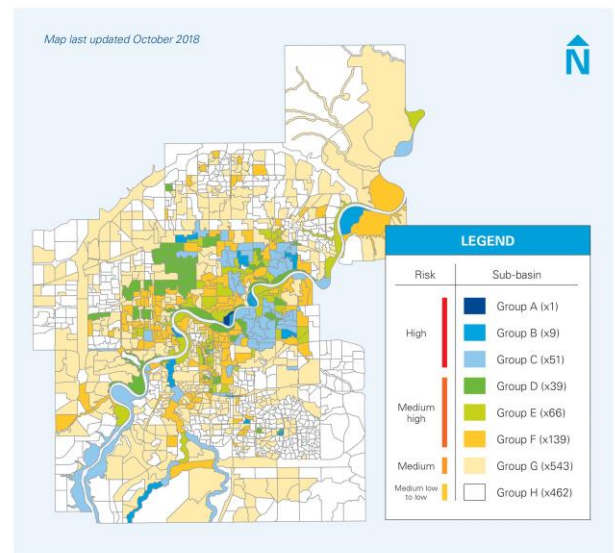
The maps produced through this project are primarily intended for risk assessment and to guide planning for investment and utilities adaptation. They illustrate about 1300 stormwater sub-basins identified within Edmonton’s urban boundary and assess those facing greatest risk in the three scenarios. EPCOR does not provide a horizon or design standard through these maps. Instead, they argue that the maps effectively serve to identify areas where attention is, or will be, needed rather than offering flood level projections. They find that regional flooding is primarily topographically dependent and, therefore, flood areas are consistent across various storm scenarios. For this reason, no time horizon is stated for the resulting maps. The maps illustrate risk levels based on exposures to stormwater volumes and topography where there is greater risk of water pooling and flooding. The risk assessment factors considered for this process were selected to align with the City of Edmonton’s Climate Adaptation and Action Plan (2018) (S. Ancel, 2019; D. Koleyak, 2019).

As part of this process, EPCOR engaged community members to determine public priorities for flood protection and response. Risks for each sub-basin were considered through four interests: Health and Safety, Environment, Financial and Economic Impact, and Social or Service Level Impact. A series of randomized lists of flood impacts, according to three levels of impact (moderate, major and extreme) were provided to residents for ranking, determining that Health and Safety was ranked of highest priority across all three levels.

SCENARIO 2 Public Opinion



- Health and Safety | 30%
- Environment | 15%
- Social | 30%
- Financial | 25%

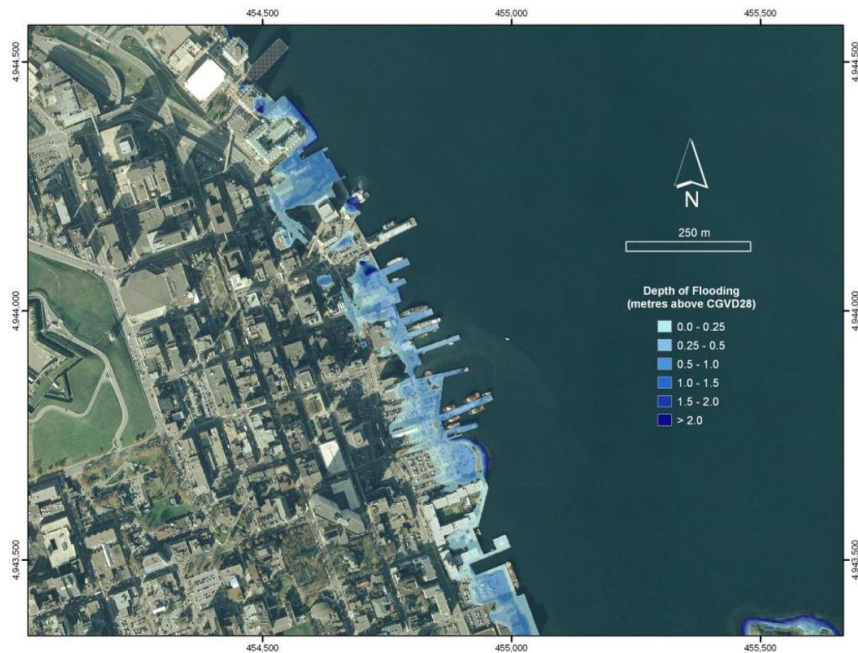


Edmonton Flood Impact Maps, October 2018.
Available at <https://www.epcor.com/>


4.4 Halifax Harbour, Halifax Regional Municipality, Nova Scotia

The urban centre of Halifax Regional Municipality, with a population of over 400,000, is most densely developed along the shoreline of Halifax's harbour, leaving significant industry, residential, commercial and recreational development and infrastructure vulnerable to sea-level rise and flooding caused by storm-surge events. In 2003, Hurricane Juan caused record flooding in the downtown core, alerting the municipality to the impacts of climate change and rising water levels.

In 2006 the HRM municipal council approved the Regional Municipal Planning Strategy, which included new policies to address climate change. A study of coastal flooding for Halifax harbour was produced in 2009 through consultation with local climate change scientists. The intention of this study was to select an appropriate policy standard according to a 100-year horizon flood scenario. This project used 90 years of tide gauge data, collected from 1920 to 2009 and crustal vertical motion data collected from 2002 to 2009. These data sources were used to determine historical water level rise, found to be 32 cm over the last century due to land subsidence and sea-level rise. Tide gauge data was also used to assess the frequency and maximum water levels from extreme storm events (Forbes et al., 2009).




Scenario 2c. Page 15 of Forbes et al. (2009).



This study was designed around three scenarios for a 2100 horizon: a low water level scenario with high likelihood of exceedance and high risk of negative impacts but low cost of adaptation, a medium water level scenario with moderate risks and costs, and a high water level scenario with higher adaptation costs and low probability of exceedance. The low water level was designed using historical rate of sea-level change, while the medium and high water level scenarios are built using climate change projections. The medium level scenario was designed using upper-limit sea level rise projections from the 2007 report produced by the Intergovernmental Panel on Climate Change. Finally, the high water level scenario is informed by Rahmstorf's (2007) upper-limit estimate of 1.3 metres over 100 years. Additionally, the low and medium scenarios are simulated using upper bound storm surge levels of 2-year, 10-year, and 50-year return events. GIS software informed by LiDAR surveys was used to simulate floods for all scenarios.

The report produced by Forbes et al. (2009) acknowledges uncertainty resulting from available sea-level rise projections, stating that Rahmstorf's (2007) projections were used as a response to criticisms of the IPCC's AR4 projections, which were thought to be too conservative. Uncertainty also results from the selection of certain climate variables over others, where a number of potentially relevant factors are not accounted for by this study, such as glacial melt. This report suggests that a precautionary approach should be applied when selecting a water-level scenario and developing policy in response to water level projections. For instance, it recommends that a 2 metre buffer be applied on top of scenario findings for planning purposes in order to safely account for flood impacts.

Of the multiple scenarios, HRM council was able to select the scenario they felt was most relevant for guiding development, new design standards, and a future adaptation plan. In 2010, council selected Scenario 2C for use as policy reference. The intention of the 100-year time horizon was to allow for incremental adaptation measures for infrastructure renewal and updating. It was reportedly seen as the best option for motivating long-term changes (Natural Resources Canada, 2010). While policy is still being developed, the HRM introduced an interim measure of a 2.5 metre minimum above the mean high water mark for ground floor elevation for development along the Halifax waterfront. HRM's updated Regional Municipal Planning Strategy (2014) [2.3.5] amended this standard to 3.8 metres above the Canadian Geodetic Vertical Datum (CGVD 28), which is not an increase to the standard given that the CGVD28 is below the mean high water mark. Halifax has seen a trend towards adaptive design in recent waterfront developments; however, without a long-term strategy it is unclear how and when such developments will respond to changing water levels over time. Future HRM plans also involve



conducting risk and vulnerability assessments to anticipate social and economic risk due to natural hazards, including flooding (Miedema, 2018).

Since the completion of this study, the IPCC's AR5 report (2014) was released, modelling mean global sea level rise using additional variables (i.e. improved understanding of glacial and ice sheet melt, as well as ocean thermal expansion). The AR4 projections, which guided Scenario 2c, have been shown to be underestimated, with a high likelihood of exceedance.

For further reading on Nova Scotian flood mapping projects, see:

Webster, T.L. (2010). Flood risk mapping using LiDAR for Annapolis Royal, Nova Scotia, Canada. *Remote Sensing* 2, 2060 – 2082.

Daigle, R.J. (2016). Sea-level rise and coastal flooding estimates for Hantsport: based on IPCC 5th assessment report. Nova Scotia Department of Environment.

Daigle, R.J., and Richards, W. (2011). Scenarios and guidance for adaptation to climate change and sea-level rise: NS and PEI municipalities. Report for Nova Scotia Department of Environment and Atlantic Adaptation Solutions Association.

Webster, T., McGuigan, K., Collins, K., and MacDonald, C. (2014). Integrated river and coastal hydrodynamic flood risk mapping of the LaHave River Estuary and Town of Bridgewater, Nova Scotia, Canada. *Water* 6, 517-546.



5.0 Conclusion

There is limited precedent for municipal climate change flood mapping in Canada, and approaches to flood modelling and scenario building differ significantly between planning authorities. In order to inform Nova Scotia's Municipal Flood Line Project, this report summarized relevant planning horizons, presented considerations for scenario building as found in literature and practice, and offered sample approaches to climate change flood mapping performed by Canadian municipalities.

Our findings conclude that planning horizons range according to the areas of planning where flood mapping is applied or assessed. For instance, infrastructure adaptation was found to be a common priority for flood planning, as exemplified through EPCOR's assessment of flood risk using sub-basins and the City of Surrey's long-range climate modelling to 2200. Long-term planning horizons, ranging from 10 to 50 or more years, were found to be beneficial for motivating change and investment that addresses potential future conditions, while short-term horizons, often between 2 and 5 years, are useful for limiting assumptions and uncertainty, preparing incremental planning action and adapting to changing conditions or information over time. A combination of both short and long-term horizons is often employed by municipalities to maintain a long-term vision achieved using short-term goals that offer greater opportunity to review and adapt plan strategies.

This report finds that a minimum time horizon appropriate for climate change flood line mapping to inform planning is 30 to 35 years, with 5-year updates of flood modelling.

Our research into planning considerations for flood line mapping found that challenges include:

- determining who should be involved in the scenario building process and how they should contribute or be accommodated (such as experts, stakeholders, or the public);
- addressing the uncertainty of future projections through different policy provisions or the selection of model variables (such as making transparent assumptions, building adaptive policy that can be effectively updated to reflect new data, or planning for a range of flood scenarios);
- defining a balance between encouraging consistency and reliability while also encouraging innovation throughout all levels of the process; and,
- understanding how decision-makers receive, interpret, and respond to flood line standards.

Recommendations [pg. 2] have been provided through this report on the considerations listed above. More research can be done to assist the Province of Nova Scotia with addressing the above challenges.



6.0 Annotated Bibliography


The following sources were gathered from Canadian municipal plans, websites, and databases. All academic articles were collected through Dalhousie Libraries and were interpreted with some consultation from practicing Canadian planners and research professionals. They are provided here for further reading.

AMEC. (2014). Inland flood risk mapping and modelling, Hillsborough river basin, Prince Edward Island. *PEI Department of Transportation and Infrastructure Renewal.*

This report was produced for the Province of Prince Edward Island's Department of Transportation and Infrastructure to provide a flood risk assessment for the Hillsborough River Drainage Basin based on the impacts of climate change. This flood mapping does not incorporate sea-level rise in its assessment of inland flooding. To develop a climate change scenario, this study uses IDF curves modelled using local historical data, acquired since 1964, and climate projections provided by the Intergovernmental Panel on Climate Change's 2007 report. Future climate scenarios are modelled using nine precipitation durations (5, 10, 15 and 30 minutes, and 1, 2, 6, 12 and 24 hours) and six return intervals (2, 5, 10, 25, 50, and 100 years). The furthest planning horizon considered in this report is 2100. The resulting 48 scenarios are aggregated into a mean, maximum, and 90th percentile precipitation intensity scenario. When presenting the results of this modelling, the report addresses the impact of regional climate drivers, limitations of current knowledge base, and assumptions necessary for the modelling techniques as sources of uncertainty. Planning approaches are also discussed through one-zone, two-zone, and special policy area concepts and examples of policy options are presented. It is recommended that flood protection standards be updated to define planning horizons, flood frequency, and peak flood level to apply to the assessment of all future development, and that future policy frameworks acknowledge the increased risk of flood seen through climate change projections.

Armenakis, C., and Nirupama, N. (2014). Flood risk mapping for the City of Toronto. *Procedia Economics and Finance* 18, 320-326.

This study promotes flood risk mapping for the City of Toronto and demonstrates a method of mapping flood risk using ArcGIS spatial data and population vulnerability calculated using census tract data. This



approach overlays a map of low slope areas (slope of less than 2%) and land depression areas with a map locating various vulnerable persons, such as those 65 and over or 4 and younger, those who are unemployed, or with a household income of less than \$50,000 after tax. Water levels are not calculated through this exercise, instead flooding is spatially predicted using the selected terrain features of low slope and land depression areas.

Daigle, R.J. (2016). Sea-level rise and coastal flooding estimates for Hantsport: based on IPCC 5th assessment report. *Nova Scotia Department of Environment.*

Daigle's report updates sea-level rise and coastal flooding estimates for Hantsport, Nova Scotia using global sea-level estimates provided by the IPCC's AR5 Report (2014) combined with the additional application of regional data for the following climate change scenario factors; vertical land movement, land glacier and ice sheet meltwater distribution, oceanographic effects, and tidal range. This report presents sea-level rise and flooding projections for every 10 years until 2100, calculated to the represent the worst-case flooding scenarios with storm-surge return periods of 1, 2, 5, 10, 25, 50, and 100 years. IPCC AR5 estimates were modelled to include ice sheet melt in the overall global estimates, a new addition to previous estimates. Daigle uses the latest estimates for the regional impacts listed above in order to address the unique geographic and other contextual factors that influence coastal flooding in Hantsport. The resulting scenarios offer projections based on regional sea-level rise and storm surge return-period statistics. This report does not incorporate projections for precipitation rates.

Daigle, R.J., and Richards, W. (2011). Scenarios and guidance for adaptation to climate change and sea-level rise: NS and PEI municipalities. Report for Nova Scotia Department of Environment and Atlantic Adaptation Solutions Association.

In their report for the Nova Scotia Department of Environment and Atlantic Adaptation Solutions Association, Daigle and Richards provide best practices for climate scenario development in Nova Scotia and Prince Edward Island and outline relevant procedural and data source considerations. They conclude that climate change science is rapidly advancing and recommend that regular updates be made to the climate scenario building process in order for it to remain relevant.



Hallegatte, S. (2009). Strategies to adapt to an uncertain climate change. *Global Environmental Change* 19, 240-247.

This research assesses and compares the effectiveness of the following policy strategies for addressing climate change: no-regret strategies, favouring reversible and flexible options, buying safety margins, promoting soft adaptation, and reducing decision time horizons. These strategies are proposed to substitute policy development based on a single modelled scenario, which Hallegatte argues is not the most effective means of adapting for future impacts. Through this analysis, Hallegatte provides a table of sectors with corresponding investment timescales, where, for instance, water infrastructure is attributed a 30-200 year timescale, building and housing: 30-150 years, and land-use planning: greater than 100 years, in order to illustrate that robust investment needs to be made in the present to prepare for future climate change impacts; however, sources to justify these suggested timescales are not provided. Through a comparison of adaptation options and the benefits and challenges to achieving them according to the proposed strategies, Hallegatte promotes an anticipatory approach to adaptation, concluding that shorter-lived decisions, such as those with flexible turn-around and no-regret investment, should be implemented to reduce decision-making horizons, while the every-day operations of planning and other sectors should consider climate adaptation through all decision-making, promoting long-term investment through ongoing strategies.

Henstra, D. and Thistlethwaite, J. (October 2018). Flood Risk Mapping in Canada: Moving Forward on a National Priority. Policy Brief No. 141: Centre for International Governance Innovation.

This policy brief presents the state of flood mapping across Canada and presents recommendations for developing and utilizing flood risk maps. This study finds that flood mapping is not consistent between provinces and the majority of maps in use across the country are outdated. This research promotes the development of flood risk maps over flood hazard maps. Henstra and Thistlethwaite argue that flood risk maps are more supportive of policy development and promote greater public engagement and understanding of flooding impacts than flood hazard maps, which present highly technical data without detailing the potential consequences to encourage discussion. They recommend that effective flood maps include local and historical context, a clear legend, legible flood extents, definitions of scientific and technical terminology, transparency on uncertainty and limitations, data on all forms of flooding, risk reduction advice, and information to personalize the experience of flooding.




Moser, S.C. (2005). Impact assessment and policy responses to sea-level rise in three US states: an exploration of human-dimension uncertainties. *Global Environmental Change* 15, 353-369.

Moser aims to reveal human-dimension uncertainties that co-determine impact assessment and scenario building for climate change induced sea-level rise. By looking at case studies of state-level policy and management responses to sea-level rise impacts in the U.S., this research determined a number of human-dimension uncertainties that hinder the utility of climate change scenarios including varying degrees of problem awareness, varying perceptions of urgency, local value-based lenses, and interpretive capabilities. Moser's findings emphasize the different uncertainties at play when assessing sea-level rise *scenarios*, such as data sources, geospatial variation, or permeability, versus those uncertainties that influence the assessment of sea-level rise *impacts* such as economic climate and sociocultural systems. Interviews with policy-makers in U.S. communities reveal political and institutional biases that influence scenario standards, such as setting minimum water levels to allow for development that may be considered at risk by other standards. This inquiry also revealed that climate change scenarios and adaptation strategies are more likely to be adopted if local realities and barriers are considered and addressed through the downscaling of scenarios and risk assessment. Short-term events like coastal storms were found to be more easily accepted than slow onset impacts, and policy-makers were found to prefer static, expert-driven assessments that seek to limit uncertainty and variability rather than acknowledge it; however, Moser argues that the mitigation of short-term hazards is not an adequate substitute for long-term adaptation and the misrepresentation of scenarios as static and consistent undermines adaptation and policy action in the future.

Pieterse, N., and Tennekes, J. (2013). Flood hazard mapping for spatial planning: Conceptual and methodological considerations. *Taylor and Francis Group*, 779 – 784.

This paper advocates for greater spatial planning aided by flood hazard mapping to protect against future flood impacts in the Netherlands. This research develops a method for creating effective hazard maps by considering exposure characteristics of floods, in this case maximum flood depth and time of onset, and the probability of flooding, as influenced by sea level rise or rates of precipitation, and overlaying scenario outcomes with population density and land use data to illustrate potential fatalities and damages. This study does not provide information on what historical or climate prediction data was used to develop hazard scenarios, nor does it offer a timescale for the maps presented; however, Pieterse and Tennekes conclude that spatial planning policy that reduces the greatest potential harm




from flooding up to 100 years into the future. They acknowledge that planning horizons are often limited to 20 years, posing challenges for implementing infrastructure adaptation or land-use policy. Additionally, this research supports that flood hazard maps should be combined with local and regional factors inform policy-makers and decision-makers of the potential consequences of flooding in their community, deterring future development that can incur damage. While this paper does not offer concrete strategies for mapping horizons, it provides relevant recommendations for comprehensive mapping techniques in municipalities, and encourages extending scenario horizons for planning purposes, that can be applicable to Nova Scotia.

Star, J., Rowland, E.L., Black, M.E., Enquist, C.A.F., Garfin, G., Hawkins Hoffman, C., Hartmann, H., Jacobs, K.L., Moss, R.H., and Waple, A.M. (2016). Supporting adaptation decisions through scenario planning: enabling the effective use of multiple methods. *Climate Risk Management* 13, 88-94.

Star et al. suggests that choosing a single projection of future conditions does not provide decision-makers with the opportunity to adequately prepare for climate change and proposes *scenario planning* as a more effective tool for climate change adaptation and policy. Using case studies, this research looks at approaches to scenario building, comparing researcher-driven to participant-driven processes and exploratory versus normative scenarios. This research finds that mixed-method approaches lead to more tangible and credible understandings of future outcomes by combining the use of expert climate modelling with engagement of those affected by climate change predictions. Additionally, a mixed-method approach for climate change scenario building is found to encourage complexity and lead to more relevant policy decisions by considering local context and interests, such as natural resource management, like wildlife populations, alongside larger global systems. Star et al. concludes that adopting a mixed-method that acknowledges and works with existing complexity will lead to more flexible policy that aims to address a greater range of future climate conditions and impacts.

Stevens, M.R. and Hanschkl, S. (2014). Municipal flood hazard mapping: the case of British Columbia, Canada. *Nat Hazards* 73, 907-932.

This study assesses the status of municipal flood hazard mapping in British Columbia by conducting a content analysis looking at a number of variables in flood mapping categorized by administration, delineation, landscape features, and related documents. Their analysis found that, since flood hazard




maps were the responsibility of the municipality, there were varying results. Overall, flood hazard maps were found to be either non-existent, outdated, or insufficient to support effective land-use planning. Stevens and Hanschkla recommend greater guidance and intervention from senior levels of government for municipal flood mapping to ensure that maps are being produced and updated to the proper standards to guide land-use planning policy. Primarily, this report recommends erring on the side of caution by encouraging municipalities to calculate projections for less frequent, higher magnitude flood events, such as 500-1000 year floods, in order to limit potential risk of hazard to future development, or to incorporate a buffer zone in addition to delineated flood lines. The Province of Nova Scotia may consider the recommendations of this paper by building scenarios that illustrate higher risk events.

Webster, T., McGuigan, K., Collins, K., and MacDonald, C. (2014). Integrated river and coastal hydrodynamic flood risk mapping of the LaHave River Estuary and Town of Bridgewater, Nova Scotia, Canada. *Water* 6, 517-546.

This paper produces a flood risk map for the Town of Bridgewater using the high-resolution lidar on land and bathymetric data for the river channel and coast. Tidal influence impacts the LaHave River extending to downtown Bridgewater. No storm surge data was available for Bridgewater so the closest measured storm surge in Halifax is used (1 m), along with 50 and 100-year return periods. Twelve simulations are produced through this modelling. These simulations are produced by combining the 50 and 100-year discharge events at 65% and 99.5% probability with normal high tide as well as normal high tide with 2.2 m surge as well as normal high tide with a 3.5 m surge. These scenarios present the worst-case flood scenarios for the LaHave River and find greater risk of flooding upstream of the tidal extent, while the downtown area of the river is vulnerable to sea level-rise and storm surge events. No recommendations are made for planning.

Woodruff, S.C. (2016). Planning for an unknowable future: uncertainty in climate change adaptation planning. *Climatic Change* 139, 445-459.

This article argues that planning in practice does not sufficiently address uncertainty through climate projections or adaptation policy due to misguided assumptions about forecasting accuracy, as well as a number of political and institutional barriers to decision-making. Through a content analysis of 44 local climate adaptation plans in the United States and interviews with planners in three U.S. communities,



Woodruff uncovers that robust and flexible adaptation strategies are often impeded by a single scenario approach to climate forecasting, led by the misconception that there is a correct climate projection and that acknowledging uncertainty is counterproductive to adaptation. Practicing planners were found to be reluctant to suggest robust adaptation policy due to feasibility concerns and push-back from decision-makers. Woodruff recommends that planners develop and work with a range of future scenarios and implement a variety of adaptive strategies in order to address the uncertainty by preparing for multiple future projections. The Province may consider recommending multiple climate change scenarios to be used by Nova Scotia municipalities in order to address uncertainty by acknowledging and planning for a range of potential outcomes.

APPENDIX I: Table of planning time horizons in-use across a sample of flood-sensitive Canadian municipalities

By surveying a selection of nearly 130 plans for 86 historically flood-sensitive communities across Canada, our research has produced a sample of planning time horizons currently in use in Canada. This investigation shows the varied state of planning policy related to flood mapping and lack of consistency across the country.

