2024 Nova Scotia Municipal Flood Line Mapping

OVERVIEW

DEPARTMENT OF MUNICIPAL AFFAIRS AND HOUSING

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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: Flood Mapping Guidance for Municipalities** (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** (Specification) 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 work[1].
- 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 high, medium, and lower priority reaches of the watersheds and 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 seiching. 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 at least 3 months at a 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 high and medium priority reaches are acceptable, and any additional mechanisms identified in the Statement of Work are applicable. The consultant will also be expected to 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 sieching 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 defendable 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.

MGA Schedule B

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***.

MGA Schedule B

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.

MGA Schedule B

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 (W0=62,636,856.0 m2s-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 be in the Maritimes where the new datum will be higher by 65 cm, meaning lower elevations for the region.

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Nova Scotia Municipal Flood Line Mapping

Appendix A: Flood Mapping Guidance for Municipalities

Contents

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 guide that allows municipalities to customize their flood analysis to the most relevant factors that influence flood risks. Flood scenarios that are associated with a specific return period need to produce flood extents 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 which mechanisms produce conditions that might occur in a specific watercourse during flooding. Careful consideration of flood mechanisms that may exist in the study area will allow the municipality to generate flood extents that are representative of actual floods experienced at the site.

The following sections describe the process to be followed by the municipality throughout the project. It includes a description of the steps to be taken and how each one will support the selection of flood mechanisms. Each step can then be checked off in the Checklist presented in Chapter 5 and included in the Request for Proposals (RFP) to form the Scope of Work (SoW).

1.2 Steps to be taken by the Municipality

1.2.1 Flow chart of main steps

Following an expression of the need for a flood study, a 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 this process, collect, and report the information shared. The flow chart presented in Figure 1 provides steps that will help develop RFPs that include relevant information for the flood studies.

For the study scope to be meaningful and representative of 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 a flood mapping study is to provide support for future development regulations in floodplain areas. Therefore, flood maps need to be informed by local experience of flooding and show vulnerabilities along the watercourse or coast. The earlier the stakeholders, community members, and the public are involved in the process, the more likely 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 for engaging First Nations communities are 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 coordinating 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. Consultants can 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 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 limitations of modelling can be understood, and future flood line mapping can incorporate additional data.

In Step 2 of Figure 1, vulnerabilities are discussed. Vulnerabilities in this context specifically relate to land use, infrastructure, or services that are 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 a study, then, discussions can be held to determine which ones are sufficiently important and may influence the flood mapping study. For example, if a hospital is close to a potential floodplain, special consideration should be given to 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, upgrading hydraulic structures, etc.), but could lead to increased flooding at the site.

Following this, a municipality will use the information gathered to decide which flood mechanisms to include in the study. 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

STEP 1

Look for relevant information and data in land use planning documents and asset management plans. Collect available data on historic flood events. Hold internal discussions between engineering, planning, EMO, and operations staff to collect known internal information about the area and flooding risks. Conduct data gap analysis.

Prepare initial lists of:

- Known flood mechanisms.
- Available internal information.
- Known areas vulnerable to flooding.

STEP 2

Meet with potential stakeholders, which may include First Nations communities, provincial departments, business associations, and local associations, including watercourse protection groups, which may hold valuable information.

Update the above lists with focus on extracting vulnerabilities and past flood history. Note specific areas of concern from stakeholders.

STEP 3

Meet with the public and other interested groups. The goal is to collect information and engage the public early in the flood mapping process.

Finalize the above lists with focus on extracting vulnerabilities and past flood history. Note specific areas of concern from the public.