PLANNING HORIZONS (YEARS)						
CANADIAN COMMUNITY	Land Use (Municipal Plans)	Review Period for Land Use Plan	Population Forecasting	Climate Change Adaptation/Action	Integrated Community Sustainability Plan	Strategic Plans
Halifax NS	25		20			5
Annapolis NS	5					
Cape Breton NS			20			
Annapolis Royal NS	5-10					7
Pictou NS	25-50			5		5
Chester NS	20			0-5, 5-20, 20+		5-10
Digby NS						5
Lunenburg NS						
Yarmouth NS	5-10			25-100		5
Wolfville NS	5, 10, 20		5-10	5-20		3
Windsor NS		8		5-10, 10+		
Hantsport NS		7				
Truro NS	5,20					
Stewiacke NS	20		20	5		20
Clark's Harbour NS						
Port Hawkesbury NS						
Oxford NS	20					5
New Glasgow NS	25-50		10-20	25-50		2-3
Mulgrave NS						
Middleton NS	5-10					5
Lockport NS			20		30-50	5

CANADIAN COMMUNITY	Land Use (Municipal Plans)	Review Period for Land Use Plan	Population Forecasting	Climate Change Adaptation/Action	Integrated Community Sustainability Plan	Strategic Plans
Kentville NS		5	20			
Bridgewater NS				5-7	20-30	
Berwick NS		5				
Amherst NS	15, 25					
West Hants NS		8		20-30		
Shelburne NS				20-30	20-30	5
Antigonish NS					25+	5
Queens County NS	25			25		10-15
Kings County NS	34					
Colchester County NS	20	8				5
Cumberland County NS		5				5
Pictou County NS	25-50					1, 2-5
Argyle County NS						
Barrington County NS		5-10				5
Richmond County NS						
Victoria County NS					3-5	3-5
Clare County NS		5			25+	
Guysborough County NS	20	5				
Inverness County NS		5			25+	3
Lunenburg County NS		5				5
East Hants County NS	20					3
Digby County NS					20-30	3
St. Mary's County NS		5				
Yarmouth County NS						5
Antigonish County NS					15	
Shelburne County NS						
London ON	20		20			4
Peterborough ON			30			10
Mississauga ON	35					40
Bracebridge ON	20					10
Huntsville ON	20					20

CANADIAN COMMUNITY	Land Use (Municipal Plans)	Review Period for Land Use Plan	Population Forecasting	Climate Change Adaptation/Action	Integrated Community Sustainability Plan	Strategic Plans
Toronto ON	30			30+		5
Brantford ON	30		10, 20			4
Chatham/Kent ON	25		25	20		20
Cambridge ON	20		15			3
Calgary AB	30-60					3
Edmonton AB	10			30		10
Bragg Creek AB	10-12		15			10
High River AB	10, 30		30			3
Charlottetown PEI	10			5		
St. John NB	24					
Vancouver BC	1, 4, 10, 20			10		4
Maple Ridge BC			17			
Surrey BC	28		28	40		10
Grand Forks BC	5, 15-20		20	20		5
Thompson-Nicola BC			25			20-25
Okanagan-Similkameen BC		5-10	30			4
Lower Post BC						
Osoyoos BC		5-10	30			4
Princeton BC	5, 15-20					4
Saskatoon SK	30-40		30-40			10
Wadena SK						
Regina SK	25		25			4
Estevan SK						
Badger NL	10		5			
St. John's NL	10					3
Stephenville NL	10					
Montreal QB	10		10	4-7		10
Gaspe QB						
Mauricie QB						
Outaouais QB						

CANADIAN COMMUNITY	Land Use (Municipal Plans)	Review Period for Land Use Plan	Population Forecasting	Climate Change Adaptation/Action	Integrated Community Sustainability Plan	Strategic Plans
Ste-Marie-de-Beauce QB						3
Tuktoyaktuk NWT						
Nahanni Butte NWT						
Upper Liard YK						

LAND USE:

Percent of communities reviewed whose plans had time horizons	50% (43)
Longest time horizon	60
Shortest time horizon	5
Mode	20
Median	20
Percent of communities whose land use plans had a stated review period	17% (15)
Longest review period	10
Shortest review period	5
Mode	5
Median	5

POPULATION FORECASTING:

Percent of communities reviewed whose plans had time horizons	28% (24)
Greatest time horizon	40
Shortest time horizon	5
Mode	20
Median	20

CLIMATE CHANGE ADAPTATION/ACTION:

Percent of communities reviewed whose plans had time horizons	23% (20)
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Greatest time horizon	100
Shortest time horizon	4
Mode	5
Median	20

INTEGRATED COMMUNITY SUSTAINABILITY PLAN (Atlantic Provinces Only):

Percent of communities reviewed whose plans had time horizons	20% (of Atlantic communities) (17)
Greatest time horizon	50
Shortest time horizon	3
Mode	30
Median	25

ECONOMIC/STRATEGIC:


Percent of communities reviewed whose plans had time horizons	58% (50)
Greatest time horizon	40
Shortest time horizon	1
Mode	5
Median	5

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Developing Future Climate Rainfall Intensity-Duration-Frequency (IDF) Relationships – Final Report

Prepared by:

Jason KarisAllen, Jenny Hayward,
Rob Jamieson, & Barret Kurylyk

Centre for Water Resources Studies
Department of Civil and Resource Engineering
Dalhousie University

Prepared for:

Department of Municipal Affairs
Nova Scotia Environment
Government of Nova Scotia

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List of Abbreviations

Abbreviation	Long-Form
AMEC	Amec Foster Wheeler Environment & Infrastructure
AR4/5/6	Fourth/Fifth/Sixth Assessment Report
ATCED	Alberta Transportation and Civil Engineering Division
AVs	Atmospheric Variables
CBCL	CBCL Limited
C-C	Clausius-Clapeyron
CMIP5/6	Fifth/Sixth Coupled Model Intercomparison Project
CORDEX	Coordinated Regional Climate Downscaling Experiment
CR&A	Conestoga-Rovers & Associates
CSA	Canadian Standards Association
ECCC	Environment and Climate Change Canada
GEV	Generalized Extreme Value
GCM/RCM	Global/Regional Climate Model
ICLR	Institute for Catastrophic Loss Reduction
IDF	Intensity-Duration-Frequency Curve
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration
NASA	National Aeronautics and Space Administration
NARCCAP	The North American Regional Climate Change Assessment Program
NRCan	Natural Resources Canada
PCIC	Pacific Climate Impact Consortium
PMP/PMF	Potential Maximum Precipitation/Flood
RCMES	The Regional Climate Model Evaluation System
RCP	Representative Concentration Pathway
SDSM	Statistical Downscaling Model Version 5.2
SWGs	Stochastic Weather Generators
WMO	World Meteorological Organization

Summary

The Government of Nova Scotia is planning to develop provincial standards and guidance for municipal floodplain mapping. In typical modern floodplain mapping studies, hydrological and hydraulic models are developed to determine the floodplain extents. Extreme rainfall projections are used to parameterise design storms that are used as inputs for these hydrological models. Extreme rainfall projections are commonly extracted from region-specific Intensity-Duration-Frequency curves (IDFs). Previous methods of generating IDFs relied on historical data alone under the assumption of climate stationarity. Climate change is generally expected to impact regional extreme rainfall frequency and intensity in Canada; therefore, methods which incorporate projected climate change projections into IDF relationships are becoming more frequently adopted. This report contextualizes the challenges associated with accounting for climate change in IDF relationships and reviews methods and software packages currently available to facilitate this process in municipal floodplain modeling.

Two suitable approaches were identified to account for climate change in IDF relationships: 1) the semi-physical Clausius-Clapeyron (C-C) scaling method; and 2) the statistical IDF_CC tool. IDF_CC is an online statistical tool developed by the Institute for Catastrophic Loss Reduction at Western University to help estimate the impact of climate change on IDF relationships in Canada for application in engineering and planning (ICLR, 2019). In contrast, the C-C method is based on the physical principles that govern the temperature-dependent moisture holding capacity of air. Both approaches permit the estimation of future sub-daily and 24-hour extreme rainfall; however, both methods also have intrinsic limitations. Although climate projections will always carry some uncertainty, it is expected that the recommended methods will be phased out once more physically based approaches become practicable. **Meanwhile, it is recommended that both the C-C method and IDF_CC tool be applied conservatively in parallel to generate future climate extreme rainfall projections for municipal floodplain modelling in Nova Scotia.** It is also recommended that the Province of Nova Scotia collaborate with other organizations to help facilitate the development and maintenance of future climate rainfall projection software packages and datasets.

1.0 Background

The Intergovernmental Panel on Climate Change (IPCC) is an internationally recognized authority on climate research and development. The collaborative Fifth Assessment Report (AR5) provided by IPCC states that it is 95% likely that human contributions are causing the majority of observed climate warming (IPCC, 2014). In the near and distant future, more regions are expected to experience an increase in the frequency and intensity of extreme precipitation events, which implies an increased likelihood of flooding (IPCC, 2014). Furthermore, coastal regions are very likely to experience higher rates of erosion and submergence due to rising sea levels and a potential for more intense coastal storms (IPCC, 2014). Planning and designing under the assumption of stationarity, using historical data alone, is no longer advisable (CBCL, 2017; CR&A, 2015; NRCan, 2018).

In order for municipalities to make informed planning decisions, they must first identify potential vulnerabilities. Floodplain¹ models that account for expected changes in future climate conditions can be used to assess these potential vulnerabilities. Floodplain models can be used to map expected changes in floodplain distributions to inform land use planning. There is currently no national standard for approaching such work, but several consulting firms have recently completed related studies in Atlantic Canada (e.g., AMEC, 2015; AMEC, 2015a; AMEC, 2013; CBCL, 2018; CBCL, 2017; CBCL, 2016).

Essential considerations for producing future climate floodplain maps include:

- 1) future rainfall projections;
- 2) future sea level rise and storm surge projections; and
- 3) planning time horizons.

The Government of Nova Scotia is planning to develop a new provincial standard for municipal floodplain mapping, which includes climate change projections. The province has engaged a group of academics in the province to propose a defensible approach to floodplain delineation for Nova Scotia that includes current climate change projections. While there has been notable improvement, there remains significant uncertainty in future climate projections, particularly for extreme precipitation (IPCC, 2014). Given the current challenges in climate science, the best result for this standard is a defensible approach to floodplain modelling based on the most current information and thorough consideration of the uncertainties that future projections involve. It is appreciated that a well-defined floodplain standard must be established for economical, social and political reasons (e.g., new developments, insurance, legislation), but any recommendations made herein should be reviewed and adjusted regularly to account for significant developments in climate science.

¹ A floodplain is defined in this report as the area surrounding a river channel that is submerged during high water events (Government of New Brunswick, n.d.). Flooding extents are expected to be impacted by climate change.

This report includes a review of approaches that can be used to develop future climate Intensity-Duration-Frequency curves (IDFs). The reader is referred to the companion report prepared by the Climatology Research Group (García-García et al., 2019) or the IPCC AR5 (2014) for more information on downscaling and climate models, and to CSA (2012) for additional information about IDFs.

1.1 Climate Modelling

Climate modelling is a rapidly developing, multifaceted field that is challenging researchers to push the boundaries of science. There are many models projecting climatic conditions for the 21st century. The fifth iteration of the Coupled Model Intercomparison Project (CMIP5) was a program that collected, evaluated, and disseminated climate projections from global climate models (GCMs) that were used in the IPCC AR5 (IPCC, 2014). The sixth iteration (CMIP6) is currently being developed and should be reviewed upon completion. It is expected that CMIP6 climate model projections will be available by ~2020 and that the Sixth Assessment Report will be finalized in 2022 (Eyring et al., 2016; IPCC, 2017). Climate models are useful in the context of future floodplain modeling because they generate estimations of future climate variables required for the analysis (e.g., precipitation, sea level rise, wave behaviour, and temperature).

At this time, there are several available resources for compiled global and regional climate projections (e.g., North American Regional Climate Change Assessment Program (Mearns et al., 2014), Coordinated Regional Climate Downscaling Experiment (CORDEX, 2018), Pacific Climate Impacts Consortium (PCIC, 2014), and the Environment and Climate Change Canada Statistically Downscaled Climate Scenarios (ECCC, 2018)). It should be noted that the Environment and Climate Change Canada Statistically Downscaled Climate Scenarios are sourced from the most recent PCIC dataset. Among other factors, each model dataset is limited or biased to a varying degree by its spatial and temporal resolution, internal variability, projected variables, downscaling² technique(s), boundary conditions, initial conditions, observational and pre-observational (climate proxies) record, intrinsic model characteristics, and forcing emissions scenario³. Furthermore, methods of evaluating the relative performance of climate models in order to select the most appropriate for a region or task are still contentious. Applying climate models in engineering practice becomes challenging due to the significant uncertainties involved in model projections. Some sources suggest applying a multi-model ensemble approach in order to address the uncertainty and bias of individual models (e.g., ECCC, 2018; IPCC, 2014; Wilby & Dawson, 2007). In this way, a range of climate projections can be analyzed. Considering the variability among model projections for precipitation (IPCC, 2014; PCIC, 2014), this is one of the more conservative approaches, as it allows decision makers to consider the range of potential future conditions and make recommendations based on the risk-tolerance of their project. However, some approaches are more computationally intensive relative to others and require

² Downscaling techniques mathematically synthesize fine-resolution information from coarser model data. These techniques are discussed in greater depth in Section 1.2 Downscaling Methods and García-García et al. (2019).

³ Forcing emissions scenarios refer to potential profiles of global anthropogenic emissions that are expected to impact climate dynamics in the future (Government of Canada, 2018c). These emission profiles are expected to span the plausible range of future scenarios and are incorporated into global climate models to project possible future climate conditions.

niche expertise, making them less feasible for application in municipal floodplain modelling in Nova Scotia.

The most current emissions scenarios, or Representative Concentration Pathways (RCPs), are RCP 2.6, 4.5, 6.0, and 8.5, which quantitatively represent the future atmosphere radiative forcing in Watts per m² (Government of Canada, 2018c). Previous studies have used the emission scenarios from the AR4 (i.e., B1, A1T, B2, A1B, A2, A1F1). However, recent studies in Atlantic Canada have adopted RCP4.5 and/or 8.5 for applied climate projections (e.g., AMEC 2015, CBCL, 2018; CR&A, 2015; Finnis, 2013; Peck et al., 2012). This is due in part to the fact that many GCMs have only been run with RCP 4.5 and 8.5 as emissions scenarios. RCP 8.5 represents a future where very little is done to curb global emissions.

1.2 Downscaling Methods

Downscaling designates computational strategies that use coarse-resolution GCMs, (with typical gridded resolutions on the order of 100s of kilometers), to derive data at a gridded resolution of ≤ 50 km that are better suited to local scale applications such as floodplain modelling. Methods fall into two broad categories: 1) dynamical and 2) statistical.

Dynamical methods use coarse-resolution GCM data as boundary forcing conditions for more localized transient, process-based climate models (Schardong et al. 2018; Wilby & Dawson, 2015). These methods tend to be computationally intensive and expensive, but they allow modellers to account for localized factors that influence climate (e.g., orography and coastal dynamics; Luca & Elia, 2012; Mearns et al., 2013; Wilby & Dawson, 2015). Refer to García-García et al. (2019) for additional information about dynamical downscaling.

The generation of statistical downscaling datasets is relatively rapid and inexpensive, as they instead statistically associate GCM projections with observed historical records using comparatively simple relationships (Schardong et al., 2018; Thanh & Remo, 2018; Wilby & Dawson, 2015). Statistical downscaling can be further divided into synoptic weather typing, stochastic weather generators, and transfer functions (Wilby & Dawson, 2007). However, applying these methods to effectively downscale precipitation data has proven more challenging than other climate variables due to the complexity and variability of the driving mechanisms (CBCL, 2017; Tranberth et al., 2003; Wilby & Dawson, 2007).

The physical processes that generate precipitation often occur at finer scales than the spatial resolution of GCMs. This explains the greater uncertainty associated with precipitation projections than with other climate variables like air temperature. Model intercomparison studies have demonstrated that both statistical and dynamical methods represent historical climate conditions with comparable skill, but it is challenging to compare the relative skill of the future projections effectively (Halmstad et al., 2012; Wilby & Dawson, 2007; Wilby & Dawson, 2015).

1.3 Intensity-Duration-Frequency Curves

Intensity-Duration-Frequency (IDF) curves provide estimations of extreme rainfall probability, duration, and intensity. They are commonly applied by engineers, planners and hydrologists to inform design decisions (CSA, 2012). Environment and Climate Change Canada (ECCC) has precipitation data dating as far back as the 1840s with data available for 8761 weather stations

and over 1500 still active in 2018 (Government of Canada, 2018b). ECCC has used these data to generate short-duration IDF information for 549 weather stations across Canada (i.e., for rainfall events up to 24-hrs) (Government of Canada, 2018a). ECCC generates IDFs by fitting at least 10 years of historical rainfall records to a Gumbel probability distribution (i.e., Generalized Extreme Value Distribution Type-1), using the method of moments⁴ (CR&A, 2015; Finnis, 2013; Peck et al., 2012). Historical IDF information for the stations in the Atlantic Provinces can be accessed through the Extreme Precipitation in Atlantic Canada Web-Tool or the IDF_CC web-tool (ICLR, 2018; NRCC, 2016). If the reader is unfamiliar with how historical IDFs are traditionally produced, please refer to CSA (2012), as a detailed explanation is beyond the scope of this review.

It is advisable to consider climate change in municipal flood planning strategies (CBCL, 2017; CR&A, 2015; NRCan, 2018). IDF relationships have historically been calculated using observed data from precipitation monitoring stations alone, but methods do exist to account for how IDF relationships may be altered due to the impacts of climate change. Future patterns of rainfall can be estimated in several ways, including statistical manipulations, climate models, climate indices, and analyses of physical properties that control climate.

⁴ Other probability distributions more accurately fit some regional rainfall trends and the method of L-moments may be a more robust approach to curve parameterization (Peck et al., 2012; Pérez et al., 2003). In fact, several case studies have found that the Gumbel distribution is not the best distribution to represent their observed IDF data (CBCL, 2018; CBCL, 2017; Peck et al., 2012).

2.0 Scope of Report

The contents of this report will summarize available tools and approaches to account for **future rainfall projections in floodplain modelling**, with a focus on the development of future IDF information (i.e., IDF information that accounts for potential future climate conditions). Additional consideration is given to the use of Potential Maximum Precipitation in municipal floodplain modelling applications. As commissioned by the Government of Nova Scotia, the objective of this report is to recommend a systematic, conservative, defensible, and cost-effective approach to incorporate projections of future rainfall into municipal floodplain modelling.

3.0 Rainfall Projections in a Changing Climate

It is becoming increasingly common to incorporate climate model projections into decision making; therefore, several approaches for generating future rainfall projections have been developed that utilize the information from these models. These approaches are broadly categorized here as statistical, dynamical, and semi-physical (i.e., Clausius-Clapeyron scaling method). Although dynamical climate modelling may be the most sophisticated option to predict extreme precipitation, it typically requires significant expertise, resources, and time. As a result, the more simplistic, albeit less theoretically sound, statistical and semi-physical methods become more feasible to implement in practice. The following sections will review select tools and computational methods that can be applied to generate rainfall projections for municipal floodplain modelling in a changing climate.

3.1 IDF_CC Web-Based Tool

IDF_CC is an online statistical downscaling tool developed by the Institute for Catastrophic Loss Reduction (ICLR) at Western University. ICLR is an independent institution established by the insurance industry to mitigate the impact of natural disasters (ICLR, 2019). This tool was designed to help estimate the impact of climate change on IDF relationships in Canada for application in engineering and planning (ICLR, 2019). The user interface is intuitive, and guidance can be found in the accompanying user's manual (Schardong et al., 2018b).

This tool allows users to project future IDF relationships for any ECCC station up to the year 2100, using a limited selection of GCMs and RCPs. The current version of the software (Version 3.0) incorporates estimations for all ungauged areas in Canada using a machine learning algorithm and the nearest ECCC stations. As with all precipitation forecasting, the outputs of this program should be interpreted cautiously, especially the ungauged projections in areas with poor surrounding station coverage. This tool is constantly evolving and incorporating new functionalities; a re-evaluation of this software may be necessary if the software changes significantly from what was reviewed for this study. The following sections provide a summary of the background processes and functionality of the IDF_CC tool. For more information, refer to Schardong et al. (2018a).

3.1.1 Historical Data

Climatological data in IDF_CC are sourced from ECCC weather stations with a minimum of 10 years of data (i.e., gauged locations) and used to generate historical IDF curves with Gumbel and Generalized Extreme Value (GEV) distributions (Schardong et al., 2018a). Estimations of historical data for ungauged locations is synthesized from time series of 31 Atmospheric Variables (AV) between 1979 and 2013 from the North American Regional Reanalysis and European Era-Interim databases using machine learning algorithms (Table 1) (Schardong et al., 2018a).

Table 1. Atmospheric variables imported by the IDF_CC tool. The mean and maximum value for each variable were considered, except for precipitation, where only the mean variable was imported as the maximum precipitation value is the predictand of the machine learning algorithm. This table is adapted from Schardong et al. (2018a).

Predictor Number	Atmospheric Variable (AV)
1-2	Near-surface air temperature
3	Mean precipitation
4-5	Downward shortwave radiative flux (surface)
6-11	Geopotential Height (1000hpa, 850 hpa, 500 hpa)
12-13	Total cloud cover
14-15	Total wind speed
16-21	Specific humidity (1000 hpa, 850 hpa, 500 hpa)
22-23	Mean sea level pressure
24-25	Convective available potential energy
26-31	Vertical velocity (1000 hpa, 850 hpa, 500 hpa)

The reanalysis AVs are imported for all Canadian grid-points and bilinearly interpolated to each ECCC gauged station (Schardong et al., 2018a). After processing, reanalysis data are used to estimate historical IDF curves with GEV distributions. All historical IDF curve interpolation equations are fit using Differential Evolution (Schardong et al., 2018a).

3.1.2 Climate Models

IDF_CC includes 24 raw GCMs with variable resolutions (Table 7, Appendix A) selected from the CMIP5 and 9 downscaled bias-corrected Canada-wide climate models from the PCIC (Table 8, Appendix A), which cover a period from 1950 to 2100 at a gridded resolution of approximately 10 km. Bias correction was conducted by the PCIC using the statistical Bias Correction/Constructed Analogues with Quantile mapping reordering method (BCCAQv1). The GCM data in IDF_CC has been spatially interpolated to station locations using an inverse square weighting method. The PCIC GCMs and the raw GCMs are maintained separate for analysis purposes; however, the user can analyse each ensemble independently to consider their range of projections. The developers of IDF_CC suggest considering both ensembles to inform decisions (Schardong et al., 2018a). Other known climate models were excluded from the tool because of accessibility issues or a lack of the variables of interest (Schardong et al., 2018a).

3.1.3 User Input Options

The IDF_CC interface requires several user inputs before presenting/exporting results:

- 1) Gauged/ungauged location – Within the “IDFs for Ungauged Locations” tab, any coordinates may be selected in Canada. In contrast, within the “IDFs for Gauged Location” tab, only ECCC stations are available for selection. As an additional function, users may load in a custom dataset for analysis at any location in Canada.

- 2) Climate model – 33 individual climate models are available for analyses from the PCIC and CMIP5. Two multi-model ensemble options are available which calculate either the ensemble of 9 PCIC models, or the ensemble of 24 raw GCMs from the CMIP5.
- 3) Period of projection – IDF_CC limits users to projecting 50-year ranges between 2006 and 2100. Given the restriction of the future projection periods, the 2050-2100 period provides the most forward-looking projection; any other 50-year range could be considered, depending on the application.

3.1.4 Computational Processes

The developers of IDF_CC have proposed that statistical downscaling methods are more practical than dynamical downscaling methods for generating future rainfall information because of the reduced computational requirements (Schardong et al., 2018a). This advantage is demonstrated by the relatively efficient statistical computations that generate projections within IDF_CC. IDF_CC automates the analysis of climate model and reanalysis datasets using machine learning algorithms (i.e., Support Vector Machines), statistical transfer functions (i.e., Quantile Delta Mapping), frequency analyses (i.e., GEV distribution), and graphing algorithms to output future rainfall projections in a functional format. A detailed review of how IDF_CC calculates ungauged historical IDF and future IDF is found in Appendix B. For a more complete understanding of the background computations of IDF_CC, the reader is referred to Schardong et al. (2018a).

3.1.5 Output of IDF_CC

The IDF-CC tool provides several forms of output for both gauged and ungauged locations in Canada that could be utilized flexibly in floodplain analyses. Future IDF graphs display the median rainfall intensity or total rainfall for the selected period, whereas uncertainty boxplots for each rainfall duration offer quartile values (i.e., Q1, Q2, Q3) and the lower and upper bounds of the projection period. At this time, 95th percentile values may be calculated from data within a .csv file using the “Export All Results” option. Further details about the outputs are outlined in Table 2 for reference.

Table 2. Summary of the outputs of the IDF_CC Tool. Future IDF outputs are available for all 33 GCMs outlined in Appendix A for any ranges ≥ 50 years between 2006-2100. Rainfall can be analyzed as total rainfall (mm) or rainfall intensity (mm/h) at any stage. Rainfall Event Duration = R'; RT = Return Period(s); GL = Gauged Locations; GL&UL = Gauged and Ungauged Locations.

#	Output	Qualifying Output Details
1	Station Information	<ul style="list-style-type: none"> •Station Name and Numerical ID •Period of Data Record •Coordinate Location
2	Historical IDF Data	<ul style="list-style-type: none"> •Gumbel (GL Only) and GEV Distributions •Graphical and tabular data format •R' of 5, 10, 15, 20 and 30 minutes •R' of 1, 2, 3, 6, 12, 18, 24 hours •RT of 2, 5, 10, 25, 50, 100 years

		<ul style="list-style-type: none"> •Interpolation equations •Downloadable IDF data files
3	Future IDF Data	<ul style="list-style-type: none"> •GEV Distributions <ul style="list-style-type: none"> •Graphical and tabular data format •R' of 5, 10, 15, 20 and 30 minutes •R' of 1, 2, 3, 6, 12, 18, 24 hours •RT of 2, 5, 10, 25, 50, 100 years •RCPs 2.6, 4.5 and 8.5 scenarios available •Interpolation equations •Downloadable IDF data files •Uncertainty Boxplots <ul style="list-style-type: none"> •Every RT, R' and RCP future scenario •Downloadable uncertainty data files
4	Comparison Graphs	<ul style="list-style-type: none"> •GEV – RT Distributions <ul style="list-style-type: none"> •Compares rainfall projections for each RT, R' and RCP to historical data

3.1.6 IDF_CC Tool Limitations

The statistical temporal scaling method applied by IDF_CC **assumes that sub-hourly rainfall events will scale at the same rate as daily rainfall events**. However, there is an increasing body of evidence to suggest that, because rainfall events of different length and intensity have different driving processes (e.g., regional convective storms compared to synoptic storms), daily and sub-daily extreme events will not scale at the same rate (e.g., Ali & Mishra, 2018; CSA, 2012; Molnar et al., 2015; Singleton & Toumi, 2012; Tranberth et al., 2003). This limitation is based on physical precipitation formation processes and is acknowledged by the IDF_CC tool developers (Simonovic et al., 2016).

IDF_CC outputs are limited by the accuracy of the applied GCMs, selected downscaling techniques, and the current understanding of climate science. Some of this uncertainty is reflected by the variable range of precipitation projections among the various climate models within IDF_CC (ICLR, 2018). The use of raw CMIP5 GCMs for daily rainfall projections may also be criticized for its poor theoretical defensibility, as their resolution is extremely coarse. Furthermore, IDF_CC currently excludes several GCMs and does not incorporate RCMs. Thus, IDF_CC does not represent the entire range of available models, nor does it analyse the relative “skill” of the select GCMs (e.g. by k-fold cross-validation). The IDF_CC tool is somewhat inflexible and tightly controls how users may interact with data; however, this could be perceived as an advantage as it limits opportunities for human error and bias to be introduced.

IDF_CC is managed and supported by the ICLR at Western University and is potentially limited by upkeep and funding considerations. There are uncertainties regarding ongoing support and enhancement of IDF_CC that necessitate further inquiry. For example, upon finalization of the CMIP6, a significant overhaul of the software will have to be undertaken to ensure that IDF_CC remains relevant. Even now, a more comprehensive ensemble of statistically downscaled climate models is available from PCIC/ECCC that could replace the existing ensemble of 9 PCIC bias-corrected GCMs. There are opportunities to enhance IDF_CC to better meet the needs of practitioners by collaborating with the ICLR. For

example, the calculation of the 95th percentile of future rainfall projections could be automated instead of users having to do this computation externally. Alternatively, a custom climate model input operation, an extreme value distribution selection framework, and a more comprehensive climate model ensemble could be considered. Direct consultations with the ICLR should clarify the expected sustainability and potential adaptability of this tool.

Finally, IDF_CC only generates projections for 50-year intervals, which is in excess of typical climate normals that range from 5-30 years (NOAA, n.d.; WMO, 2017). This interval size may skew projected median values. However, the WMO also states that climate normals beyond 30 years may be appropriate when dealing with extreme precipitation to more accurately capture the spatial and temporal variability of analysed periods (WMO, 2017). Likewise, Arguez and Vose (2011) suggest that climate normal standards need to be reviewed and modified to better reflect the influence of a changing climate. In any case, a range of output within the 50-year window is available for consideration in IDF_CC, but specific output parameters will need to be designated for standard practice (e.g., median, third quartile, 95th percentile, upper bound value).

3.1.7 IDF_CC Tool Advantages

The Institute for Catastrophic Loss Reduction has developed a very rapid, easy to use, free, and easily accessible software package for IDF curve development. The primary advantage of IDF_CC is that it automates computational processes that would otherwise consume time and resources, and users require very little knowledge or training to use this tool effectively. Also, IDF_CC is the only software package reviewed that provides estimations for future sub-hourly rainfall events, which could be very important in floodplain assessments. In addition, the range of uncertainties are available for consideration within the tool, and historical and future IDF curves are readily available for export. Finally, the numerical extreme rainfall values for historical and future projected IDFs can be exported for external analyses, and custom historical datasets can be imported into the tool. Table 3 summarizes some of the main advantages and disadvantages of the IDF_CC tool.

Table 3. Select advantages and disadvantages of the IDF_CC tool for future IDF development.

Advantages	Disadvantages
Sub-daily rainfall projections achievable	Dependent on the accuracy of GCMs, statistical techniques and the quality/quantity of the historical record
Virtually no data handling, training, or computations required	Inflexible interface options (i.e., projection period, GEV curve fit, GCM selection)
Data available for all of Canada	No measure of relative “skill” of GCMs
Accessible on all operating systems online	Does not utilize RCM data
Applicable graphical and tabular output	Assumes daily and sub-daily rainfall will scale at the same rate

Extremely rapid and easy to use	Uncertainty regarding tool upkeep
	Climate model ensembles require updating

3.2 The Clausius-Clapeyron Scaling Method

The Clausius-Clapeyron (C-C) equation represents the moisture-holding capacity of air and its dependence on temperature. Some climate scientists have used this equation to suggest that extreme precipitation will increase by approximately 7% per degree Celsius ($\sim 7\%/^{\circ}\text{C}$) in the future (Trenberth et al., 2003). This approach is inspired by physical principles, (i.e. it could be referred to as semi-physical), but it is most comparable to statistical scaling methods.

3.2.1 Overview of C-C Scaling Research

Westra et al. (2013) collected data from 8326 high-quality weather stations across the globe and demonstrated that the global median rate of daily precipitation increase was between 5.9 and 7.7%/°C. Although this supports the claim that a scaling rate $\sim 7\%/^{\circ}\text{C}$ is observable for the median daily extreme precipitation at the global scale, the same study demonstrates significant latitudinal variation (Westra et al. 2013). In addition, the authors were uncertain if these findings should be applied to sub-daily timescales (Westra et al. 2013). Similarly, there is a suggestion in the literature that $\sim 7\%/^{\circ}\text{C}$ may be inadequate to characterise extreme convective rainfall events and may serve as a lower limit for design in certain regions (Blenkinsop et al., 2015; Lenderink, et al., 2017; Trenberth et al., 2003). Limited study scopes, varying or undefined climatological and orographic factors, and different evaluation criteria make the direct comparison of study findings difficult. In addition to these challenges, a paper by Koutsoyiannis (2012) questions the accuracy of the C-C equation form that is most commonly applied.

Different studies at the regional scale have illustrated the potential for rainfall-temperature scaling that ranges from below that predicted by C-C scaling up to double, with significant seasonal variability and dependency on moisture availability (e.g., Blenkinsop et al., 2015; Lenderink, et al., 2017; Pall et al., 2007; Singleton & Toumi, 2012; Wang et al., 2017). Prein et al. (2016) even suggest that the relationship between temperature and extreme rainfall is too complex to simply extrapolate the scaling rate from historical data. There are many documented cases where the $\sim 7\%/^{\circ}\text{C}$ appears to be followed, and other studies that give reason to question the regional-scale applicability of this method for anything other than preliminary evaluations. As such, it is likely that a regional-scale assessment would have to be conducted to assess regional temperature-moisture trends in Nova Scotia in order to determine an appropriate scaling factor. Alternatively, conservative estimates of scaling factors, which are supported in the literature, may be used as a surrogate for regionalized assessments. Ultimately, more sophisticated multivariate methods are being developed that may supersede the bivariate scaling relationship prescribed by the C-C method (e.g., Cheng & AghaKouchak, 2014; Wilby & Dawson, 2007).

3.2.2 Application & Limitations of C-C Scaling Factors

The existing body of evidence in support of the C-C relationship is thought to be sufficiently compelling by many members of the scientific community to warrant its

inclusion in future IDF methods (e.g., Prein et al., 2016; Wang et al., 2017). How the temperature-moisture relationship should be applied to account for climate change in IDF information is still the subject of research and discussion.

One possible method begins with the extraction of the expected mean daily maximum temperatures from a multi-model ensemble of RCMs/GCMs for the future period in question. Temperature projections could then be interpolated to a particular station location. The relative temperature change between the historical model period and future period of the multi-model ensemble could then be extracted⁵. Following this analysis, a 7%/°C scaling factor could be applied directly to observational IDF rainfall extremes expected to be dominated by synoptic patterns (i.e., generally >12 hours), and super-C-C factors could instead be applied to rainfall durations dominated by convective events (e.g., 10-14%/°C for events <6 hours). This method yields event-based future rainfall projections, as opposed to complete IDFs, which is adequate for floodplain modelling. In the C-C scaling method, future rainfall projections (R_{Future}) are related to present day observed rainfalls of the same duration ($R_{Historical}$), the prescribed scaling factor (SF), and the relative temperature change (ΔT) of the multi-model ensemble by Equation 1:

$$R_{Future} = R_{Historical} * (SF)^{\Delta Temp} \quad \text{Equation 1}$$

The exact scaling factors applied to each rainfall duration can be easily modified and should be reflective of regional conditions; however, a 7%/°C scaling factor is often perceived as a minimum value for conservatism, as latent heat release and environmental factors may enhance moisture-convergence (Blenkinsop et al., 2015; Lenderink, et al., 2017; Tranberth et al., 2003; Wang et al., 2017). There is currently no standard for which GCMs or RCMs to include in this analysis, which temperature parameter is most appropriate (e.g., daily, annual, median, upper bound), or which scaling factors should be applied, and limited historical reference data will hinder the assessment of regional temperature-moisture scaling relationships. A general C-C scaling process is described in Figure 1 for clarity.

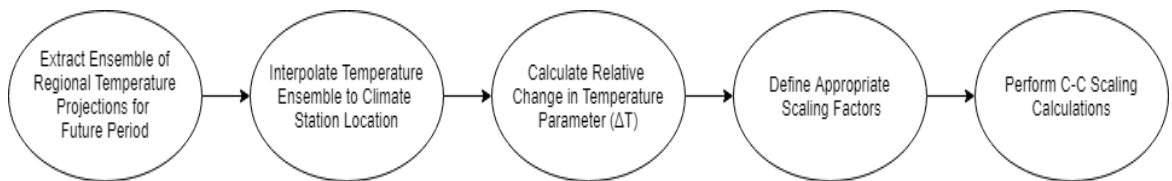


Figure 1. Generalized C-C scaling approach for generating future event-based rainfall projections.

Despite the limitations and oversimplifications intrinsic to the application of C-C scaling factors, the reality is that there are few other methods that yield estimations for sub-hourly

⁵ A historical and future 30-year period of reference is likely appropriate for temperature projections based on justifications found in WMO (2017). Also, the results across GCMs are more consistent for temperature than precipitation (Schardong et al., 2018a), which supports the adoption of a relatively short projection period.

time scales and are sufficiently simple to implement in practice. Additionally, it has been demonstrated by Schardong et al. (2018c) that the semi-physical C-C and statistical IDF_CC projection methods yield comparable rainfall projections. Given the uncertainty involved at this time in all rainfall projection strategies, it would be prudent to include C-C scaling results as part of a multi-method approach and not weigh its results more heavily than other methodologies. Table 4 summarizes some of the main advantages and disadvantages of the C-C method.

Table 4. Select advantages and disadvantages of the C-C method for future IDF development.

Advantages	Disadvantages
Based on simplified physical principles	No standards established for GCM/RCM, temperature parameter, or scaling factor selection, which creates an opportunity for introduction of bias & human error
Low to moderate computational resources and expertise required	Scaling factors vary based on the regional mechanisms of precipitation formation & data is often limited for such characterisation
Sub-daily rainfall estimation achievable	Dependent on GCM/RCM temperature projections being accurate and historical data being of adequate quality and length
Can use both GCM and RCM projections	No prescribed software to automate any of the computations & generating complete IDF curves may be tedious
Dependent on GCM/RCM and downscaled temperature projections which are considered more reliable than precipitation projections	Significant simplifying assumptions
Able to scale different rainfall durations differently	

3.3 Statistical Downscaling Model Tool

The Statistical Downscaling Model Version 5.2 (SDSM) is a Windows-based support tool associated with Loughborough University in the UK that integrates two statistical methods, stochastic weather generators (SWGs) and transfer functions, in conjunction with GCM output to develop future daily projections at point locations (Wilby & Dawson, 2007). SWGs are random number generators with strict statistical limits that restrict projections to within expected climatological bounds, whereas transfer functions are correlative equations that associate different variables and datasets. The hybrid statistical method employed by SDSM is very efficient computationally, allowing for an ensemble of up to 100 realizations with identical statistical characteristics to be generated simultaneously. In the newest version (Version 5.2), the tool also permits users to evaluate the performance of models based on k-fold cross-validation

and includes a new data portal to access region-specific reanalysis variables (Wilby & Dawson, 2015). SDSM has been evolving since the early 2000s and has been applied in hundreds of published studies across the world, predominantly in China, Canada, and Iran (Wilby & Dawson, 2016).

3.3.1 SDSM Computational Process

This section will discuss the basic processes that SDSM conducts to generate future climate projections. First, the user must select what parameter they want to project (i.e., Extreme Precipitation). Next, observational and reanalysis data must be imported into the tool by the user. SDSM screens the datasets to assist with the selection of appropriate seasonal predictors. Based on user directives, the tool will develop empirical predictor-predictand relationships using dual simplex or least squares optimization algorithms (Wilby & Dawson, 2007). The empirical relationships are applied to calibrate the weather generator for the baseline period (Wilby & Dawson, 2007). Finally, an imported GCM scenario is used to perturb the weather generator, yielding daily future projections of the selected parameter. The outcomes of the realizations are statistically analysed, presented graphically within the tool, and can be downloaded for external analyses.

3.3.2 SDSM Limitations

The SDSM tool is only Windows based, so Mac or Linux users would have to mount Windows on a virtual system. Further, the entire SDSM interface allows users flexibility in the definition of the model realizations, which requires climatological expertise that most municipal or engineering professionals would likely have to acquire. The magnitude of the (extreme rainfall) projections is heavily impacted by the user and so they would have to be well informed in order to make appropriate selections; the authors suggest that precipitation projections can become unrealistic if the model is not properly calibrated within the tool. Having so much user input can be beneficial if used correctly, but it also may introduce human error and bias.

The SDSM tool interface appears to be relatively simple compared to the Regional Climate Model Evaluation System (Section 3.4 Regional Climate Model Evaluation System (RCMES)), but it lacks comparable capabilities for visual representations, RCM data integration, and relative model “skill” assessment. SDSM compares the relative skill of models using k-fold cross-validation only. However, a model demonstrating “skill” in representing daily rainfall values, does not necessarily imply that the model will accurately represent sub-daily estimations (CSA, 2012). The SDSM skill metrics are also based on the comparison of baseline models with observed historical data and do not necessarily represent an evaluation of how well the model will represent future data (Wilby & Dawson, 2015).

As with all projection methods driven by GCMs and RCMs, the reliability of SDSM results are heavily impacted by the uncertainties of the forcing climate models. In acknowledgement of this limitation, the authors recommend applying an ensemble of GCMs (Wilby & Dawson, 2007). However, the tool does not facilitate this process, so the analysis would have to be conducted externally. In fact, only two GCMs (i.e., HadCM3

and CGCM2) are readily available in the SDSM suite, so alternative GCMs would presumably have to be compiled, spatially normalized if necessary, and imported by the user. Generating IDF curves based on ensemble data in this way would prove to be a time consuming process, with several opportunities for errors.

There are graphing capabilities built into the software, but since sub-daily projections are incompatible with the tool, SDSM has little potential for producing useful IDF information. On many levels, SDSM is not as well suited as the IDF_CC web-tool for the particular application of future IDF development. Table 5 summarizes some of the main advantages and disadvantages of the SDSM tool.

Table 5. Select advantages and disadvantages of the SDSM tool for future IDF development.

Advantages	Disadvantages
Can generate an ensemble of 100 realisations with identical statistical profiles	No estimate for sub-daily rainfall
Moderate computational complexity	Dependent on GCM projections being accurate and historical data being of adequate quality and length
Moderate expertise required	Significant data management required
Assists with predictor selection, data screening and sophisticated data analysis	Does not automate multi-model ensemble calculations
	Does not generate IDF curves automatically (data would have to be exported, synthesized and analysed or manipulated using the tool's frequency analysis functions)
	Not meant to utilize RCM data
	Many opportunities for error, bias, and model instability to be introduced
	Windows-based software package

3.4 Regional Climate Model Evaluation System (RCMES)

The Regional Climate Model Evaluation System (RCMES) is an open-source software package developed in Python and the Apache Software Foundation's Open Climate Workbench project. This tool was funded by the National Aeronautics and Space Administration (NASA) to support national and global climate modelling initiatives (e.g., NARCCAP and CORDEX). One of the greatest challenges that climate modelling faces today is developing methods of comparative analysis that inform researchers of the particular advantages and shortcomings of each climate model (Lee et al., 2018; Schadong et al., 2018a). The RCMES interface allows users to assess and compare global and regional climate models in a reproducible manner by calculating various performance metrics, generating visual representations of data, and providing a space for rigorous collaboration and peer-review (Lee et al., 2018). RCMES also has various built-in reprocessing

capabilities in order to reorganize, regrid, and represent climate data as the user requires. Some datasets are preloaded into the software, but users can also load in external datasets that they have collected or data directly from the Earth System Grid Federation servers, which are connected to the software package.

3.4.1 RCMES Limitations

The RCMES is open-source and relatively new, so it is being collaboratively adapted continuously to meet the needs of climate researchers. The software is Linux-based, which requires Windows and Mac users to mount a virtual system to access it. In addition, a significant amount of time, training, and expertise would be necessary in order to harness the complete potential of the software due to its operational complexity. Complex model intercomparisons and future projections would be computationally intensive, potentially requiring powerful equipment, as well as a significant amount of time and data storage. This tool was produced with model intercomparison in mind and not explicitly for IDF curve development, but has close to unlimited potential because users can incorporate custom Python code (Lee et al., 2018). Thus, the user could conceivably program IDF curve generation into the software that uses outputs from the toolkits’ standard operations. Due to these inconveniences and the high level of expertise required, the RCMES is unlikely to be a tool that is easily applied in standard practice.

Table 6. Select advantages and disadvantages of the RCMES for future IDF development.

Advantages	Disadvantages
Significant task flexibility	Would require customization of Python code in order to automate the functionalities desired for application in IDF development
Can process GCM and RCM data	Dependent on GCM projections being accurate and historical data being of adequate quality and length
Built-in functions to compare any GCM or RCM by common metrics to identify model bias or relative skill for a region	Significant data management required
Several built-in databases, computational procedures, and analytical tools	High expertise required
	High computational complexity
	Many opportunities for error, bias, and model instability to be introduced
	Only a Linux-based software package

3.5 Other Rainfall Projection Methods for IDF Development

There are several other methods that have been mentioned in CSA (2012) and CR&A (2015) to generate future rainfall information, and this section will review some of these methods briefly

for completeness. These techniques are either still being applied or have evolved into more sophisticated forms in modern tools, some of which have already been discussed.

3.5.1 Extrapolation of Historical Trends

This method assumes that historically observed trends in precipitation will continue into the future. For example, Denault et al. (2006) fit a linear trend to historical data for North Vancouver and extrapolated this trend into the future to estimate rainfall. A similar approach is used to define baseline sea level projections in a tool developed by the Bedford Institute of Oceanography (BIO, 2017). How the data are fit would have a significant impact on future predictions, as well as the completeness and length of the historical record. Regardless of fit, this model assumes that historical trends will remain the same into the future, despite models projecting that this will not be the case (IPCC, 2014).

3.5.2 Delta Methods and Scale Factors

This method describes a suite of potential transfer functions that relate long-term projected rainfall and wet days, from GCMs or RCMs, to daily/sub-daily historical data and vice-versa. Transfer functions vary significantly, as they may be developed between different datasets using various statistical approaches (e.g., linear, non-linear, and data-driven). An example of this is the Quantile Delta Method applied in the IDF_CC tool (Schardong et al, 2018; Srivastav et al., 2014). Other recent case studies applying scaling factors are widely available (e.g., Thanh & Remo, 2018; O'Connor & Dillon, 2015). As described previously, the main limitation of these methods is that they assume that historically observed relationships between observational and model parameters will remain constant with time when current evidence suggests that this will not be the case.

3.5.3 Upper Confidence Intervals and Safety Factors

Another potential approach to modifying IDF information to account for future climate change is to use the upper confidence intervals for each return period (e.g., Wang & McBean, 2014). A comparable strategy is to inflate safety factors by a conservative amount (e.g., Webster et al., 2012). This strategy involves simply applying historical data more conservatively and is not particularly evidence-based. Poor judgement could result in gross over/underestimation of future rainfall that could result in unjustified losses when more evidence-driven methods are available to project rainfall.

3.5.4 Raw RCM/GCM Output

Some studies have directly applied the raw results of climate models (CSA, 2012). Given the current limitations and variability amongst different climate models, this strategy is questionable without significant validation. Furthermore, the temporal resolution of current RCM and GCM data does not provide the sub-hourly definition required for IDF relationships.

3.5.5 Nonstationary Frequency Analysis and Climate Covariates

At this time, IDF curves are typically generated under the assumption of stationarity of the historical record (Cheng & AghaKouchak, 2014). Even if the frequency analysis were based on a future climate dataset, the future IDF curve would assume the stationarity of the

range of years it represents (e.g., 2070 to 2100). Nonstationary models instead incorporate time and/or climate covariates into the frequency analysis to generate rainfall projections for the changing state of the climate with greater skill (Cheng & AghaKouchak, 2014; Trambly et al., 2013; Vasiliades et al., 2014). However, projecting future rainfall with mathematical covariate relationships assumes the stationarity of those relationships (Trambly et al., 2013).

Alternatively, nonstationary analysis can be used to generate nonstationary future IDF curves based on GCM/RCM rainfall projections, accounting for the parameter variability within the future range of years. However, one study found that assuming the stationarity of future periods improved the interpretability of projections for flood assessment applications because of the high inter-annual variability of projected covariates (Shrestha et al., 2015). This method of analysis requires a significant amount of expertise and time (Shrestha et al., 2015), and it is unclear if using nonstationary models sufficiently improved the overall quality of the projections to justify such an investment.

3.5.6 Perturbed Stochastic Weather Generators

Weather generators are typically used to randomly produce short-term rainfall projections within predefined limits based on historical data. For long-term projections, the statistical bounds of a weather generator can be inflated using the projections of future GCMs; the SDSM decision support tool applies such a strategy. Scaling relationships used to develop the weather generator remain constant, a common limitation noted with several other statistical methods (i.e., Delta Method, Quantile Delta Mapping). An advantage of this approach is that it can produce several equally possible future scenarios with the same statistical profile (Wilby & Dawson, 2007).

3.6 Potential Maximum Precipitation

The Potential Maximum Precipitation (PMP) estimates the theoretical maximum seasonal rainfall that is physically possible for a region over a particular duration event (Watt et al., 1989; WMO, 2009). If other exacerbating factors align with the PMP, then the Potential Maximum Flood (PMF) may occur (WMO, 2009). The PMP/PMF can be used as an alternative to a particular return period from an IDF curve to design infrastructure or develop a flood model. Due to the complexity of storms and the limited state of pertinent knowledge, only approximations can be made at this time. PMP is typically considered a very conservative design standard and is most often reserved for the design of major dams and floodways with very low risk tolerance (ATCED, 2004). That considered, it is unlikely to be appropriate for typical design or planning applications, but it does provide the theoretical upper bound for consideration. Additionally, PMP may be considered in an assessment so that municipalities have an approximation of the worst possible outcome. There are several methods of estimating present-day PMP that can be reviewed in the WMO Manual on Estimation of PMP (2009), but the CSA (2012) divides them into two methods which are established in industry: 1) statistical and 2) meteorological.

3.6.1 The Hershfield Statistical Method

The Hershfield statistical method is mainly applied to watersheds of under a 1,000 km² area, though it has been applied in larger watersheds (WMO, 2009). This method relies on historical data in order to represent an abstracted largest storm event that can be used to calculate the PMP at a point location (WMO, 2009). If necessary, the areal mean of the PMP can then be calculated using a storm-point area relationship. These calculations are rapid and require a low level of expertise, but the quality and completeness of the historical records can drastically modify the estimated PMP; thus, this method depends on historical rainfall records capturing the data necessary to properly characterise the PMP event (WMO, 2009). It is important to consider that 90% of the station data used to develop the Hershfield empirical relationships were in the United States, with a minimum historical record of 10 years and a minimum temporal resolution of daily measurements. A historical record of 10 years is unlikely to adequately characterise PMP effectively and there is evidence to suggest that this empirical relationship may not be consistent for Canada (WMO, 2009). Additionally, this method tends to yield lower estimates of PMP when compared to other standard methods (WMO, 2009). Both the WMO and CSA suggest that this method is less reliable than analyses based on comprehensive meteorology, suggesting that it would be imprudent to drive design using the Hershfield method (CSA, 2012; WMO, 2009).

3.6.2 Storm Modelling and Maximization

More reliable estimations of PMP can be determined using modelling of storm events and the subsequent maximization of dynamic and physical factors. These meteorological approaches require more expertise, time, and resources, but yield results that are considered better approximations of theoretical maximum rainfall (ATCED 2004; CSA, 2012). The two general approaches consist of generating PMP predictions based on either a modelled storm area or the area of the watershed itself (WMO, 2009). According to the WMO (2009), there are seven different meteorological methods to calculate PMP (e.g., local,

transposition, combination and inferential methods). These methods estimate design storms based on historical rainfall and/or flood data from the watershed, generalized physical modelling, or based on adjusted storms from adjacent watersheds (ATCED 2004; WMO, 2009). Next, the theoretical upper-limit of the moisture holding capacity for these storms is calibrated for the seasonal conditions in which they occur and are assumed to operate at maximum efficiency (ATCED, 2004; Watt et al. 1989; WMO, 2009). Finally, orographic influences may be incorporated into the model for areas with significant elevation differentials (ATCED 2004; Watt et al. 1989).

3.6.3 Limitations of PMP and Climate Change

The results of both meteorological and statistical methods for PMP predictions are heavily dependent on the length and quality of historical rainfall records (CBCL, 2017). Furthermore, there is a limited ability to quantitatively evaluate the different methods due to the current limits of climate science and historical data availability (CBCL, 2017; WMO, 2009). As such, it has become common practice to consider multiple PMP assessments as a form of quality assurance in the United States and China (WMO, 2009). Thus, an ensemble approach would be the most prudent way to consider PMP. However, **PMP is typically considered overly conservative for most municipal applications** (ATCED, 2004). To contextualize this statement, a flood assessment in Nova Scotia demonstrated that the statistical PMP, calculated using historical data and the method proposed by Hershfield, still significantly exceeded the regions 1:100-year 24-hour and 48-hour rainfall projected for the year 2100 estimated by two different methods (CBCL, 2017). At least in this case, this suggests that historical PMP estimations are more conservative than standard flood design storms that account for the climate change expected over the next century.

As mentioned, current PMP methods assume the stability of climate conditions, which has already been established as imprudent when considering IDF relationships. Involving climate modelling into PMP estimations would include another significant source of uncertainty. However, for high-risk projects whose design is driven by PMP assessments (i.e., dam design or nuclear plant design), the analysis should likely be done considering the effects of climate change. In these cases, PMP should likely be calculated using one of the more reliable meteorological ensemble methods. Alternatively, if PMP is only being considered qualitatively as a “worst-case” scenario, then applying statistical methods with historical data is likely adequate, since incorporating future climate projections would increase uncertainty. If statistical PMP values are to be included in future floodplain assessments, it should be clearly communicated that they are not intended to drive design or planning or to be interpreted as having high accuracy (i.e., PMP is not recommended for typical municipal floodplain modelling applications). Details of PMP calculation, politics and application can be found in WMO (2009), Watt et al. (1989), and ATCED (2004).

4.0 Discussion & Recommendations

This report assessed several methods of calculating future rainfall projections within the present context of climate science, but two methods were deemed most appropriate for municipal floodplain modelling applications: the semi-physical C-C scaling method and the statistical method prescribed by the IDF_CC tool. Although imperfect, these methods can be applied in a defensible, conservative, systematic, and cost-effective manner. Alternatives were considered relatively unsatisfactory to drive floodplain modelling at the municipal scale (e.g., PMP, dynamical approaches, SDSM). Thus, it is recommended as a minimum standard that the C-C method and IDF_CC tool be applied in parallel to augment historically based predictions of extreme rainfall. **See Appendix C for the in-depth recommended future rainfall projection procedure.**

Considering the amount of uncertainty surrounding current and future trends in extreme rainfall, and the known limitations and uncertainties of the prescribed methods, as described in their respective sections, it is advisable to proceed by the precautionary principle. This principle is explicit in the recommended approach by the use of the more conservative rainfall projection of two distinct projection methods (i.e., C-C scaling method and the IDF_CC method), and the use of a climate multi-model ensemble approach.

If the Government of Nova Scotia were to standardize the application of the C-C method and IDF_CC tool in hydrological floodplain modelling, additional support and investment should be considered to maintain and develop software packages. Data handling and analysis are likely some of the more laborious tasks associated with future rainfall projections, and tools like IDF_CC minimize the workload and opportunity for error throughout the process. Maintenance and development of accessible analysis tools and climate databases would facilitate municipal floodplain mapping throughout the province. It is likely that modifying existing software packages would be more cost effective and productive than developing new tools. Keeping this in mind, it has been noted that some attributes of IDF_CC may be modified to better assist municipal floodplain modelling efforts in Nova Scotia. Some potential modifications to IDF_CC for consideration include:

- 1) updating the PCIC climate model ensemble available within IDF_CC – this should be the first priority, as a more comprehensive statistically downscaled ensemble is now available from PCIC and ECCC;
- 2) incorporating the CORDEX regional climate model ensemble;
- 3) including 95th percentile rainfall projection as a direct output – this can be calculated externally, but it is inconvenient;
- 4) adding an extreme value distribution selection/optimization operation – GEV curves are not always the most appropriate curve to represent regional extreme rainfall data;
- 5) adjusting the output format of the .csv file such that it could be formatted into columns, and organised by RCP scenario on an additional worksheet, to facilitate external data analysis;

- 6) incorporating C-C scaling operations; and
- 7) including relative increase in precipitation (%) as an output.

Although an investment in this tool development is recommended, it is important to recognize that these methods (i.e., the C-C and IDF_CC approaches) will likely be phased out or refined as more comprehensive approaches are developed and become practicable. Meanwhile, it is recommended that both of the two approaches outlined be used in municipal floodplain modelling.

The recommended approach, detailed in Appendix C, relies on the PCIC statistically downscaled climate scenarios provided through the ECCC website. Climate data acquisition is accomplished using the ECCC Climate Data Extraction Tool. At this time, users must contact the Climate Services Support Desk to receive the daily projections of temperature required for the C-C scaling approach. As an additional recommendation, the Government of Nova Scotia should consider working with ECCC to make daily data more easily accessible from their database to facilitate municipal floodplain modelling in Nova Scotia.

Although it is impossible to predict how quickly climate science will proceed, and in which direction, there are certain expected developments worth mentioning that are likely to be of significant importance. For example, the next IPCC synthesis report (AR6) is expected to be complete by 2022 and will help standardize knowledge on climate change and direct future studies. Included as a component of this initiative, new global climate models will become accessible in the following years to facilitate future climate studies. Separately, the CSA is anticipated to release new IDF technical guidelines, which will propose methodologies to incorporate climate change and other valuable considerations into IDF development (CSA, 2018). This guideline is also expected to include recommendations on how to enhance climate monitoring programs (CSA, 2018). Another initiative to be aware of is that NRCan is expected to continue to publish new guidelines within the Federal Flood Mapping Guidelines Series to inform provincial and municipal stakeholders (NRCan, 2018). Looking forward, further consideration should be given to impending developments such as high resolution convective and cloud-resolving dynamical models (Prein et al., 2016), enhanced definition of the impacts of aerosols on climate (IPCC, 2014), and alternative statistical approaches (e.g., SDExRain [Yeo & Nguyen, 2017]).

5.0 Conclusion

In general, it is accepted that accounting for the potential impacts of climate change is key to making informed management decisions in engineering and planning. This report has discussed some of the current methods, tools, and challenges associated with the incorporation of climate change projections into IDF rainfall information. In the interest of public safety, a conservative approach was recommended in light of the various uncertainties associated with climate change modelling and methods of projecting future rainfall. With consideration of the current limitations of climate science, the recommended approach achieves the objective of a conservative, systematic, cost-effective and defensible method of projecting future rainfall. As the science progresses, it is anticipated that the recommended approach will be phased out or refined as more comprehensive methods are developed and become practicable. Meanwhile, the recommended approach supplies a conservative and defensible estimation of potential future rainfall for use in municipal floodplain modelling in Nova Scotia.

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Appendix A: IDF_CC Climate Models

Table 7. Raw CMIP5 GCM model ensemble in IDF_CC tool. Table adapted from Schardong et al. (2018a).

Model	Centre Name	Realizations	GCM Atmospheric Resolutions (Lon. vs Lat.)
bcc_csm1_1	Beijing Climate Center, China Meteorological Administration	1	2.8 x 2.8
bcc_csm1_1 m	Beijing Climate Center, China Meteorological Administration	1	2.8 x 2.8
BNU-ESM	College of Global Change and Earth System Science	1	2.8 x 2.8
CanESM2	Canadian Centre for Climate Modeling and Analysis	5	2.8 x 2.8
CCSM4	National Center of Atmospheric Research	1	1.25 x 0.94
CNRM-CM5	Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et de Formation Avancee en Calcul Scientifique	1	1.4 x 1.4
CSIRO-Mk3-6-0	Australian Commonwealth Scientific and Industrial Research Organization in collaboration with the Queensland Climate Change Centre of Excellence	10	1.8 x 1.8
CESM1-CAM5	National Center of Atmospheric Research	1	1.25 x 0.94
EC-EARTH	EC-EARTH	1	1.25 x 1.25
FGOALS_g2	IAP (Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China) and THU (Tsinghua University)	1	2.55 x 2.48
GFDL-CM3	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory	1	2.5 x 2.0
GFDL-ESM2G	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory	1	2.5 x 2.0
GFDL-ESM2M	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory	1	2.5 x 2.0
HadGEM2-AO	Met Office Hadley Centre	1	1.25 x 1.875
HadGEM2-ES	Met Office Hadley Centre	2	1.25 x 1.875
IPSL-CM5A-LR	Institut Pierre Simon Laplace	4	3.75 x 1.8
IPSL-CM5A-MRMIROC5	Japan Agency for Marine-Earth Science and Technology	3	1.4 x 1.41
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology	1	2.8 x 2.8
MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology	1	2.8 x 2.8
MPI-ESM-LR	Max Planck Institute for Meteorology	3	1.88 x 1.87
MPI-ESM-MR	Max Planck Institute for Meteorology	3	1.88 x 1.87
MRI-CGCM3	Meteorological Research Institute	1	1.1 x 1.1
NorESM1-M	Norwegian Climate Center	3	2.5 x 1.9

Table 8. Models used in the IDF_CC tool from the PCIC ensemble. BCCAQ method was applied to downscale the original models to a gridded resolution of ~10 km. Table adapted from Schardong et al. (2018a).

Bias Correction	Model	Centre Name	Original (Lon. vs Lat.)
BCCAQ	CanESM2	Canadian Centre for Climate Modeling and Analysis	2.8 x 2.8
BCCAQ	CCSM4	National Center of Atmospheric Research	1.25 x 0.94
BCCAQ	CNRM-CM5	Centre National de Recherches Meteorologiques and Centre Europeen de Recherches et de Formation Avancee en Calcul Scientifique	1.4 x 1.4
BCCAQ	CSIRO-Mk3-6-0	Australian Commonwealth Scientific and Industrial Research Organization in collaboration with the Queensland Climate Change Centre of Excellence	1.8 x 1.8
BCCAQ	GFDL-ESM2G	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamic Laboratory	2.5 x 2.0
BCCAQ	HadGEM2-ES	Met Office Hadley Centre	1.25 x 1.875
BCCAQ	MIRCO5	Japan Agency for Marine-Earth Science and Technology	1.4 x 1.41
BCCAQ	MPI-ESM-LR	Max Planck Institute for Meteorology	1.88 x 1.87
BCCAQ	MRI-CGCM3	Meteorological Research Institute	1.1 x 1.1

Appendix B: IDF_CC Detailed Computational Processes

B1. Computations for Ungauged Historical IDF in IDF_CC

Imported Atmospheric Variables (AVs) are analyzed in order to produce a statistical estimate of the historical IDF information at all reanalysis grid-points. Once the AVs have been fetched for the reanalysis grid and interpolated to the station locations, a machine learning algorithm (i.e., Support Vector Machines) evaluates the 31 AVs and optimally incorporates those which have strong correlations with extreme precipitation into a computational model for each rainfall duration (Schardong et al., 2018a). This is done at each precipitation gauging station independently by systematically correlating the observed historical data of extreme precipitation with reanalysis AVs using chi-squared tests to compare two linear regression models. Because of its consistency as an effective predictor, mean precipitation is the initial predictor at all locations (Schardong et al., 2018a).

The IDF_CC tool then applies the nearest station-calibrated machine learning algorithms to the imported reanalysis gridded dataset to produce a preliminary estimate of the historical IDF information at all ungauged grid-points. These preliminary estimates are bilinearly interpolated to each ECCC weather station and compared to the observed data to develop a correction factor at each station location (i.e., observed rainfall divided by AV projected rainfall) (Schardong et al., 2018a). These correction factors are in turn bilinearly interpolated across the reanalysis grid and multiplied by the preliminary estimates of historical IDF data (i.e., the rainfall estimates based on AV correlations) (Schardong et al., 2018a). This final step nudges the estimated rainfalls of the machine learning algorithms towards nearby observational data; thus, if few stations are nearby, or it is suspected that nearby stations are not reflective of the climate dynamics of the area in question (e.g., different altitude, topography, solar radiation), the results should be interpreted cautiously.

B2. Projecting Historical IDF Curves into the Future in IDF_CC

Both historical datasets (i.e. gauged and ungauged stations) will be referred to as *observed historical* data herein. *Climate model* projections are in reference to the user-selected GCM(s) within the tool. Similar procedures are used to statistically estimate future rainfall intensities for both gauged and ungauged (i.e., AV predicted) locations. First, data-driven functions of precipitation establish a statistical relationship between climate model baseline quantiles and the observed historical quantiles; this process is referred to as temporal scaling and is inspired by a method proposed by Hassanzadeh et al. (2014). Temporal scaling associates the quantiles of sub-hourly observed data to daily climate model values and assumes that this ratio will remain constant with time. Next, a statistical relationship is established between the model baseline rainfall projections and the model future projection period under the forcing of each RCP scenario (i.e., scaling or Quantile Delta Mapping Method). The final step is to scale observed historical rainfall estimates by relating both statistical relationships (Schardong et al., 2018a). This method attempts to correct model bias and incorporate the changes between future and historical GCM projections. The entire process is summarized graphically in Figure 2 for gauged locations.

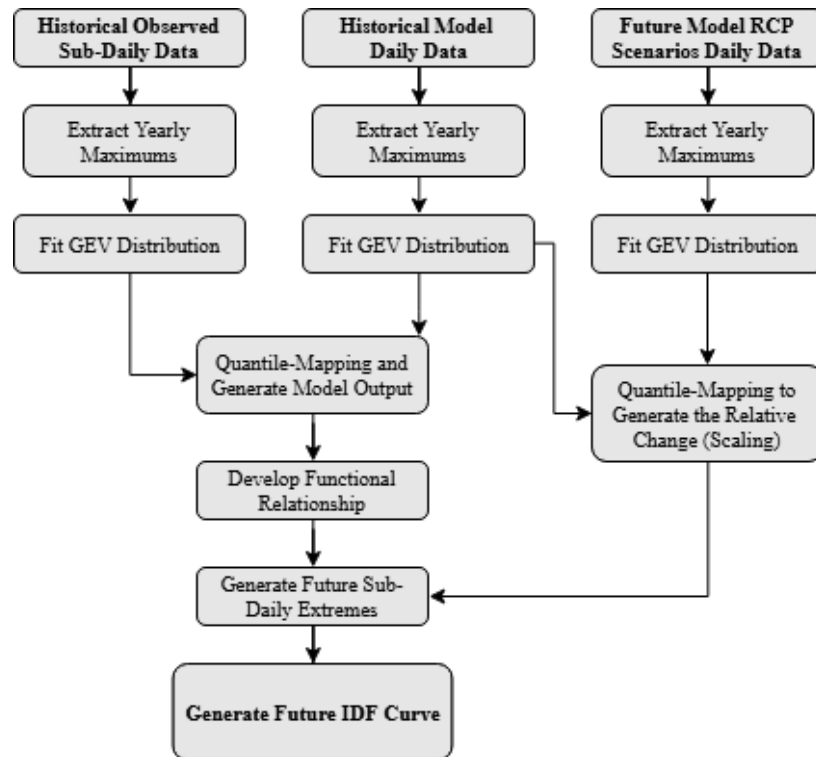


Figure 2. Equidistant Quantile-Matching method applied by the IDF_CC tool to generate IDF curves for gauged locations. This diagram has been adapted from Schardong et al. (2018a).

**Appendix C: Procedural Recommendations for Future Rainfall
Projections used in Municipal Floodplain
Modelling in Nova Scotia**

C1. Future Rainfall Projection Procedure

The following sections will provide a detailed procedure of the recommended minimum standard to determine future rainfall projections for use in floodplain modelling in Nova Scotia. Municipal floodplain assessments that are demonstrated to exceed or supplement this analysis method are encouraged; however, practitioners should consult with the Department of Municipal Affairs for approval of alternative methods. The procedure has been divided into “Phases” to improve the clarity of the procedure only (i.e., the order in which these tasks should be performed is at the discretion of the practitioner). Figure 4 provides an abridged graphical representation of the recommended procedure.

Phase I: Historical Data Collection and Analysis

- 1) Based on professional judgement, identify a climate station with a representative *observational dataset* of rainfall for your watershed (e.g. ECCC climate station). Define $Y_{\text{obs-end}}$ as the end date of this *observational period*.
- 2) Conduct a frequency analysis on extreme rainfall data using professional judgment to determine the most appropriate extreme value distribution OR utilize available frequency analysis. Justify selection.
- 3) If the selected climate station data is unavailable in IDF_CC, create a custom station and import rainfall data.
- 4) Perform a sensitivity analysis on the watershed to determine which rainfall durations are associated with flooding.
- 5) Identify historical 1:20 and 1:100 year design rainfall magnitudes.

Phase II: ECCC Climate Model Data Collection & Rainfall Projections Using Semi-Physical C-C Scaling Method

- 1) Extract region-specific ensemble of statistically downscaled future climate model projections from ECCC Climate Data Extraction Tool (accessed through: <https://climate-change.canada.ca/climate-data/#/downscaled-data>). Recommendations for the tool inputs are found in Table 9.

Table 9. Recommended input for the ECCC Climate Data Extraction Tool (Future Data).

Prompt	Recommended Input
Variable	Max Temperature
Future/Historical	Future
Emissions scenario	RCP 8.5
Time Interval / Time of year	**Daily
Value Type	Actual Values
Ensemble Percentile	95 th Percentile
Date Range	2006-01 to 2100-01

**Contact Climate Services Support Desk for daily data if necessary

- 2) Extract region-specific ensemble of statistically downscaled historical climate model projections from ECCC Climate Data Extraction Tool. Recommendations for the tool inputs are found in Table 10.

Table 10. Recommended input for the ECCC Climate Data Extraction Tool (Historical Data).

Prompt	Recommended Input
Variable	Max Temperature
Future/Historical	Historical
Emissions scenario	RCP 8.5
Time Interval / Time of year	**Daily
Value Type	Actual Values
Ensemble Percentile	95 th Percentile
Date Range	1951-01 to 2005-12

**Contact Climate Services Support Desk for daily data if necessary

- 3) Define *modeled historical period* as $Y_{\text{mod-start}}$ to $Y_{\text{obs-end}}$, where:

$$Y_{\text{mod-start}} = Y_{\text{obs-end}} - 30 \text{ years}$$

For example, for the *observational period* of XXXX-2016, the prescribed *modeled historical period* would be 1986-2016. Define the *model future period* as 2070-2100.

- 4) Interpolate temperature projections to station location. Justify method used.
- 5) Compute the mean daily maximum temperature for both the *model historical period* and the *model future period* of 2070-2100 using projections from the ECCC Climate Data Extraction Tool (i.e., the 30-year average of extracted daily maximum temperature projections).
- 6) Calculate relative change in 95th percentile mean daily maximum temperature (ΔT) between *modeled historical period* and the *model future period* of 2070-2100.
- 7) Using Equation 1, perform C-C scaling calculations using ΔT , a Scaling Factor (SF) of 14% for rainfall durations ≤ 6 hrs, a SF of 7% for rainfall durations > 6 hrs, and the observed 1:20 and 1:100 year design storm magnitudes ($R_{\text{Historical}}$). This will yield a future rainfall projection (R_{Future}) for both the 1:20 ($R_{1:20\text{CC}}$) and 1:100 year ($R_{1:100\text{CC}}$) design storms using the C-C scaling method.

$$R_{\text{Future}} = R_{\text{Historical}} * (SF)^{\Delta T_{\text{emp}}} \quad \text{Equation 1}$$

Phase III: Rainfall Projections Using IDF_CC Statistical Scaling Tool

- 1) Register and log in to IDF_CC web-tool (accessed through: <https://www.idf-cc-uwo.ca/home>). For inquiries regarding the use/design of the IDF_CC tool, see Schardong et al. (2018a) and (2018b).
- 2) In the “IDFs for Gauged Locations” tab, select the ECCC climate station (i.e. “Gauged Location”) identified in Phase I OR input custom station dataset in the “Manage Stations” subtab.
- 3) “Export all Results” for each available ensemble within IDF_CC (Figure 3), with the exception of the “Raw GCMs Ensemble”, for the period of 2050-2100. This will download a .csv file with IDF information for each ensemble, and it will generate interactive online results for all RCP emissions scenarios.

The screenshot shows the IDF_CC web-tool interface. At the top, it says "IDF for: HALIFAX ID:8202200". Below that are three tabs: "Station Info", "IDF historical data", and "IDF under climate change". Under "IDF under climate change", there are four sub-tabs: "Climate Model Selection", "Scenario RCP 2.6", "Scenario RCP 4.5", "Scenario RCP 8.5", and "Comparison Graphs". The "Climate Model Selection" sub-tab is active. It contains instructions: "1. Select the time period to update the IDF curve under climate change. The tool will use Climate Model data for the selected range. The available range is 2006 to 2100. Please select at least a 50 year projection period." Below this is a range selector showing "From 2050 to 2100". Below that is instruction "2. Select a Climate Model to see results. Climate models are listed by name:". There are two radio buttons: "Bias Corrected" (selected) and "Raw GCMs". Below these is a dropdown menu showing "All Models Ensemble, Ensemble". At the bottom of the form are two buttons: "Calculate IDF for Future" and "Export all Results". The "Export all Results" button is circled in red.

Figure 3. Example of input window within IDF_CC for future projections. Period of projection = 2050-2100. Location = Halifax ECCC climate station. Climate models = Bias Corrected Ensemble.

- 4) Calculate the 95th percentile rainfall for 1:20 and 1:100 year rainfall events for each ensemble independently using the RCP 8.5 data found within the .csv files or by using available output. This approach yields a minimum of two future rainfall projections using the IDF_CC tool, the 1:20 and 1:100 projections for the “Bias Corrected Ensemble” ($R_{1:20IDFBC}$ & $R_{1:100IDFBC}$, respectively), as well as the projections from other ensembles that may become available in IDF_CC in the future ($R_{1:20?}$ & $R_{1:100?}$, respectively).

Phase IV: Selection of 1:20 and 1:100 Design Storms

- 1) Compare the magnitudes of $R_{1:20IDFBC}$, $R_{1:20?}$, and $R_{1:20CC}$. Select the most conservative estimate ($R_{1:20}$) of the three calculated values.
- 2) Compare the magnitudes of $R_{1:100IDFBC}$, $R_{1:100?}$, and $R_{1:100CC}$. Select the most conservative estimate ($R_{1:100}$) of the three calculated values.
- 3) Use $R_{1:20}$ and $R_{1:100}$ to generate design storm hyetographs.

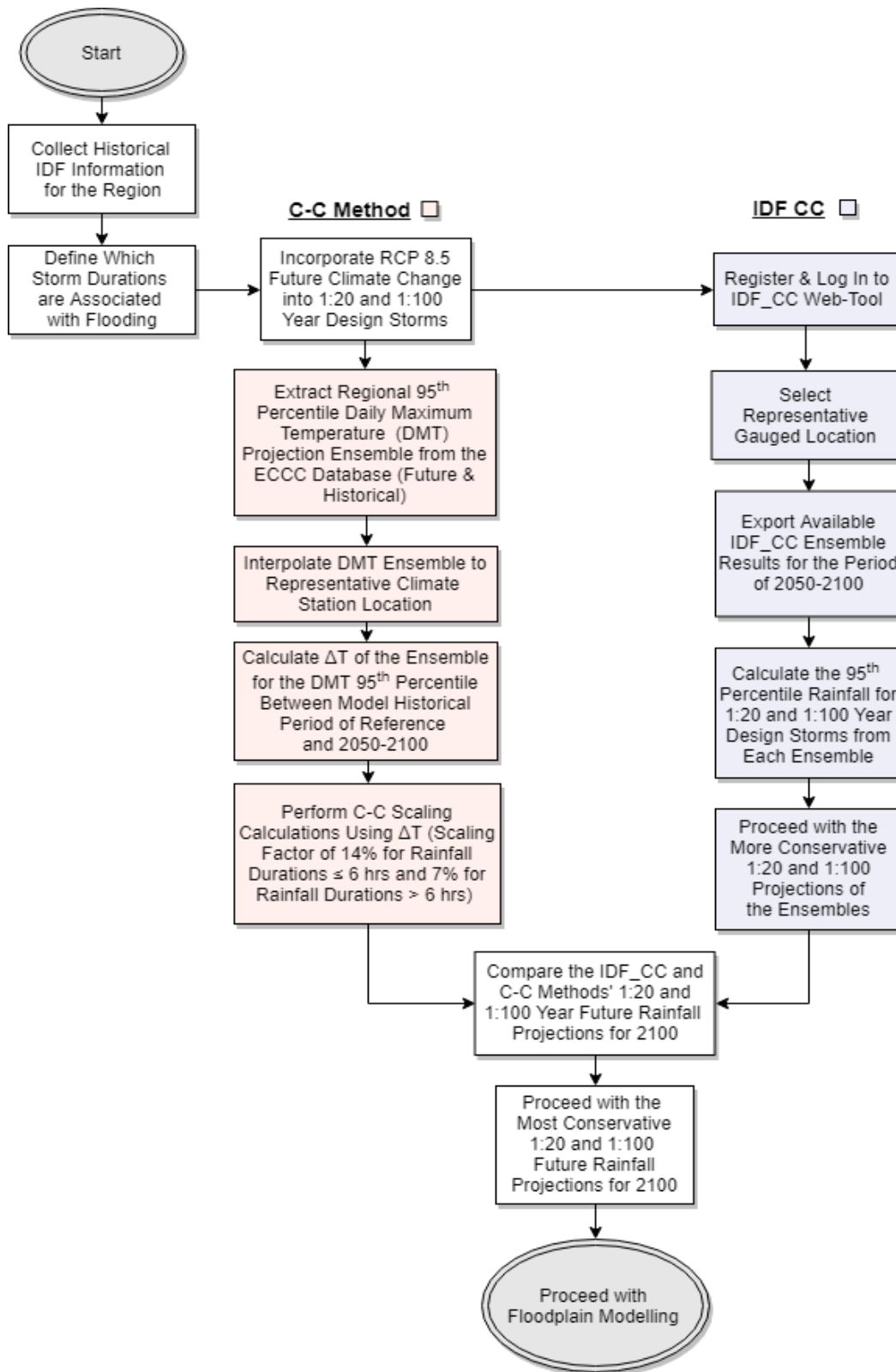


Figure 4. Recommended future rainfall projection procedure for floodplain modelling.

Phase V: Optional Assessment Components

Based on professional judgment, the following components may be included into the municipal floodplain modelling assessment.

- 1) Consider providing an intermediate projection horizon to help support municipal incremental change. The suggested projection horizon is the year ~2050 (i.e. 2025-2075 in IDF_CC using the 95th percentile value).
- 2) IDF_CC can provide estimates of historical IDF relationships, at high resolution across Canada, using reanalysis datasets and machine learning algorithms. These locations are designated by the user and are termed “Ungauged Locations” within the IDF_CC tool. These estimates may be projected into the future using the same statistical method applied to observational datasets at “Gauged Locations”. Based on professional judgement, these could be considered as additional options to add extra redundancy and conservatism into the rainfall projection procedure. Attention should be given to the limitations of this method, which are commented on in Appendix B1 and Shardong et al. (2018a).
- 3) For qualitative consideration of a potential “worst-case” scenario, the practitioner may consider including a statistical Potential Maximum Precipitation scenario as part of their floodplain assessment.

Nova Scotia Floodline Delineation: Guidance for Sea Level Rise and Storm Surge Projections



Draft report prepared by:

Danika van Proosdij and Ray Jahncke

Department of Geography and Environmental Studies
Maritime Provinces Spatial Analysis Research Centre (MP_SpARC)
Intertidal Coastal Sediment Transport Research Unit (In_CoaST)
Saint Mary's University

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Executive Summary

Coastal communities in Nova Scotia are currently experiencing the effects of coastal flooding due to storm surge and the combined effects of high tides and wave run-up. These hazards will only increase with sea level rise associated with climate change over the coming decades. Accurate, high resolution flood mapping of current and future flood hazard across the Province is essential for effective adaptation and to ensure all communities are equally informed of their risk. Accurate province wide flood mapping requires consensus on the datum and coordinate system of digital elevation models, realistic sea level rise and storm surge scenarios. This report examines and assesses the required scientific components to be considered and included in standard development and flood mapping exercises. This includes the most currently accepted national relative sea-level rise projections under differing climate change scenarios including plausible upper bounds, vertical datum and tidal surface models upon which to apply these projections as well as considerations for calculation of storm surge.

Extreme total sea levels are calculated as the sum of the relative sea level rise (RSLR) projection (incorporating regional effects of vertical crustal motion), Higher High Water Large Tides (HHWLT) and storm surge. RSLR projections are particularly sensitive to post-glacial adjustments of the earth's crust. Therefore, we recommend that the projections presented in James et al., 2014 be used since they incorporate the most spatially comprehensive dataset of vertical crustal motion available from the Canadian Geodetic Survey. In addition, NRCAN is anticipated to be releasing these data as interpolated grids. The worst case scenario (95% percentile, RCP 8.5) is between 1.09 m (Tusket) to 1.12 (Baddeck) by 2100. As a precautionary measure, James et al., 2014 recommend an additional 0.65 m of sea level rise to account for the potential contribution of the West Antarctic ice sheet resulting in a total of 1.63 to 1.68 m rise in water level by 2100. These projections are most appropriate for areas with low risk tolerance. At the present time, based on our current understanding of ice sheet dynamics and literature review, the 95% upper bound for RSLR projections for 2100 is very unlikely to exceed 2 m. However, James et al., 2014 does not include the contribution of increase in tidal amplitude (estimated 0.1 m) in the upper Bay of Fundy and this component should be incorporated for any RSLR for this region.

Extreme Total Sea Level values are calculated to represent the worst-case flooding scenario whereby a storm-surge event would occur near the high portion of the tidal cycle or Spring tides and how this will vary under different relative sea level rise scenarios. All of the previous flood mapping reports in the region have historically used HHWLT values provided for CHS tide stations and applied a chart datum (CD) to geodetic conversion to them. However, given the uncertainties in CD to geodetic conversions and low confidence in predictions from a number of CHS stations, we recommend that the new hydrographic datum for Canada be used (Robin et al., 2016). This Hydrographic Vertical Separation Surface (HyVSEPS) was developed to connect CD to the national geodetic reference frame which captures the relevant spatial variability as modelled by integrating ocean models, water levels, GPS observations, sea level trends, satellite altimetry and a geoid model. However, this surface is should be used with caution in the Upper Bay of Fundy at the present time due to lower reliability in areas with extensive intertidal zones due to it extreme tidal range.

A variety of approaches have been applied in the past to calculate storm surge including establishment of a benchmark storm, hindcasting based on historical wind speeds, applying return probability statistics to long

term records (> 19 yr) of total sea levels from tide gauge data, or storm surge modelling. Typical storm surge return periods used in the past at 1:20 and 1:100 scenarios. The type of approach used will be entirely dependent on the availability of data. The application of wave run-up to extreme sea level calculations has only been applied to Halifax Harbour.

A critical component of accurate flood line mapping is ensuring that the vertical datum of your terrestrial surface is the same as the extreme sea level projection. In 2013 NRCAN took advantage of advances in geospatial technology and shifted to a more accurate vertical datum, CGVD2013 to replace CGVD28 which has been used extensively in the past (and currently is being used) for flood line mapping. However, many digital surface models that are currently used in many areas of the province are in CGVD28. In addition, since some previous reports or applications do not have robust metadata associated with them, unless the datum is explicitly referenced, there is a high potential for error. An error which could result in extreme water levels being off by 64 cm in Halifax for example. Therefore, detailed and accurate metadata are essential and it is recommended that future flood mapping assume the CGVD2013 datum and the GRS80 ellipsoid, NAD83(CRSR)2010.

Overall, the availability of standardized, province wide data for high resolution topographic data, newer RSLR and tidal parameters provide excellent promise for Nova Scotia to create flood maps that are applicable to a wide range of scenarios.

1. Introduction

Coastal communities in Nova Scotia are currently experiencing the effects of coastal flooding due to storm surge and the combined effects of high tides and wave run-up. These hazards will only increase with sea level rise associated with climate change over the coming decades. Accurate, high resolution flood mapping of current and future flood hazard across the Province is essential for effective adaptation and to ensure all communities are equally informed of their risk. At present, detailed flood risk mapping has been conducted primarily for communities that have high resolution digital elevation models (DEM) derived from LIDAR (e.g Forbes et al., 2009; Webster et al., 2011; 2012; Fedak and van Proosdij, 2012; MacDonald and Webster, 2016). Many of these were conducted as a part of the Regional Adaptation Collaborative (RAC) projects funded by NRCAN and led by the Atlantic Climate Adaptation Solutions Association. ACASA was a partnership among the provincial governments of Newfoundland and Labrador, Nova Scotia, Prince Edward Island, and New Brunswick, and regional stakeholders including non-profits, tribal governments, and industry. It has an extensive library of previous reports, projects and associated tools (<https://atlanticadaptation.ca/>).

In 2015, the Advanced Geomatics Research Group (AGRG) at COGS, in collaboration with Dalhousie University's School of Planning, created a DEM of Nova Scotia that integrated the highest resolution topographic data available for all areas of the Province (e.g. LIDAR – 1m, pictometry – 2m or NTSDB 20 m grid, 5 m contour). Manuel et al., 2016 used the 5 and 10 m contours as flood risk proxies to assess social vulnerability of NS communities to be used for planning purposes. More recently Webster et al. 2017 created a web viewer for the *Maritime Coastal Flood Risk Map* which permits users to 'flood' contours up to 12 m based on 1-2 m resolution LIDAR DEMS in select areas of the Province and for EMO, to identify roads at risk and plan evacuation routes. The lack of upper plausible flood boundary and scenario guidance decreases its applied effectiveness. However, the combination of high resolution, hydraulically connected DEMs with detailed infrastructure, asset mapping along with realistic coastal hazard scenarios do provide excellent opportunities for emergency planning (e.g. MacDonald and Webster, 2016; van Proosdij et al., 2018). The majority of flood assessments have been conducted using a bathtub or flat water approach across hydraulically connected surfaces which has been shown to be effective for planning purposes (e.g. Webster et al., 2006; Webster et al., 2012); producing similar results in high or extreme scenarios when compared to hydrodynamic models (Fedak and van Proosdij, 2012). Many of these combine RSLR projections with a range of region specific wave scenarios. However, they are not as effective for lower flood scenarios where surface roughness and/or permeability play a more important role or nearshore bathymetry influences wave transformation. Application of hydrodynamic modelling (e.g. Delft3D, Mike21 or TuFLOW) for flood mapping in the province is rarer and mostly applied to communities with large tidal rivers, with large fluvial discharge during storm events (e.g. CBCL, 2016; Webster et al., 2012b; 2012c; Fedak and van Proosdij, 2012). Others such as Xu and Perrie (2012) apply wave forecast models to quantify the effects of extreme waves and run-up in Halifax Harbour. All are dependent on accurate high resolution land based DEMS and for the latter, detailed nearshore bathymetric mapping and seamless land/water interface elevations.

Accurate province wide flood mapping requires consensus on the datum and coordinate system of DEMs, realistic sea level rise and storm surge scenarios. The purpose of this report is to examine and assess the

required scientific components to be considered and included in standard development and flood mapping exercises. It will examine the relevant components of sea level rise, geodetic datums, most currently accepted national projections of sea-level rise under differing climate change scenarios, storm surge and tidal surface models.

2. Sea Level Rise

According to the Intergovernmental Panel on Climate Change (IPCC) AR5 assessment report published in 2013, “the rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (high confidence)” (IPCC, 2013). Historically, globally, sea level rose at a mean rate of $1.7 \pm 0.2 \text{ mm}\cdot\text{yr}^{-1}$ between 1901 and 2010, while between 1993 and 2010, sea level rose at a faster rate of $3.2 \pm 0.4 \text{ mm}\cdot\text{yr}^{-1}$ (Church et al., 2013). Over the last decade, there have been significant advances in our ability to model changes in sea level and increased confidence in their predictions.

2.1. Scenarios of Global Sea-level Rise

Global sea-level is projected to rise over the next century, but the projected magnitude of this rise depends on greenhouse gas concentrations, modelled as ‘Representative Concentration Pathways’ (RCP) (Figure 1) (IPCC 2013). The median global sea-level rise at 2100, relative to 1986-2005, 43 cm for RCP2.6 and 73 cm for RCP 8.5. The upper bound of the RCP 8.5 scenario is 98 cm (Table 1).

Table 1: Projected global sea-level rise (Church et al., 2013a: Table 13.5)

	RCP2.6	RCP4.5	RCP6.0	RCP8.5
Global mean sea-level rise by 2081-2100 (m)	0.40 [0.26-0.55]	0.47 [0.32-0.63]	0.48 [0.33-0.63]	0.63 [0.45-0.82]
Global sea-level rise by 2100 ¹ (m)	0.44 [0.28-0.61]	0.53 [0.36-0.71]	0.55 [0.38-0.73]	0.74 [0.52-0.98]

¹Numbers are the median value and the 5% to 95% confidence range of sea-level rise relative to 1986-2005.

The RCP scenarios represent a fundamentally different approach to examining climate futures than was taken in the development of the previous (SRES) scenarios (Nakicenovic and Swart, 2000) used in the IPCC 4th Assessment Report. Advances in process-based understanding of dynamics of and contributions to global sea level rise have led to additional components being added (Church et al., 2013). The sea-level rise estimates published in AR5 now include dynamical modelling of accelerated ice sheet melting (Greenland and Antarctica), not included in the AR4 report. Due to the constraint of the low AR4 sea-level rise estimates, the previously generated flooding scenarios that were widely adopted for Nova Scotia (e.g. Richard and Daigle, 2011) adopted semi-empirical (SEM) approach (Rahmstorf, 2007) which yielded a ‘conservative’ 85 cm estimate of global sea level rise (Daigle, 2016). Sea-level projections based on simple relationships between global atmospheric temperatures (or heat flux) and global sea-level rise, termed semi-empirical projections (Rahmstorf, 2007), estimate larger amounts of sea-level rise by 2100 (e.g., 75–190 cm, Vermeer and Rahmstorf, 2009; 60–160 cm, Jevrejeva et al., 2010) (Church et al., 2013). However recent advances in understanding of ice sheet stability as well as the wide variability of semi-empirical results stimulated the IPCC to place lower confidence in these findings (IPCC 2013;

Atkinson et al., 2016). AR5 also reflects the consensus that, for semi-empirical (SEM) approaches published after AR4 with significantly higher upper bound levels (e.g. > 2 m), that “*despite their successful calibration and evaluation against observed 20th century sea level record, there is low agreement in their projections and no consensus in the scientific community about the reliability of the SEM projections, and there is low confidence in their projections.*” (IPCC, 2013). Greater confidence is placed on process-based models. Based on Representative Concentration Pathways (RCP) scenarios, likely sea level rise projections for 2100 range from 26 to 81 cm (IPCC, 2013) (Error! Reference source not found.Figure 1).

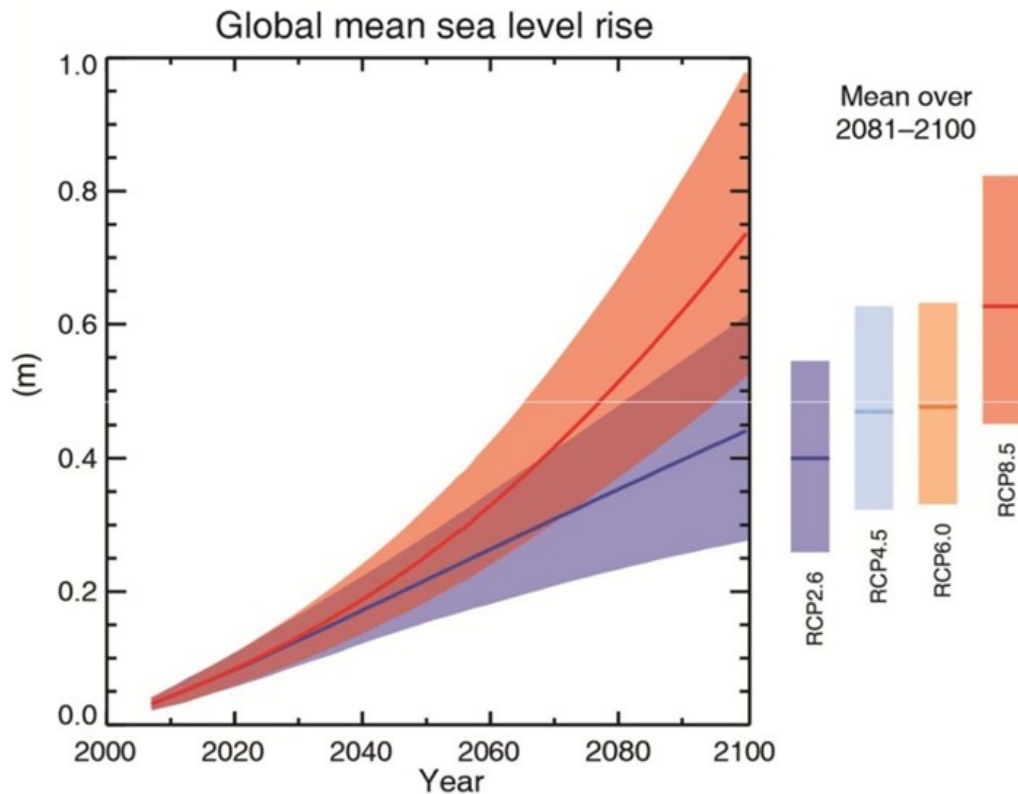


Figure 1: Upper and lower bounds of projected sea level rise relative to 1986–2005 for relative concentration pathways RCP 2.5 to 8.5 (Figure SPM.9, IPCC, 2013). The lines indicate the median projection and the shading indicates the assessed likely range. The projected mean sea-level rise for 2081–2100 is given on the right for all four RCP scenarios

2.2. Individual Components of Regional Sea-level Rise

Global, or absolute, sea level is projected to rise over time due to thermal expansion of the oceans (steric effect) and surface melting as well as discharge of land ice to the oceans (e.g. Milne et al., 2009). However, sea-level change is not distributed equally across the globe due to a differences in a combination of regional factors such as crustal subsidence and isostatic rebound (collectively referred to as ‘vertical land motion’), redistribution of glacial meltwater and dynamic oceanographic effects (James et al., 2014; Atkinson et al., 2016). In some areas of East Coast Region, sea levels are falling due to isostatic rebound after retreat of glaciers (Atkinson et al., 2016). It is therefore important to use ‘downscaled’ regional results that integrate these variables (James et al., 2014) and use relative versus absolute changes in sea level. More detailed discussions are available in Milne et al., 2009 and James et al., 2014.

2.2.1. Global Sea-Level Rise

Global sea-level rise has contributions from a variety of components. These include thermal expansion of the upper layer of the ocean (often termed steric effect), mountain glaciers and ice caps, the Greenland and Antarctic ice sheets, and land water storage (Church et al., 2013). An important, but poorly constrained factor in projections of global sea level rise is the stability of the West Antarctic Ice Sheet (Church et al., 2013). The primary concern is that given the majority of the West Antarctic Ice Sheet is based below sea level, hence in direct contact with warming oceans, it is sensitive to thermal erosion and subsequent destabilization (Daigle, 2016). The AR5 Summary of Policymakers (IPCC, 2013) reports:

“Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the likely range during the 21st century. However, there is medium confidence that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century”

James et al., (2014) have addressed this uncertainty by suggesting that an additional scenario be generated in which the RCP8.5/2100 scenario (RCP8.5 + W.Ant) is augmented by 65 cm of sea-level rise assumed to be sourced from the West Antarctic ice sheet. This scenario is most appropriate for adaptation applications where the tolerance to the risks of sea-level rise is very low.

2.2.2. Vertical Land Motion

Vertical land motion (VLM) refers to a post-glacial adjustment of the earth’s crust. During the last ice age, the significant weight of the continental ice sheet caused the land beneath it to subside and areas at the periphery such as coastal areas to ‘bulge’. After the ice sheets retreated, the greatest rebound (uplift) occurred in the Hudson Bay Area while many areas in Nova Scotia lowered. It is important to account for the effect of local vertical land motion in generating projections of relative sea-level. Areas of positive (upward) glacial isostatic adjustment, will reduce the amount of sea-level rise experienced at a site and, if large enough, may cause sea levels to fall (James et al., 2014). GPS stations across Canada, and internationally, have been in continuous operation since the early 1990’s (James et al., 2014). Over time, this network has grown and provide standardized, spatially coherent information on vertical land motion (Craymer et al., 2011). The vertical arrows on the map identify the present-day vertical movement field measured by GPS at established stations from 1994 to the end of 2013 (Figure 2). Rates of vertical crustal motion in the East Coast Region at 22 selected sites are provided in Appendix A of James et al., 2014. However, the change in relative sea level due to the vertical motion arising from glacial isostatic adjustment (GIA) is a combination of vertical crustal motion, change in the vertical position of the geoid and a spatially-uniform term that is introduced to conserve global water mass (James et al., 2014). James et al (2014) therefore applied an empirical relationship (derived from ICE-5G GIA model by Peltier, 2004) to transform the vertical crust motion measured at GPS stations to equivalent sea-level change (in James et al 2014, Appendix B). The primary difference between the most recent published relative sea level rise reports (i.e. James et al., 2014; Han et al., 2016) is the density and sophistication of inclusion of the empirical uplift data.

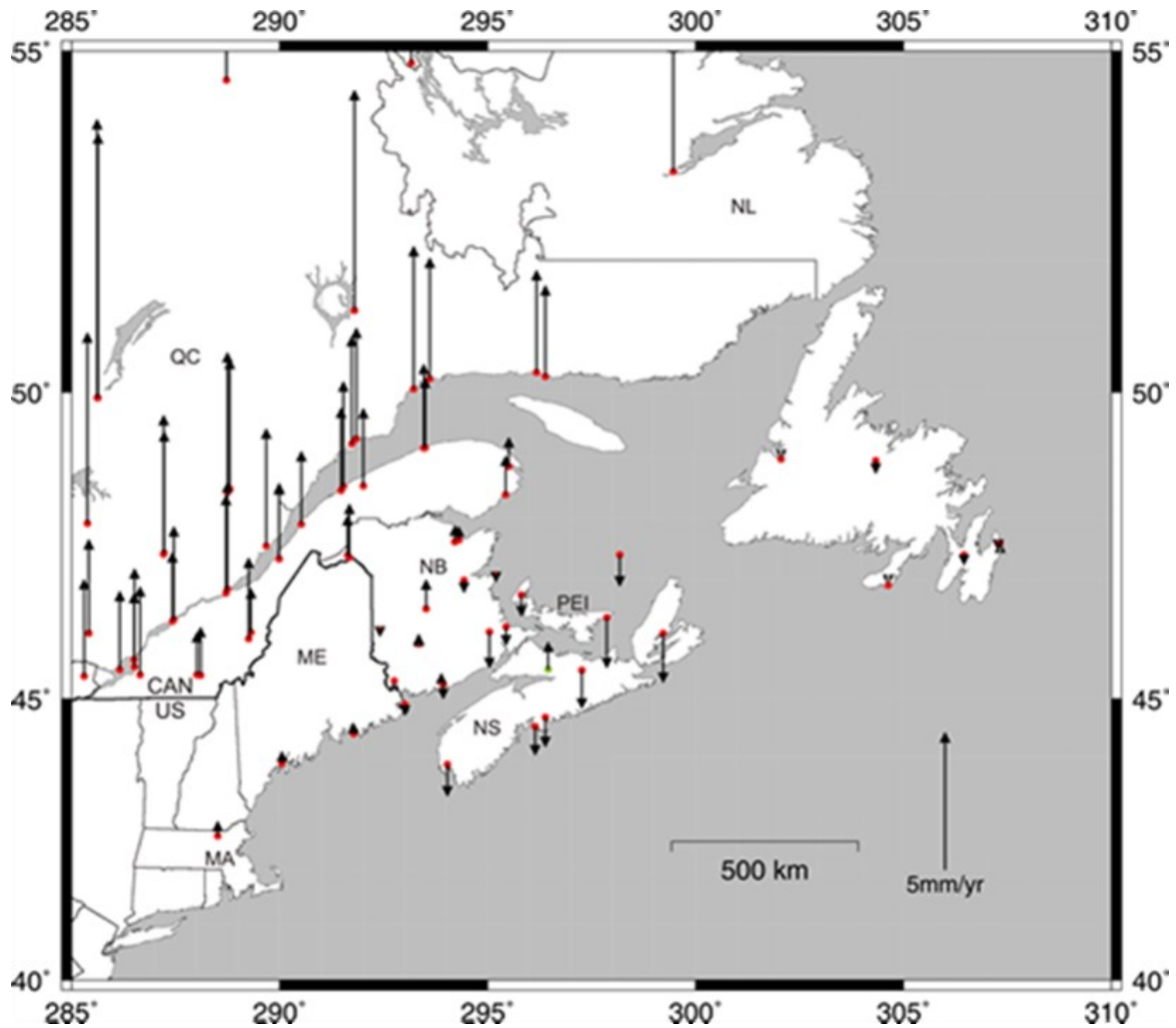


Figure 2: Location of GPS stations and associated vertical motion measurement (in Savard et al., 2016)

2.2.3. Distribution of Glacial Meltwater

Meltwater from ice sheets, ice caps and glaciers is not distributed uniformly throughout the world's oceans (Farrell and Clark, 1976; Mitrovica et al., 2001; 2011). Ice masses exert a gravitational pull on surrounding ocean waters, drawing them closer and upwards. As an ice sheet melts, it exerts a reduced gravitational pull on the surrounding ocean water, causing the nearby ocean surfaces to fall. In addition, as the weight of the ice is removed from the underlying solid surface, the land responds elastically, rising relative to the ocean. The impact of this factor decreases proportionally with distance away from the meltwater source. Figure 3 shows sea-level change over the global oceans for sources of sea-level rise originating from Antarctica, Greenland and mountain glaciers and ice caps. In each panel, the source is assumed to provide $1 \text{ mm} \cdot \text{yr}^{-1}$ of average global sea-level rise. Sea-level will fall close to the source of melting ice and rise slightly higher than the global average further away (James et al., 2014). This site-specific response can also be referred to as 'sea-level fingerprinting'. For example, for every cm of meltwater from Greenland, Atlantic Canada would see a reduced sea-level rise portion of approximately 0.4-0.5 cm, whereas for every cm of meltwater from Antarctica, we would experience an increased proportion of approximately 1.1 cm (Daigle, 2016). For every cm of meltwater from mountain

glaciers and ice caps, Atlantic Canada would see a reduced proportion of approximately 0.8 to 0.9 cm (Figure 3) (Daigle, 2016).

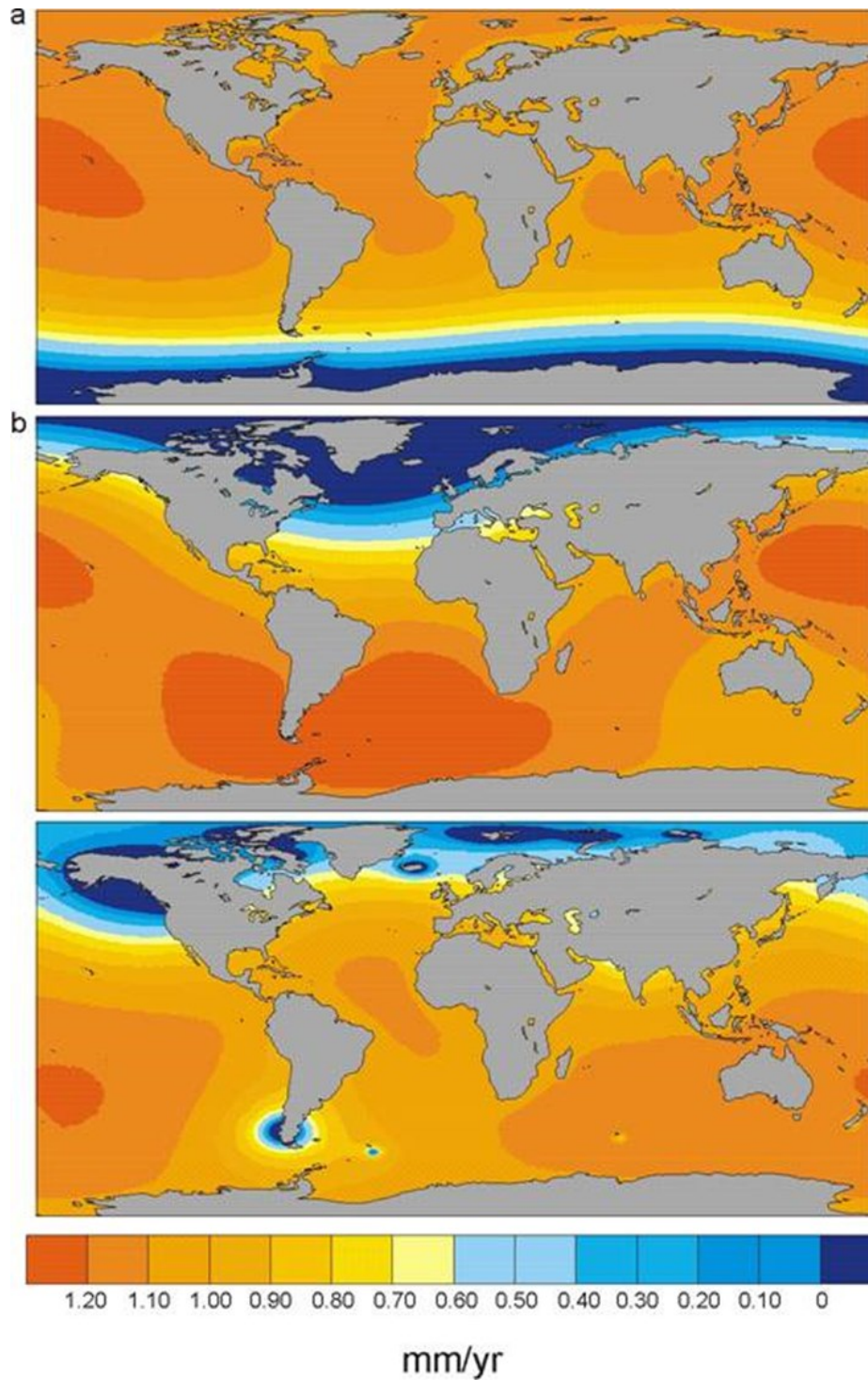


Figure 3: The amount of sea-level rise, in millimeters per year, for an assumed $1 \text{ mm}\cdot\text{yr}^{-1}$ contribution to global sea level rise from a) Antarctica, b) Greenland, and c) mountain glaciers and ice caps (source: Mitrovica et al., 2001 in James et al., 2014)

2.2.4. Regional Oceanographic Effects

Global ocean currents, such as the Gulf Stream, generate dynamic sea-surface topography of more than one meter in amplitude, which reduces present regional sea levels (James et al., 2014; Yin, 2012). Yin (2012) computed a large number of models for the RCP scenarios for thermal expansion and dynamic sea-level change and noted that a predicted diminution of the Gulf Stream is predicted for the northeastern North America in the coming century. James et al (2014) have calculated this component (range of 18-20 cm per century) for Atlantic Canada locations for RCP 8.5.

2.2.5. Bay of Fundy Tidal Range

The hypertidal (>16 m) conditions of the Bay of Fundy are created by combined natural resonance of water moving through the system (approximately every 13 hrs) and the tides driven primarily by the M2 (lunar) tidal constituent (high tide every 12 hr 25 min). Based on a study of long-term water levels from tide gauges from Boston to Halifax and throughout the Gulf of Maine, Greenburg et al. (2012) observed that the amplitude of Bay of Fundy tides has been slowly increasing. They estimated that by 2100, the combination of VLM and amplitude change would increase the amplitude of Bay of Fundy tides by 30 cm in the Upper Bay. Given that they assumed at that time a VLM component of 20 cm per century, 10 cm is left for amplitude change. Daigle (2016) applied a scaled version of this parameter (9 cm for 2010-2100) when calculating sea-level rise at Hantsport in the Avon River.

2.3. Projections of Relative Sea-level Rise for Nova Scotia

James et al. (2014) calculated regional sea-level rise scenarios for 22 locations in Atlantic Canada and adjoining Gulf of Maine, taking into account the respective effects of fingerprinting, dynamic oceanographic effects and the most comprehensive VLM records available, for each of the RCP scenarios (Figure 4). The projections are initially derived from digital files of projections of regional sea-level change that accompanied the release of AR5 (Church et al., 2013), then refined with site specific GPS uplift rates throughout the region. Additional details are provided in James et al., 2014. Projections are all provided relative to 1986-2005. Relative sea level rise projections for RCP8.5/2100 for Nova Scotia are slightly larger than the global mean (James et al., 2014) (Table 1)(Figure 4). Detailed analyses are provided in James et al. (2014, 2015) for Baddeck, Truro, Halifax and Tusket, Nova Scotia for RCP 2.6, 4.5 and 8.5, summarized in Appendix A and illustrated in Figure 5. Table 2 presents the average projected sea-level change for all scenarios including contributions from the West Antarctica ice sheet. The data from all stations have been used by NRCAN to create an interpolation surface of RSL for Atlantic Canada which is anticipated to be released publically in summer 2019 and can be used to determine RSL projects for locations between sample stations (Appendix B). Surfaces were generated by combining oceanographic modelling extrapolated to the coastline from the offshore and spatial interpolation using krigging in ArcGIS.

Table 2:: Average Projected Sea-level Change (in cm), 2081-2100 relative to 1995. (James et al., 2015). Median values presented with 5th and 95th percentiles in brackets. ¹values do not include increases in Bay of Fundy tidal amplitude

Location	RCP 2.6	RCP4.5	RCP6.0	RCP8.5	RCP8.5+WAnt
Tusket	50.0 [23.8 - 76.3]	59.4 [32.7 - 86.1]	62.0 [32.6 - 91.4]	77.1 [45.7 - 108.6]	162.9
Halifax	51.4 [24.2 - 78.6]	59.9 [32.6 - 87.1]	63.8 [34.2 - 93.3]	77.4 [45.1 - 109.8]	165.2
Truro¹	51.5 [25.6 - 77.5]	60.7 [34.4 - 87.1]	63.1 [33.8 - 92.4]	77.9 [47.1 - 108.8]	164.1
Baddeck	55.7 [29.2 - 82.3]	64.4 [37.8 - 91.1]	67.3 [37.6 - 97.1]	81.3 [50.3 - 112.3]	168.1

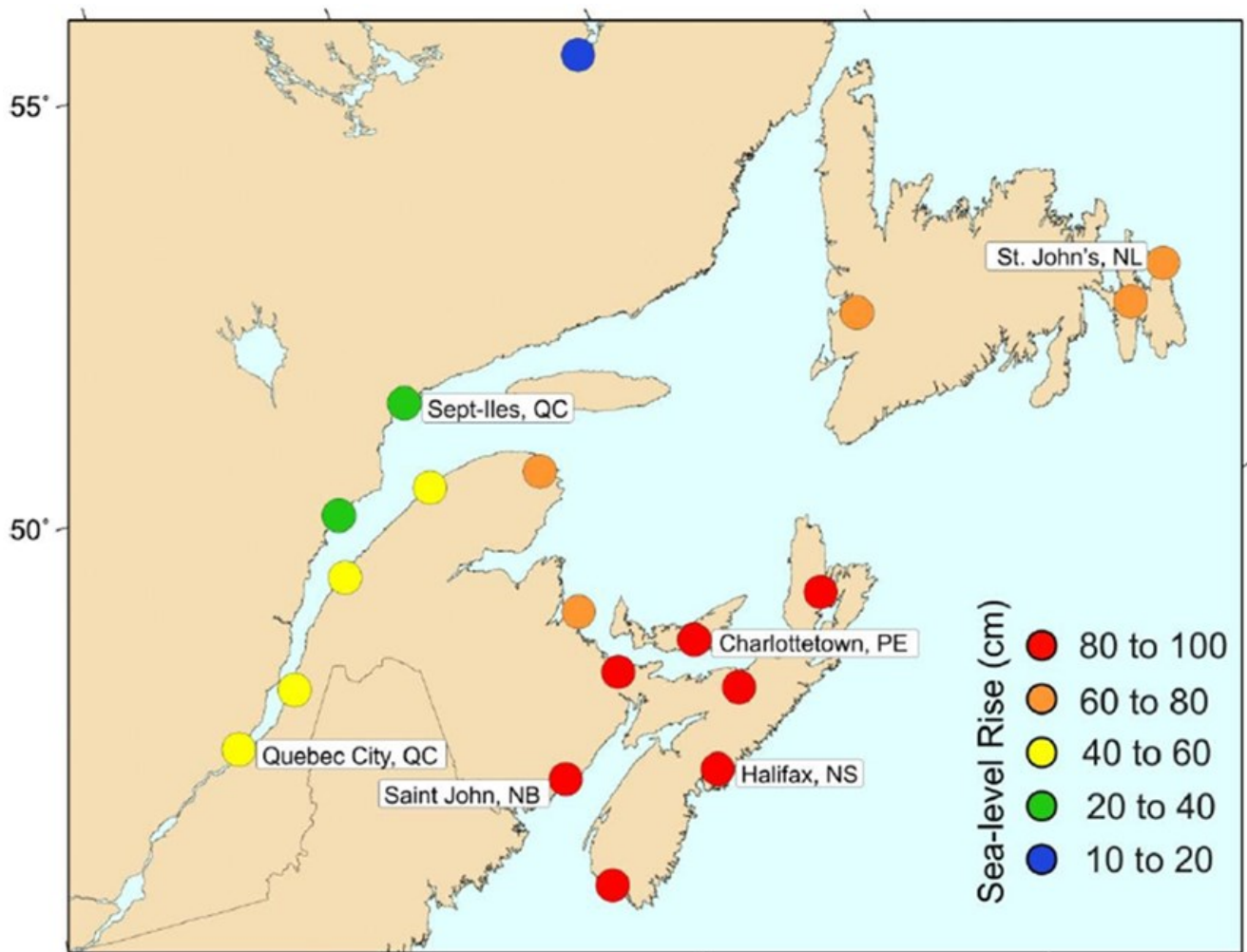


Figure 4: Projected relative sea-level change by 2100, relative to 1986-2005, for RCP8.5 calculated from James et al., 2014. (Source: Savard et al., 2016).

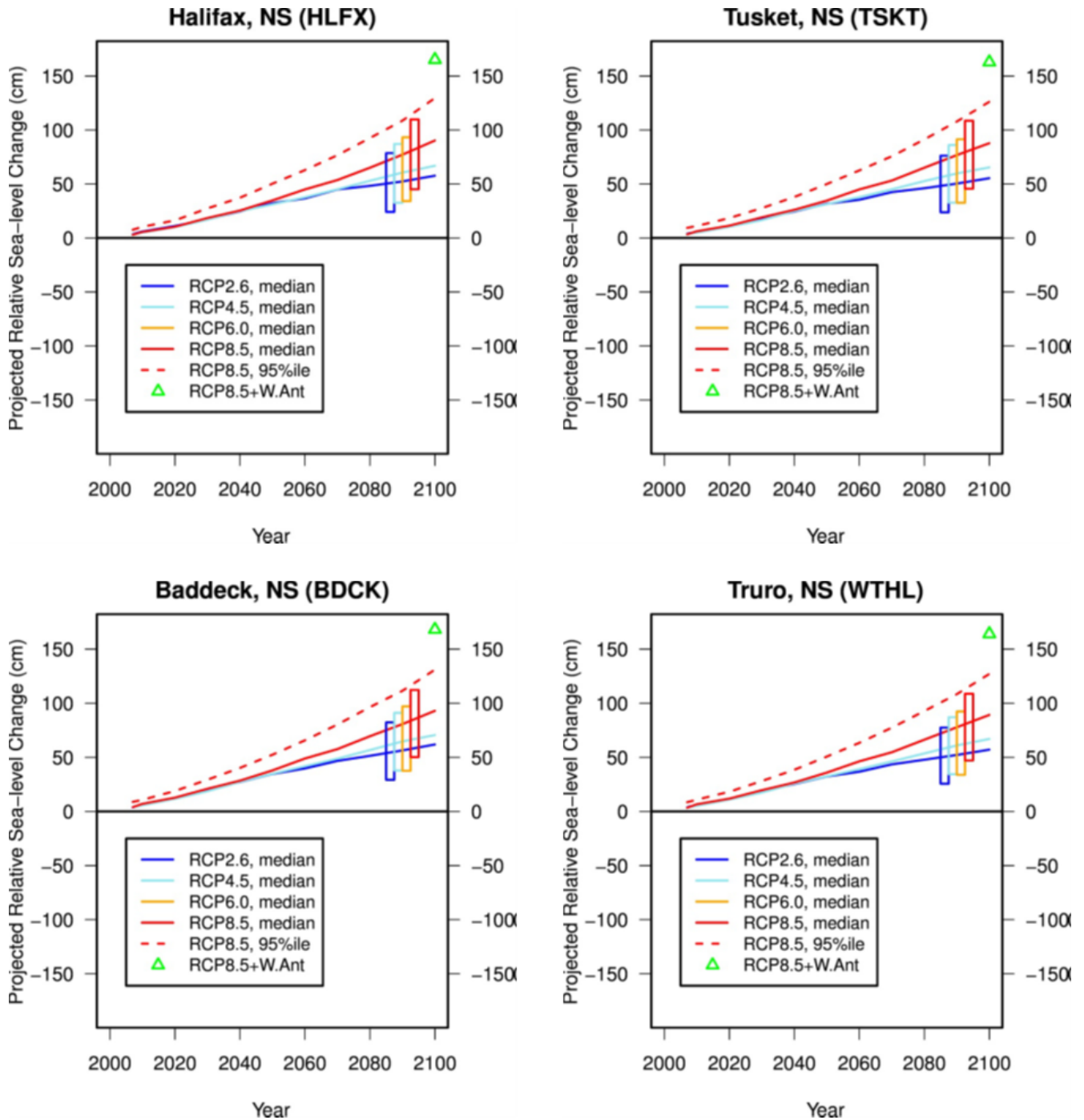


Figure 5: Projected relative sea-level change for RCP2.6, RCP4.5 and RCP8.5 (median values, solid lines; 95th percentile of RCP8.5, dashed line) (James et al., 2014). Rectangles also include RCP6.0 and give the 905 confidence range (5-95%) of the average for the time period 1081-2100. RCP8.5+W.Ant is the median projection of RCP8.5 plus an additional 65 cm of global sea-level rise from West Antarctica (green triangle) (James et al., 2015).

2.4. Probabilistic Sea-level Rise Scenarios

In 2017, NOAA published its *Global and Regional Sea Level Rise Scenarios for the United States* (Sweet et al., 2017). It reported on the production of gridded relative sea level (RSL, which includes both ocean-level change and vertical land motion) projections for the United States associated with updated global mean sea level (GMSL) scenarios. Based on the interpretation of recent literature, the authors recommend a revised ‘extreme’ upper-bound scenario for GMSL rise of 2.5 m by year 2100. The 0.3m to 2.5 m GMSL range for 2100 is broken into 0.5 m increments and aligned with emissions-based, conditional probabilistic storylines and global model projections into size GMSL rise scenarios: *Low* (0.3m), *Intermediate-low* (0.5m), *Intermediate* (1.0m), *Intermediate-High* (1.5 m), *High* (2.0m) and *Extreme* (2.5 m) (Sweet et al., 2017). Bayesian reasoning represents a formal, probabilistic extension of the method of multiple working hypotheses, involving the identification of either a discrete or continuous set of alternative hypotheses or an assessment of the strength of prior evidence for each hypothesis. It is based heavily on Kopp et al. (2014) who constructed probabilistic projections of the factors driving GMSL rise as the basis of their estimates of the probability of different levels of relative sea level change (conditional on alternative scenarios of greenhouse gas emissions) at a global tide gauge network. This is different from the approach applied in the IPCC AR5 report by Church et al., 2013 who stresses the central or ‘likely’ range (66% probability) of 21st century rise in GMSL based primarily on process-based models. In those models, there is roughly a one-third probability that sea level rise may lie outside the ‘likely’ range. In part to address this, in recent years there has been an increase in the application of probabilistic estimates of future GMSL (e.g. Kopp et al., 2014; Oppenheimer and Alley, 2016; Jackson et al., 2018) and inclusion of meltwater contributions from Antarctica. Their approaches also use guidance from ‘scientific experts’ and semi-empirical models. However, there is not consensus at this time within the scientific community as to the reliability of the probabilistic approach. For example, while Han et al., (2016) apply the NOAA scenarios, they exclude the High (2.0 m) and Extreme (2.5 m) scenarios because these include semi-empirical scenarios which are of low confidence according to the IPCC AR5 assessment (Church et al., 2013; Han et al., 2016). Han et al. (2016) projections were accepted by DFO and applied to their Can-EWLAT tool. Their ‘high’ scenario predicts RSLR to just under 2.0 m by 2100 by including accelerated melt of the Antarctic ice sheet (Han et al., 2016). Therefore, while the probabilistic scenarios cannot and should not be discounted; the *high* and *extreme* scenarios should be applied with caution and only in areas with very low tolerance for risk and a long term planning horizon. Han et al. (2016) present more plausible regional SLR scenarios at selected tide gauge stations in Canada that can support coastal engineers and managers in the design and maintenance of coastal infrastructure. However, they do not include the most recent and accurate VLM surface (based on increased spatial availability of GPS data) available from the Geodetic Survey of Canada.

The projection of future sea-level rise depends on an understanding of the mechanisms driving its evolution in space and time, an understanding which has evolved over time and resulted in a range of projected upper bounds. Horton et al., 2018 provides an excellent, comprehensive review of the current methodologies and data sources used to reconstruct the history of sea-level change over geological (e.g. Pliocene, Holocene) and instrument (tide-gauge and satellite altimetry) and tools used to project future sea-levels. An important element of this is understanding how different mechanisms drive spatial variability and uncertainty in regional sea-level projections. A detailed discussion of the statistical methods or measurements of uncertainty of

different driving mechanisms is beyond the scope of this report. However, Figure 6 modified from Horton et al.'s (2018) review of 54 sea-level projection papers between 2012-2018 provides a useful graphical representation of the 5-95th, 17-83rd percentiles and median values of the projections. The RCP 8.5 scenarios are indicated in purple, just above the dotted line. The upper bound of the majority of those projections is less than 1.5 m and this upper bound is for simulations allowing for an aggressively unstable Antarctic ice sheet (Horton et al., 2018) and is consistent with the approach of James et al., 2014. Only 2 studies provide upper bounds greater than this: Wong et al. 2017 (2 m) and Kopp et al., 2017 (2.5 m), both of which place significant emphasis on Antarctic dynamics.

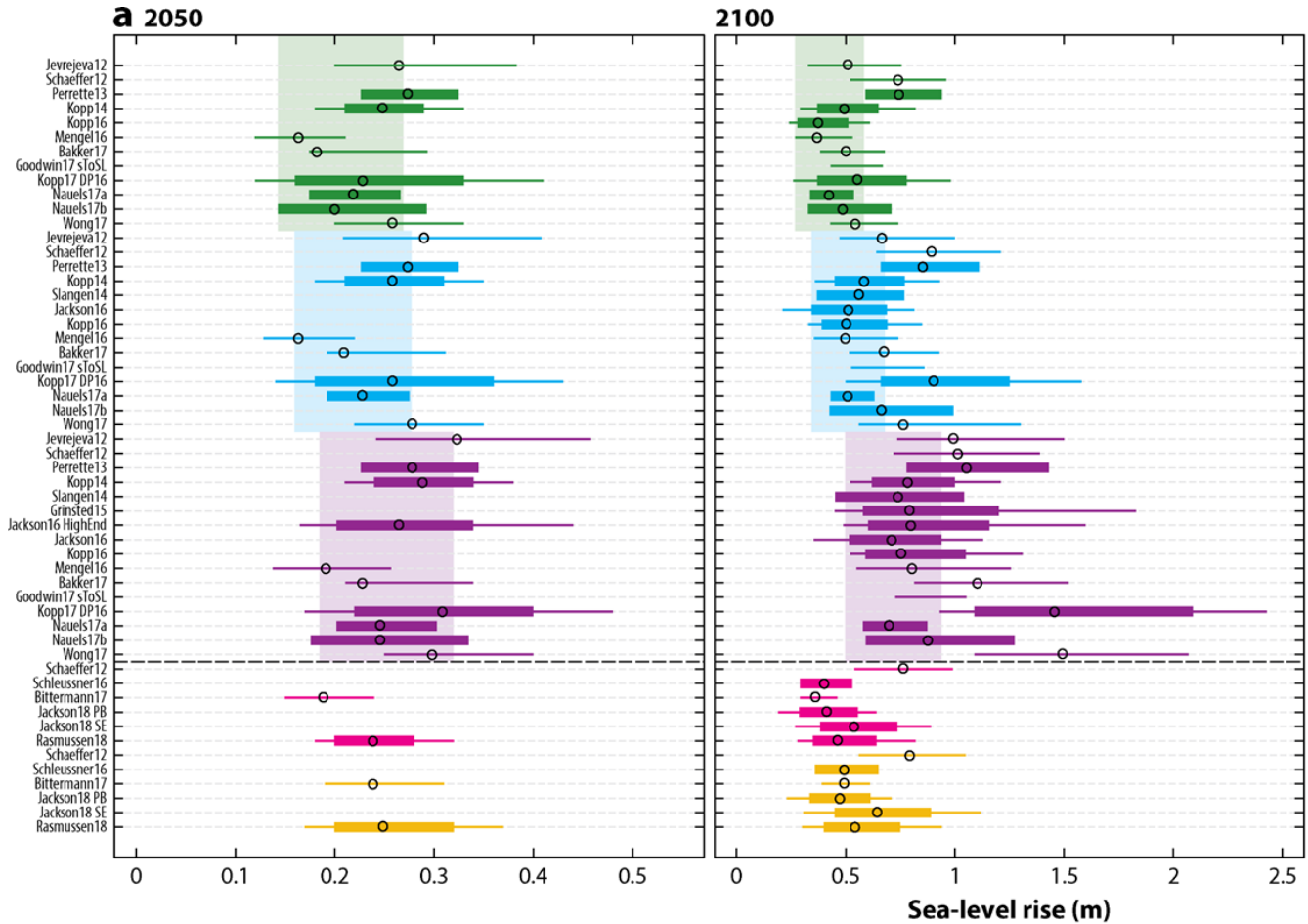


Figure 6: a) near-term (2050) and b) mid-term (2100) sea-level rise projections for RCP2.6, RCP4.5 and RCP8.5 scenarios, as well as for scenarios stabilizing global mean temp at 1.5 degrees C and 2.0 degrees C above pre-industrial levels. Thin bars represent 5-95th percentile ranges, thick bars the 17th – 83rd percentile ranges and circles the median global mean sea-level rise projections (in meters). Modified from Figure 6 in Horton et al., 2018.

3. Datums

The definition of vertical datum is essential to any discussion of tides and flood levels since by their nature, differ between terrestrial and nautical sources. Nautical charts use chart datum (CD) which is a vertical reference established at tide gauges and used as a zero height for nautical charts and tide tables. In Canada, this targets

LLWLT which is a level so low that water will very seldom fall below it which is important for safe navigation. However, in most cases, the currently adopted CD is offset from LLWLT, especially where CD was established a long time ago and/or in areas of large relative sea level changes (Robin et al., 2014). Water levels recorded at tide gauges and published in predicted tide tables are all relative to a local CD. In order to be used for flood mapping, these values need to be converted to geodetic datum.

In November 2013, Natural Resources Canada (NRCAN) released the Canadian Geodetic Vertical Datum of 2013 (CGVD2013), which is now the new standard for heights across Canada. This new height reference system is replacing the Canadian Geodetic Vertical Datum of 1928 (CGVD28). It is defined by the equipotential (level) surface $W_0 = 62,636,856.0 \text{ m}^2\text{s}^{-2}$, which represents by convention the coastal mean sea level for North America (NRCAN, 2017; Véronneau and Huang, 2016). It lies approximately below the coastal Pacific sea level by 17 cm and above the coastal Atlantic sea level by 39 cm. This means that the coastline in the area of Halifax would have a negative elevation ($H = -0.39 \text{ m}$) while the coastline for the area of Vancouver has a positive elevation ($H = 0.17 \text{ m}$) (Figure 7). CGVD2013 is realized by the Canadian Gravimetric Geoid model of 2013 (CGG2013), Epoch 2010, which provides the separation between the GRS80 ellipsoid and the above described surface in NAD83(CRS), making it compatible with Global Navigation Satellite Systems (GNSS) such as GPS. It is a fundamental shift from geodetic levelling to geodetic modelling. CGVD28 was historically defined by the mean water level at five tide gauges: Yarmouth and Halifax on the Atlantic Ocean, Pointe-au-Père on the St-Lawrence River, and Vancouver and Prince-Rupert on the Pacific Ocean in 1928. The datum was then propagated in land using geodetic levelling measurements and used the hybrid geoid model HTv2.0. It is important to note however that CGVD28 is still the vertical datum referenced for a large number of elevation models in the region and previous sea level rise and flooding report will provide flood levels relative to this datum (e.g Richards and Daigle, 2011; Daigle, 2016; MacDonald and Webster, 2016; CBCL, 2017; van Proosdij et al., 2018). One of the reasons why there may be a reluctance to shift from CGVD28 to CGVD2013, is the elevation of mean sea level relative to observations. For example, mean sea level in 2001 was only 0.24 m above CGVD28 in Halifax (Forbes et al., 2009), making it easier for the public to interpret flood mapping layers (e.g. MacDonald and Webster, 2016; Webster et al., 2018). The CGVD2013 datum in Halifax will now be higher by 65 cm compared to CGVD28 (Figure 7). Given that new RTK GPS surveys being conducted on provincial infrastructure (e.g. roads, dykes) are being collected in CGVD2013, there is a high potential for error if these surveys are integrated into digital elevation models in CGVD28 without the proper conversion either way. Detailed and accurate metadata are essential and it is recommended that future flood mapping assume the CGVD2013 datum and the GRS80 ellipsoid, NAD83(CRS)2010.

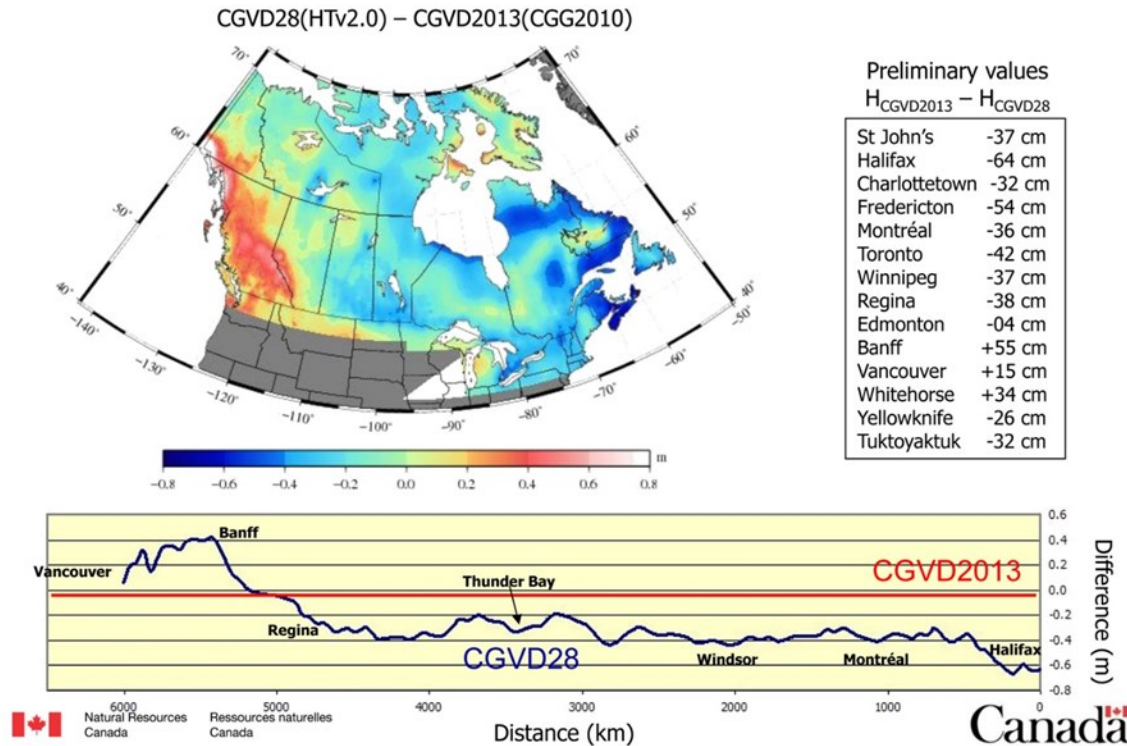


Figure 7: Difference between CGVD28 (HTv2.0) and CGVD2013 (CGG2013). Changes range from -65 to +50 cm across Canadian landmass. The largest changes occur in the Maritimes where the new datum is 65 cm higher, meaning lower elevations in the region (adapted from Véronneau, 2014)

4. Tides

Tides are the predictable rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the Moon and the Sun, and the rotation of the Earth. Tidal amplitudes vary over time based on the proximity and relative position of the moon over the earth's surface, and the relative alignment of the moon and the sun. This creates a series of periodic variations in water level that vary on different time scales, and the coincidence of the peaks in these levels will cause higher water levels to be observed. These include:

- 0.517 diurnal cycle (12 hr 25 min)
- 14.77-day spring/neap cycle,
- 27.55-day perigee/apogee cycle (closest and further position of earth's orbit around sun)
- 206-day cycle due to spring/neap and perigee/apogee cycle overlap, and
- longer-term lunar nodal (18.61 year) cycle, the 8.95-year cycle of lunar perigee (which influences sea level as a quasi 4.4-year cycle) (Haigh et al, 2011; Gratiot et al., 2008).

Haigh et al. (2011) noted that area of large tidal range such as the Bay of Fundy, the 18.61-year cycle is dominant and correctly modelled increases of tide elevation in 1997 and 2015. The next period of higher tides is therefore predicted for 2034. The astronomical Saros cycle (18.03 years) has also been reported to be historically associated with higher water levels (Desplanque and Mossman, 1999) and climatic variability (Keeling and Wharf, 2000).

4.1. Higher High Water Large Tides (HHWLT)

HHWLT is the average of the yearly highest highs predicted over a 19-year astronomical cycle. Extreme Total Sea Level values are calculated to represent the worst-case flooding scenario whereby a storm- surge event would occur near the high portion of the tidal cycle or Spring tides and how this will vary under different relative sea level rise scenarios. Each Canadian Hydrographic Services (CHS) tide gauge station is assigned HHWLT, MWL and LLWLT values relative to CD based on measured water level records at that location. The length of these tidal records vary and therefore the confidence in assigned values varies between stations.

In the early 1990s, the CHS recognized that they needed to link chart datum to a national geodetic reference frame, primarily to take advantage of advances in hydrographic mapping and Global Navigation Satellite Systems (GNSS) technologies. Existing tide gauge benchmarks were surveyed using GNSS and new or revised water level observations were established. In the early 2000's there were enough CD to ellipsoid separations established to create a simple models linking CD to the ellipsoid (separation models, or SEPs). Not surprisingly, these simple SEPs were often inadequate because they did not include any data between tide stations and offshore (Robin et al., 2014). There was a need to produce physically realistic SEPs that accurately represented spatial variabilities as a range of scales. In 2010, the CHS and the Canadian Geodetic Survey (CGS) launched the Continuous Vertical Datum for Canadian Waters (CVDCW) project (Robin et al., 2014). This project was also supported by DFO's Ocean Sciences group and oceanographers from academia and private industry. Nineteen-year water level predictions were calculated using tidal constituents derived from regional tide gauge records, for an epoch centered on 2010 and target water levels (e.g. HHWLT) were extracted from these predictions. It should be noted that before being included in the CVDCW, each station is assigned a quality indicator or confidence level based on the experience and knowledge of the regional DFO team (Figure 8).



Figure 8: Confidence in HHWLT value associated with CHS tide stations based on assessment by regional CHS office. Note low confidence for Halifax is the station within the harbour.

Prior to being integrated into the SEP, all of the tide station observations are brought up to the 2010 epoch (Robin et al., 2014). It is important to bring tide station observations which may be up to 100 years old and GNSS observations which may be up to 20 years old to a common epoch since epoch updates can be up to ± 1 m in height (Robin et al., 2014). Most GNSS data can be brought up to the Epoch 2010 with the crustal velocity model using NRCan’s datum and epoch transformation software TRX (Canadian Geodetic Survey, 2014). Mean water level (MWL) is estimated relative to CD based on water level observations made at the time CD was established. This is also the time CD is fixed relative to a land-based marker by tying it to one or more station benchmarks by geodetic levelling. MWL, however, is not fixed to anything, and changes relative to land, and therefore relative to CD. As a result, the offset between CD and MWL (CD_MWL) changes with time due to crustal uplift or subsidence combined with changes in sea level. Hence the differences in CD to geodetic conversions reported in previous reports for the same station. Assuming a station is not lost or disturbed due to coastal erosion, local instabilities or anthropogenic alterations of harbors or tidal inlets, both CD and the benchmark will move relative to NAD83 at the rate of vertical crustal motion. MWL will move relative to NAD83 at a rate of absolute sea level rise, and relative to CD at the combined rate of sea level rise and crustal motion (Robin et al., 2014).

The trend in relative sea level has been measured at stations with more than 20-30 years of water level observations. However, this is not possible for the majority of tide stations. Regional estimates of absolute SLR are calculated from a combination of long-term station data and NRCan’s crustal velocity model. These estimated are then in turn combined with NRCan’s crustal velocity model to estimate relative SLR at each station (Robin et al., 2016):

$$SL_{adjust} = (2010 - Epoch_{obs}) \times SLR_{rel}$$

where

$$SLR_{rel} = SLR_{abs} - V_{crust}$$

The SL_{adjust} is the sea level correction in meters, $Epoch_{abs}$ is the year that the CD-MWL was last measured, SLR_{rel} is the relative sea level rise in meters per year, V_{crust} is the crustal velocity in meters per year and SLR_{abs} is absolute sea level rise in meters per year. SL_{adjust} is then applied to all water level datums referenced to CD (e.g. LLWLT, MWL, etc..) (Robin et al., 2016). Regional SLR_{abs} has been estimated from CHS tide gauges with co-located GPS as 1.7-1.8 mm/yr for the 20th century (James et al., 2014).

4.2. Hydrographic Vertical Separation Surfaces (HyVSEPS)

The goal of the CVDCW project was to “develop a surface connecting CD to the national geodetic reference frame which captures the relevant spatial variability as modelled by integrating ocean models, water levels, GPS observations, sea level trends, satellite altimetry and a geoid model” (Robin et al., 2014). The importance of this initiative cannot be overstated, as it creates a common reference frame linking bathymetry with topography which is essential for accurate coastal flood modelling. Since it is a national surface covering all of Canadian coastal waters, it can help define coastlines and intertidal zones at the national level and serve as a baseline for sea level rise and other climate change adaptation strategies (Robin et al., 2014). Ultimately, this new surface model defines a new hydrographic datum for Canada (Robin et al., 2016). Full details of how the model was created are available in Robin et al., 2014 and 2016.

The working grid consists of a finite element (FEM) grid onto which observed and modelled data are integrated (Robin et al., 2014). The boundaries of this grid extend up to or over shorelines. Four different layers are then applied to the working grid: geoid height (N), Dynamic Ocean Topography (DOT), tidal regime and a difference layer (warp) (Robin et al., 2016).

A geoid model is a gravitational ‘level’ surface which best represents Mean Sea Level (MSL) and is the foundation of the SEP. Undulations in the geoid are caused by variations in gravitational attraction resulting primarily from density variations in the land mass. The geoid maps where water would rest if it was equally dense and informally stratified everywhere and not moving (e.g. no waves or currents). The HyVSEPS uses the Canadian Gravimetric Geoid model of 2013 (CGVD2013), which was adopted in November 2013. It integrates data from terrestrial gravity measurements (land, ship, airborne observations) as well as gravity measurements from dedicated satellite gravity missions (Robin et al., 2014). Since geoid heights are calculated relative to the ellipsoid, it provides the SEP with a link to the ellipsoid.

However, in reality the observed MWL does not follow a ‘level’ surface due to differences in density, stratification and is affected by currents, waves and other forces. The gravitational potential (W_0) which defines CGVD2013 is the potential that best fits a selection of MWL observations around the coast of North America. Waters are typically denser in the Atlantic, resulting in a MWL approximately 40 cm below CGVD2013 (Robin et al., 2016). The difference in height between locally observed MWL and a geoid is referred to as DOT (Dynamic Ocean Topography). Due to limited data sets available of observed water levels, DOT estimates are derived from ocean circulation models and where possible validated against tide gauge and satellite altimetry observations. Once the DOT layer is summed with the geoid layer, there is a value for MWL relative to the ellipsoid at every node in the model domain, creating a Mean Sea Surface (MSS) model.

The third layer joins MSS to LLWLT and represents approximately half the tidal range and is a function of the tidal regime. Dynamic Oceanographic Model (DOM) solutions are critical in the tidal layer and provide the sole source of information on tidal variability between gauges and the offshore. They were selected from existing models developed with or by DFO’s Ocean Science Division. See Robin et al., 2016 for details.

The sum of these three layers generates a model for LLWLT relative to GRS80 Ellipsoid in the NAD83(CSRS)2010 reference frame. The final step forces or warps this model to honor CD as it exists on current hydrographic products. Overall, the bulk accuracies of the final grid is 7.5 cm for CANEAST with less reliability in areas of high tidal range such as the Bay of Fundy (Robin et al., 2016). A series of point clouds and interpolated surfaces are available that represent HHWLT relative to CD, CGVD28, CGVD2013 and GRS80 (Figure 9). It is recommended that these be used rather than the traditional approach of applying a CD to geodetic conversion at CHS tide stations.

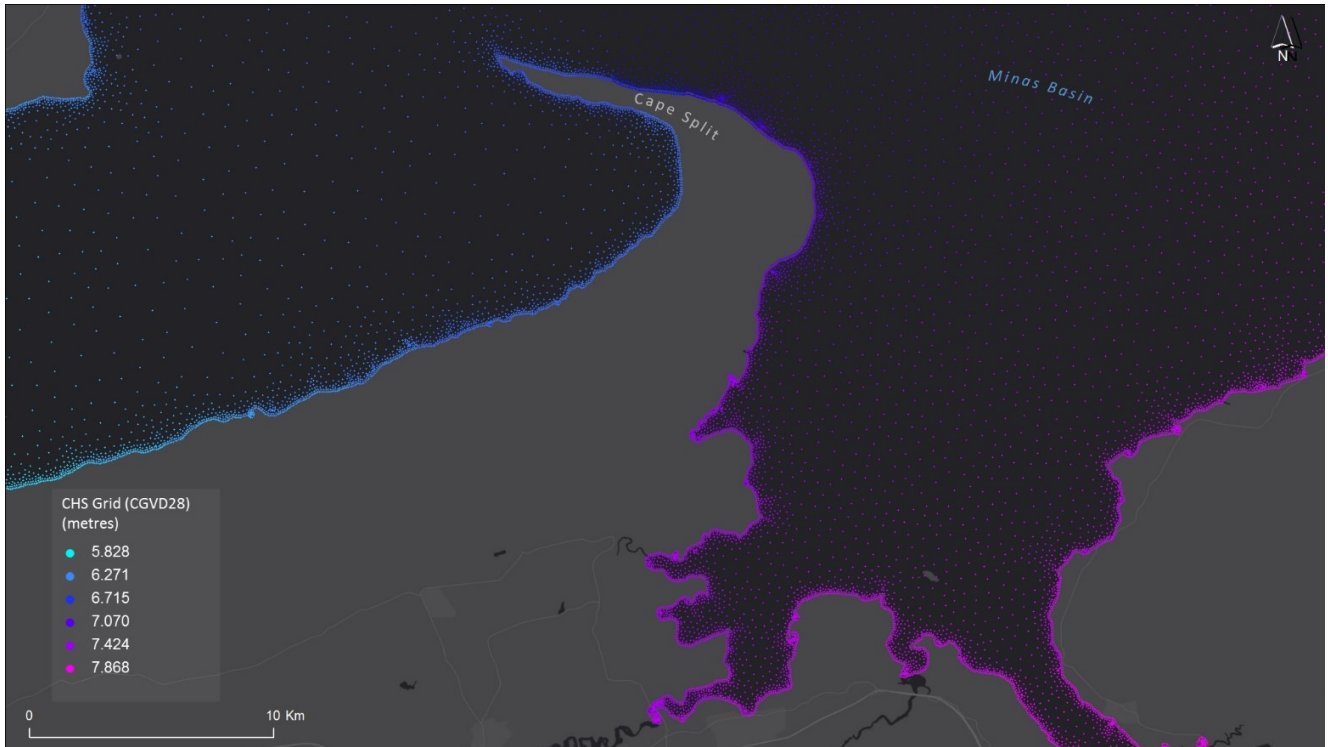


Figure 9: Example of point cloud from HyVSEPS surface for HHWL relative to CGVD28 datum in Upper Bay of Fundy.

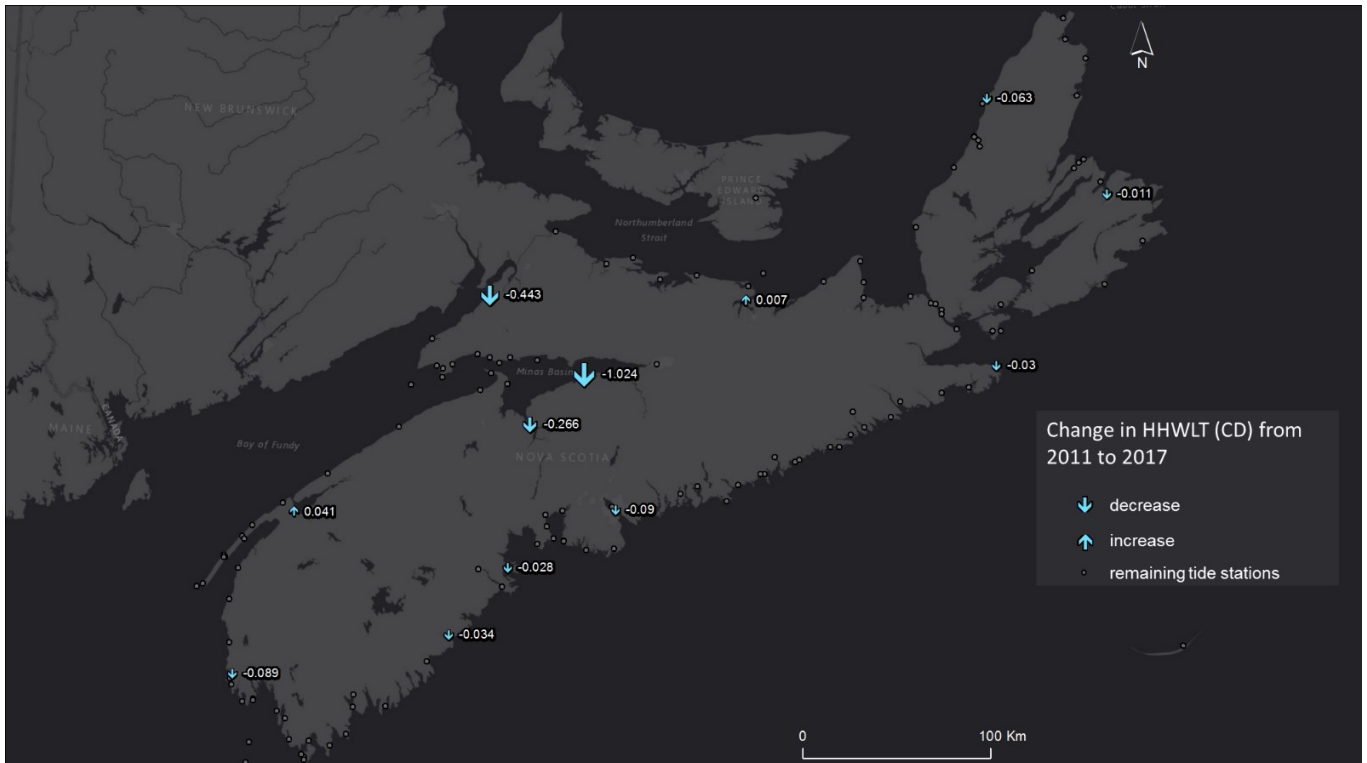


Figure 10: Difference in HHWL (CD) reported at CHS tide stations between 2011 reported and 2017 (using HyVSEPS surface). Data from CHS, 2018.

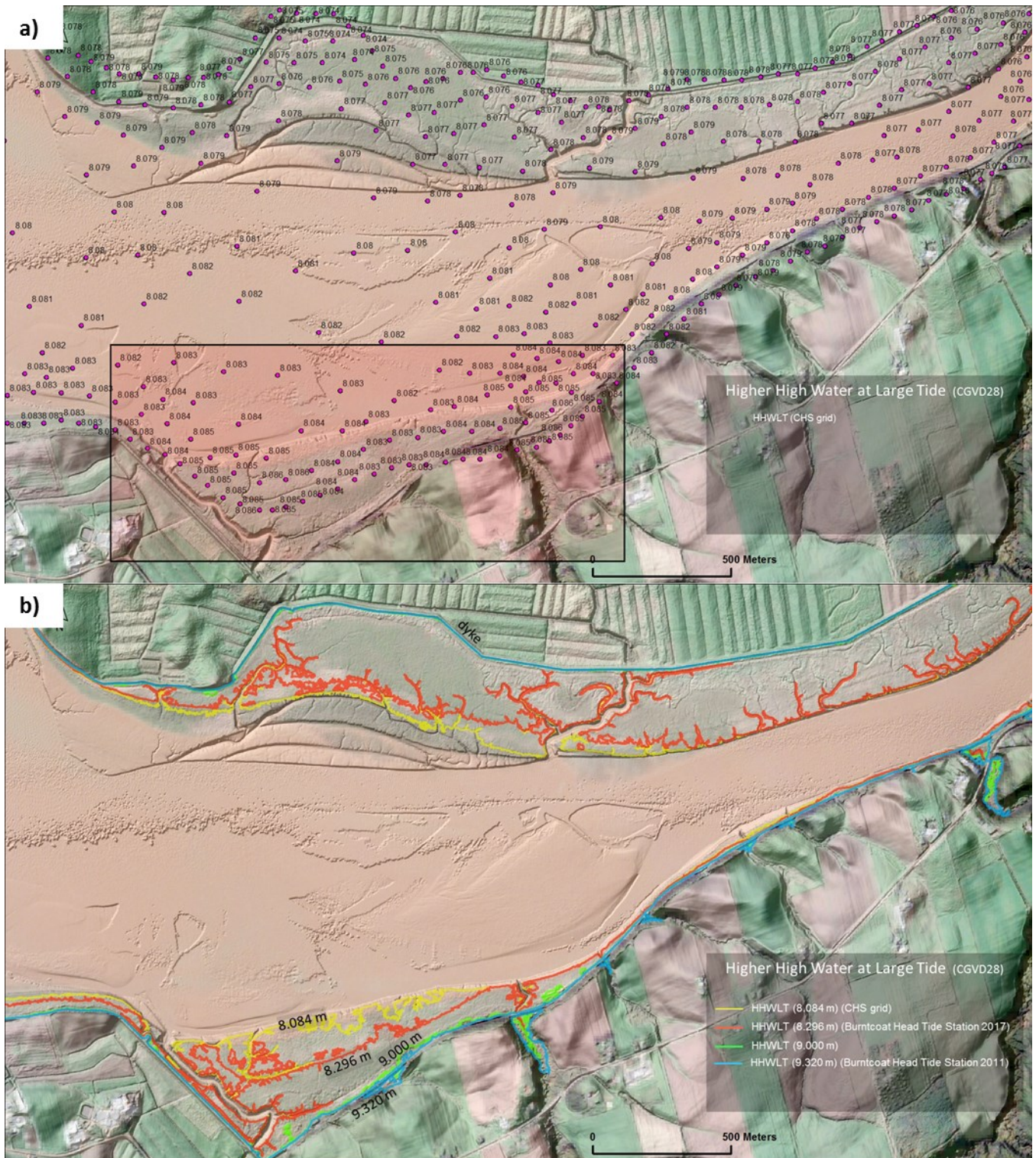


Figure 11: a) HHWLT (relative to CGVD28, in meters) based on HyVSEPS surface at Old Barns, Salmon River; b) Comparison of HHWLT contours from HyVSEPS, 2017 CHS Burntcoat Head value and 2011 HHWLT at Burntcoat Head station in relation to salt marsh vegetation. HHWLT of 9.0 m CGVD28 recorded by tide gauge at site in CBCL, 2016. Note that predicted HHWLT from 2017 grid (HyVSEPS) do not flood the marsh surface.

The majority of previous flooding and sea level rise reports however have used HHWLT values (in CD) at established CHS tide gauge stations and then applied a conversion value between CD to geodetic datum such as CGVD28. While the source of this conversion is primarily from CHS, this is often not indicated in the reports and conversion values vary between sources (e.g. Webster et al., 2012; Webster et al., 2014; Richards and Daigle, 2011; van Proosdij and Page, 2012). In addition, as mentioned previously, CHS has indicated low confidence in a relatively large number of its stations due to the limited record of measurement or loss of benchmark due to erosion (Figure 8). Although the methods used to establish HHWLT values at CHS stations differ between 2011 and 2017, in most cases the values are quite small, less than 10 cm. However, in the upper Bay of Fundy, these values vary significantly, are almost all lower in 2017 than 2011 and for Burntcoat head is as much as 1.02 m lower than previously reported (Figure 10). This creates a significant challenge for communities in this area and the confusion that is created by reporting such a significantly lower value when ‘sea level is supposed to be rising’. This area is also limited by the availability of ground truthed water levels and long term tide gauge data. The water level data that does exist through academic researchers and private sector suggest that the model values are lower than observed or that is indicated by proxies such as salt marsh vegetation zonation (Figure 11). As a result, while the new hydrographic vertical separation surfaces are a significant improvement across Canada, they should be applied with caution in areas of high tidal range such as the Bay of Fundy.

5. Storm Surge - Extreme Water Levels

Estimates of a location’s high water distribution, which forms in response to high tides and storms, are needed to assess how and when flood frequencies are likely to change under future RSL rise. A variety of approaches have been applied in the past including establishment of a benchmark storm, hindcasting based on historical wind speeds, applying return probability statistics to long term records (> 19 yr) of total sea levels from tide gauge data, or storm surge modelling. These storm surge events are typically added to RSLR and HHWLT to determine an upper bound of flood hazard conditions.

5.1. Benchmark Storms

Most coastal areas in the province have experienced a significant storm surge event that has either been captured within a local tide gauge water level record or through high precision GPS mapping of water or debris lines on land, which are used as proxies for maximum water levels (e.g Webster et al., 2011). Storm surges are created by meteorological effects on sea level, such as wind set-up and low atmospheric pressure, and can be defined as the difference between the observed water level during a storm and the predicted astronomical tide. Wind set-up refers to the increase in mean water level along the coast due to shoreward wind stresses on the water surface. One of the benefits of using a storm that has happened in the past is that community members can see that a storm of that magnitude can affect their local area, even if they may not be able to visualize the effect on top of RSLR projections. These storms typically approach 100-year storm events. For example, Hurricane Juan (Sept. 2003 – 2.1 m CGVD28) is typically used for HRM (Forbes et al., 2009) or the South Shore whereas the Groundhog Day storm in Feb 1976 (3.4 m CGVD28 at Yarmouth) exerted more of an influence in the lower Bay of Fundy. In the Upper Bay, that storm coincided with a lower tide (Desplanque and Mossman, 2004) so the impact was not as great. Areas of the Northumberland Strait such as Pictou have two Dec storms that are

used, 2.27 m CGVD28 in 1993 and 2.2 in 2010. The largest storm to impact the Bay of Fundy was the Saxby Gale in October 1869 which is said to have overtopped all of the dykes by 2 m (Desplanque and Mossman, 2004).

5.2. Hindcasting

Hindcasting involves modelling the height of waves based on a past time series of wind speeds. A number of studies (Daigle, 2016; Richards and Daigle, 2011) have extracted estimates of extreme total sea levels and associated levels of risk from published 40 year hindcast values for the North Atlantic (Bernier, 2005). Annual maxima of hourly measurements of sea level were analyzed using a Gumbel distribution (Zhai et al., 2014). These values were used to generate spatial maps of the return level of storm surges and to estimate the total return period of extreme total sea levels (Bernier and Thompson, 2006). These values are then used to calculate worst-case scenarios whereby a storm-surge event would occur during high water on Spring tides. In the opposite case where a storm-surge event coincided with a low portion of the tidal cycle, the change of flooding is reduced (Daigle, 2016). The return- period probability statistic is then calculated to represent the relative probability that a given storm surge (surge residual) would coincide with the higher portion of the tidal cycle. For example, the storm surge return levels for Hantsport, NS are estimated based on the Saint John tide gauge and range from 0.57 m (1 year) to 1.13m (100 year) events (Table 3). Surge events for other stations in NS are provided in Richards and Daigle, 2011.

Table 3: Storm surge return levels (m) for Hantsport, estimated at Saint John + 20% (Daigle, 2016)

1-Year	2-Year	5-Year	10 - Year	25 - Year	50 - Year	100 - Year
0.57± 0.2	0.65± 0.2	0.76± 0.2	0.85± 0.2	0.96± 0.2	1.04± 0.2	1.13± 0.2

5.3. Extreme Total Sea Levels using Return Probability Statistics

In areas where a long term tide gauge is established (typically greater than 19 yrs), it is possible to calculate extreme storm levels using an annual extreme values analysis. The extreme values are de-trended by subtracting the annual mean water level from the annual extreme level (hourly) and plotted showing the water levels associated with varying probabilities or return periods (Forbes et al., 2009; Bernier et al., 2001). In that instance, one can take a level for a typical strong nor-easter (2-year return period), a less frequent large storm (10-year return period) and rare but not exceptional event (50-year return period) (Forbes et al., 2009). AGRG and GeoNet Technologies Inc. developed a tool – Time-Series Modeller – to calculate the probability of a given water level occurring. It uses a time series of water level records to determine the probability and/or risk associated with a given water level occurring (Webster et al., 2008). They tested a range of extreme probabilities models such as Gumbel, Logistic and Weibull distributions (Webster et al., 2018).

5.4. Wave Set-up, Run-up and Seiche

In addition to the storm surge scenarios discussed in the previous section, wave setup (rise in mean water level due to wave breaking) and run-up (vertical distance a wave travels up the shoreline, including swash of individual waves) along with harbour seiche can increase the water levels reached during a storm event (Forbes et al., 2006). Seiche occurs due to the oscillation in water levels as water moves back and forth in an Basin. Wave run-up is a function of wave conditions, exposure and shore slope and roughness. These parameters have only been applied to date for Halifax Harbour (Forbes et al., 2009; Xu and Perrie, 2012). After Hurricane Juan, the swash limits around the Harbour were surveyed and levels were measured up to 1.7 m higher than the peak

water level at the gauge (Forbes et al., 2009). Xu and Perrie (2012) simulated waves generated by Hurricane Juan and a nested grid of two wave models (incl. SWAN, a wave model developed at Delft University of Technology). The Federal Emergency Management Agency's (FEMA) run-up model was used to estimate wave run-up elevation which is validated with recorded high water observations along the shoreline. Wave run-up within Halifax harbour was estimated as 2 m above sea level.

5.5. Flooding Tools and Applications

5.5.1. Can-EWLAT

The Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT) is a science based decision tool for planning climate change adaptation of coastal infrastructure related to future extreme water levels and changes in wave climate. It was developed primarily for DFO Small Craft Harbours (SCH) locations but can be useful for planners dealing with coastal infrastructure. CAN-EWLAT applies a statistical method to compute a vertical allowance, which is the amount that infrastructure should be raised above its current height in order to maintain the risk of flooding to be the same as it currently is. It applies extreme value theory in which techniques and models are used for describing rare extreme events, rather than the usual, such as annual maximum sea levels. These estimates are based on the method of Hunter (2012 in Zhai et al., 2014). It is based on the projection of future sea-level rise along with the uncertainties of those projections (defined by the 5th and 95th percentile limits) and historical water level records incorporating tides and surges following the approach of Hunter (2012). Sea-level rise will increase the likelihood of future sea-level extremes (Zhai et al., 2014). A key feature of this approach is that it takes into account future mean sea-level rise, and the uncertainties in projections for these changes (Hunter et al., 2013). This allowance ensures that the expected, or average, number of extreme (flooding) events in a given period is preserved and essentially within the range of experience for local residents. For each SCH site, CAN-EWLAT draws upon the vertical allowance limit for the closest tide gauge site. RSLR at these sites will soon be updated using more extensive VLM grid within James et al., 2014. The vertical allowances provided are expressed in Mean Water Level (MWL) Epoch 2010 (Figure 12).

Sea-level allowances are subject to caveats (Hunter 2014). However, given the state of knowledge and consensus at this time, Zhai et al. (2014) recommend continuing to use the sea level allowances based on the IPCC's AR5 projections for planning purposes. 'Dalcoast' (Bernier and Thompson 2006) – a storm surge model hindcast are used within CAN-EWLAT to estimate allowances at coastal sites that do not have tide gauge records. The vertical allowance provided by CAN-EWLAT is based on historical records and does not incorporate predicted changes in storm tides over the coming century because the current state of knowledge of future projections of storminess is limited. It appears however to still be included in the outputs provided (Figure 13). While CAN-EWLAT provides a valuable tool for raising coastal infrastructure at risk vertically, it is not appropriate to be used to map future flood extents laterally. In addition, it is also only available in locations with small craft harbours (Figure 14) so areas in the Upper Bay of Fundy are not represented.

CAN-EWLAT, FOX POINT, NS

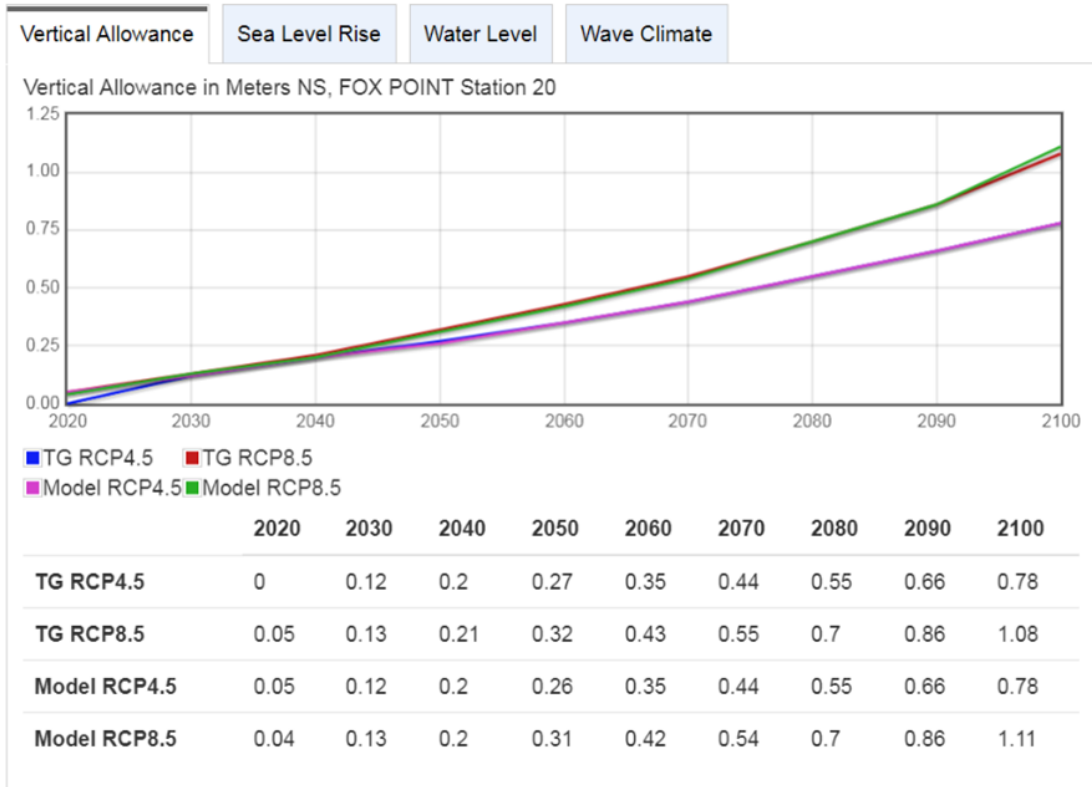


Figure 12: Example of vertical allowance calculated by CAN-EWLAT at the Fox Point Wharf.

CAN-EWLAT, FOX POINT, NS

Vertical Allowance Sea Level Rise Water Level Wave Climate

	Wave Climate (m)
CurWaveWinter (1970-1999)	0.65
CurWaveSummer (1970-1999)	0.62
ProjectedWaveWin (2040-2069)	0.65
ProjectedWaveSum (2040-2069)	0.62

Figure 13: Example of current and projected wave climate for Fox Point NS.

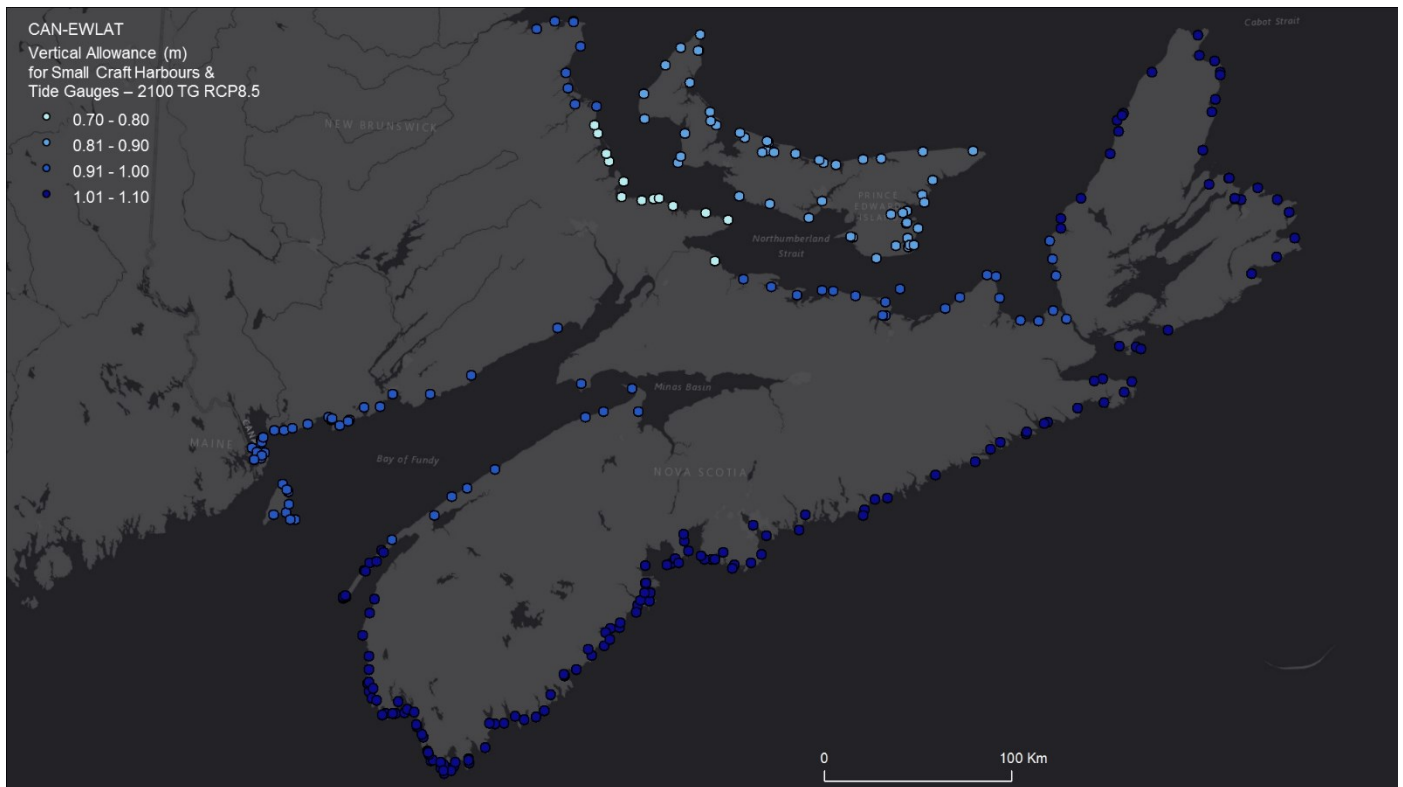


Figure 14: Spatial distribution of vertical allowances available through CAN-EWLAT for RCP8.5 2100 projection for the Maritimes

5.5.2. Emergency Coastal Flooding Decision Support System (Wester et al., 2017)

The Applied Geomatics Research Group (AGRG) developed a web-based Emergency Coastal Flooding Decision Support System to present coastal flood risk from storm surges and long term sea-level rise in the Maritimes. The project was funded by the Canadian Safety and Security Program, a federally-funded program led by Defence Research and Development Canada's Centre for Security Science (DRDC CSS), in partnership with Public Safety Canada and was locally managed by the Nova Scotia Department of Natural Resources, Mineral Resources Branch. It is a web-based mapping system that uses existing, publicly available high-resolution LIDAR elevation surveys of coastal areas where flood risk maps have been developed. This tool allows Emergency Management Officials (EMO) and other government officials to access previously developed flood maps by AGRG when a storm surge is predicted or for assessing risk to long term sea-level rise. Environment and Climate Change Canada provided 10-day storm surge predictions based on DalCoast (Bernier and Thompson, 2006), for several Atlantic coastal communities in the Maritimes. The system integrates the predicted surge water levels with predicted tide levels obtained from the Department of Fisheries and Oceans to produce total water levels (tide + surge) in CD. These values are converted to a common reference datum (CGVD28) that is used for all layers. Flood layers are then displayed over the LIDAR shaded relief map, or other background imagery so officials can see what areas may be flooded. Spatial analysis tools are available to display and query the flood depth and to identify flooded critical infrastructure and roads. The prediction does not account for waves and wave run-up. This application also allows any flood level up to 12 m CGVD28 to be selected, presumably so one can look at vulnerable areas in the future considering different relative sea-level rise predictions. However, no

guidance is provided regarding plausible upper bound scenarios and metadata available through the web portal is sparse.

6. Considerations, Challenges and Recommendations

6.1. Key Message: Confidence for RSLR predictions based on current publications = Moderate to High

Despite a lack of consensus in the literature regarding the validity of applying a probabilistic approach versus adjusted AR5 (e.g. Church et al., 2013) for high and extreme scenarios, there is agreement within the Canadian context that the upper bound is very unlikely to exceed 2 m by 2100 (Han et al. 2016; pers com T. James, Jan 22, 2019). The most important component of sea level rise for Nova Scotia is the accuracy of the vertical land motion component. James et al. (2014) incorporates the most comprehensive distribution of GPS stations in Canada through the Canadian Geodetic Survey. The uncertainty of the meltwater contribution from the West Antarctic ice sheet is addressed by adding an additional 65 cm to the RCP 8.5 2100 scenario. These values have recently been interpolated into a national RSLR surface raster with grid resolution of 0.5x0.5 degrees which is anticipated to be released publicly in the Spring of 2019. An example of this grid is provided in Appendix B.

6.2. Key Message: Confidence for HHWLT levels = moderate except Upper Fundy (poor)

The recent creation of the *Hydrographic Vertical Separation Surfaces* (HyVSEPS) for tidal variables (e.g. HHWLT) based on oceanographic models, observed water levels, GPS observations, sea level trends, satellite altimetry and a geoid model are a significant step forward for more accurate flood modelling (Robin et al., 2014). The continuous surface model provides better resolution at the local level, particularly for areas that are not close to a real-time tide gauge. It provides a common reference frame for tying in CD to both CGVD28 and CGVD2013, linking marine to terrestrial surfaces. Given the range of CD to geodetic conversions provided in previous technical reports, and low confidence in predictions at quite a number of CHS stations (Figure 8), it is recommended the previous approach of tying RSLR projections to HHWLT at CHS stations be abandoned and replaced with the use of HyVSEPS and the new RSLR surface from NRCAN/Geodetic Survey of Canada.

However, there is a risk of loss of public confidence in flood extents depicted if extreme water level projections (due to decreases in modelled HHWLT) decrease. This is particularly the case for the Upper Bay of Fundy. It is recommended that a working group be created with DFO, CHS, NRCAN, GSC and researchers/practitioners with field and modelling experience to come together to address this issue and figure out a way to move forward. At present, it is recommended that the new 2017 HHWLT values NOT be applied in areas of the Upper Bay of Fundy where there are extensive intertidal zones which are known to be poorly resolved in oceanographic models.

6.3. Key Message: Need for permanent or long term tide gauges in areas poorly resolved by existing hydrodynamic and oceanographic models

A significant challenge for accurate modelling of extreme water level scenarios, is the paucity of real-time tide gauges in the Province. In particular, storm water levels and even tidal elevations are not able to be validated or measured effectively in the Upper Bay of Fundy. This is also the area where there is greater uncertainty and reliability in existing hydrodynamic models. The boundary conditions of many of these models are driven by

WebTide (<http://www.bio.gc.ca/science/research-recherche/ocean/webtide/index-en.php>) which provided predicted 'MSL' but there is no documentation regarding the vertical datum employed nor are there alternative tide gauges to provide validation of these water levels. Although a tide gauge was installed at the Fundy FORCE station at Cape Split, the public availability of time series data is limited. It is recommended that a strategic series of water level recorder be installed for at least ice free conditions in key major tidal rivers simultaneously to gather a base data set that can be used for validation of current tide predictions for the Upper Bay.

6.4. Key Message: Selection of storm surge scenarios and approach will be a function of type of flood mapping product desired

Ultimately the selection of storm surge scenarios and approaches will be a function of the type of flood mapping product desired and the intended audience. For example, inundation maps are used primarily for EMO, for the identification of flood hazard zones (real or potential events based on flood events of different magnitudes) and aid in the management of emergency preparedness plans. Flood hazard maps display the results of hydrologic and hydraulic analyses and are applied more for engineering, regulatory design and infrastructure planning. Flood risk will often intersect either inundation or flood hazard maps with socio-economic or biophysical variables. These maps serve to identify social, environmental or economic consequences to communities during a potential flood event (NRCAN, 2018). At the base level at the Provincial scale, inundation maps could be the base level required with more complex analyses performed in areas of known vulnerability.

In conclusion, the availability of standardized, province wide data for high resolution topographic data, newer RSLR and tidal parameters provide excellent promise for Nova Scotia to create flood maps that applicable to a wide range of scenarios.

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Appendix A: Projected sea-level change (in cm) relative to 1995

Source: James et al., 2015. Median values with 5th and 95th percentiles

Tusket, NS (TSKT)

Scenario		2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
RCP2.6	5%	0.9	5.9	10.9	13.9	17.5	17.1	21.1	22.5	25.0	25.6
	median	5.5	11.1	17.8	24.5	31.7	35.4	42.5	46.1	50.4	55.4
	95%	10.1	16.3	24.7	35.1	45.9	53.7	63.9	69.7	75.8	85.3
RCP4.5	5%	0.9	2.9	6.2	14.5	20.2	21.2	26.4	30.2	33.0	34.8
	median	4.9	10.4	16.6	24.9	31.4	37.8	45.1	52.7	59.8	65.4
	95%	8.8	17.9	27.0	35.3	42.6	54.4	63.7	75.3	86.5	96.0
RCP8.5	5%	1.4	4.2	10.4	14.2	19.2	27.5	30.8	39.0	45.8	49.3
	median	6.2	11.4	19.1	26.1	34.6	45.0	53.2	65.1	76.8	87.8
	95%	11.1	18.5	27.7	38.0	50.0	62.6	75.7	91.3	107.9	126.2

Halifax (HLFX)

Scenario		2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
RCP2.6	5%	1.4	6.6	10.0	13.4	18.0	18.4	24.2	25.5	26.9	27.0
	median	6.0	11.1	17.1	24.6	32.2	36.7	45.0	48.3	52.4	57.7
	95%	10.6	15.5	24.2	35.8	56.4	55.1	65.8	71.0	77.9	88.4
RCP4.5	5%	0.8	2.1	6.9	13.8	19.5	21.5	25.8	30.1	33.5	35.0
	median	5.0	10.1	17.0	24.8	31.2	37.7	45.1	53.0	60.6	66.9
	95%	9.1	18.2	27.0	35.7	42.9	53.9	64.3	75.9	87.8	98.7
RCP8.5	5%	0.8	4.5	9.6	13.4	19.4	27.0	30.7	37.5	45.7	51.0
	median	5.6	10.4	18.5	25.4	34.8	45.0	53.7	65.1	77.2	90.3
	95%	10.4	16.3	27.4	37.3	50.3	62.9	76.7	92.6	108.7	129.6

Truro (WTHL)

Scenario		2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
RCP2.6	5%	1.4	7.2	12.5	15.2	18.8	19.3	22.2	25.1	26.9	27.6
	median	6.1	11.4	18.4	25.3	32.3	36.7	43.5	47.8	52.2	57.1
	95%	10.8	15.6	24.3	35.5	45.8	54.1	64.9	70.4	77.5	86.5
RCP4.5	5%	1.4	3.8	8.0	15.5	20.8	22.8	27.9	31.3	34.6	36.9
	median	5.2	10.9	17.5	25.6	32.4	39.1	46.2	53.6	61.0	67.0
	95%	8.9	18.0	27.0	35.7	44.0	55.4	64.6	75.8	87.4	97.1
RCP8.5	5%	2.2	5.4	11.1	14.9	21.0	29.3	31.9	39.8	47.2	51.4
	median	6.6	11.8	19.6	26.7	35.9	46.3	54.7	66.3	77.8	89.2
	95%	10.9	18.2	28.1	38.5	50.7	63.4	77.4	92.8	108.4	127.1

Baddeck (BDCK)

Scenario		2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
RCP2.6	5%	2.0	8.2	13.8	16.8	20.7	21.8	24.4	28.1	30.7	31.8
	median	6.6	12.3	19.9	27.1	34.6	39.7	46.7	51.4	56.4	61.9
	95%	11.2	16.4	26.0	37.4	48.5	57.7	69.0	74.6	82.0	92.0
RCP4.5	5%	2.0	4.5	9.1	17.2	23.3	25.4	30.1	34.3	38.4	40.2
	median	5.7	11.6	18.7	27.2	34.7	41.8	48.8	56.7	64.7	70.6
	95%	9.5	18.7	28.2	37.3	46.1	58.2	67.4	79.0	91.1	101.1
RCP8.5	5%	3.2	6.4	12.6	16.6	23.4	32.1	34.9	42.7	49.9	55.0
	median	7.0	12.7	20.9	28.4	37.9	48.9	57.6	69.5	80.7	93.0
	95%	10.7	18.9	29.3	40.2	52.4	65.7	80.3	96.4	111.5	131.0

Appendix B: Example of Relative Sea-Level Surface Model for Atlantic Canada (draft NRCAN, pending)