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 are 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 when defining the flooding mechanisms prevalent in the study watershed. However, the capacity of First Nations communities to engage varies and can be limited; decision-makers in their communities may hold multiple positions and often seek input from others before a decision is made. Consideration and time should be allowed for decision makers to juggle these 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. The earlier they are involved in the project the more they see their contributions and input shaping its outcomes. Early engagement provides opportunities for the development of land use plans that are more responsive to Aboriginal interests and values. 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 potentially affected parties at the outset of the project is to foster inclusivity and respect for 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 the goal is to protect public safety, and 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 on property development. Because zones and planning documents will be changed to align with the flood study, it is important to engage the local community early on to minimize potential conflict or concerns. 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 may 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, and the municipality should be prepared to have meaningful conversations with those who have experienced loss due to a flood event. Despite this, there may be individuals who do not see the value in restricting development. By including them in the assessment before analysis, 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 have greater support from its constituents and output a study that is better supported by local information.

A typical approach to an engagement meeting would include:

1) Presenting background information that led to the initiation of the project. This might include 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) Providing large maps, on which members of the public can note extents of past floods, or vulnerable infrastructure. This information can later be entered into a GIS database for reference.
3) Administering a questionnaire 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 of the main goals of this type of engagement will be to gather information on potential flood mechanisms that will be included in the RFP. To support and inform this process, descriptions of each mechanism are presented in Chapter 2, as well as a checklist that can be introduced in meetings and/or the RFP.

1.2.4 Recommendations for Municipal Communications

Reflect

As a municipality, it will be important to understand the core reasons for opposition to flood mapping and the social science theories[1] that help explain them. 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 positive perception of the municipality.

It is useful to take an informal audit of trustworthiness within the municipality, both citizen-to-municipality and citizen-to-citizen. This may include reflecting on and learning from past engagement campaigns and program rollouts and any conflicts that arose. 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.

Within the municipality, there must be a political commitment to support the flood mapping product and implement policies that protect both current and future citizens. It may be helpful to develop guidelines for how different categories of risk will be handled. Key operating principles should be discussed with councillors and other elected officials (e.g., MLAs), and decisions should be documented so they can be revisited later.

Involve citizens when engaging with experts

Most municipalities will not have the sufficient in-house flood mapping capabilities 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 be technical experts and proxies for the municipality, and any relationship failures will reflect upon the

[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.

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 community members in a 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 are underrepresented on council), but also for the esteem by which they are held in the community. Meaningful involvement will help citizens feel well represented, but also leverage cognitive shortcuts: if people they know and respect are advocating for flood mapping and standing behind the final product, other residents are less likely to reject the outcome.

Demonstrate the shared challenge and shared responsibility

Before conducting flood mapping, it is essential to demonstrate to citizens its necessity and the public benefits it will bring. Municipalities should lay out all the problems that may arise during 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 them in unhelpful ways. Stories and photographs of extreme events in the area, or nearby, can be used. This reminder of adverse impacts will make the issue salient without triggering instinctive responses, which might undermine the careful reflection required to tackle flood adaptation.

When a municipality gives residents complete information about the costs and benefits of flood mapping, and includes them in responses to the mapping, residents are more likely to engage with and accept the outcomes. If participants understand the necessity and benefits of flood mapping, they will feel motivated and knowledgeable enough to influence flood mitigation strategies.

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). Engagement should clearly convey that historical experience 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 are familiar with. Make sure the chairs are comfortable and that people have time to stretch and chat over coffee. Use silent ballots where social pressures might make voting or other input difficult. Finally, consider various meeting formats to maintain interest, perhaps holding them at sites near floodplains or coasts so the meeting can discuss issues in-situ.

Provide a counter-narrative to the media

Media coverage plays a significant role in extending the reach of flood mapping messages and 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 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 recent significant challenges to flood mapping and coastal adaptation 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 through citizens who have been disadvantaged by the lack of flood mapping.

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.

Advanced communication tools such as geovisualizations (i.e., maps with animations) can strengthen connection to place and convey complex information in an accessible way. 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 should be included on how users can interpret their flood risk level (i.e., frequency and amount of flooding) and how they might 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 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 a 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 most common flooding mechanisms (e.g. ice jams or floods associated with snowmelt). These meetings may lack discussion of more complex mechanisms, such as tidal amplification or seiching. It is important to collect this information prior to the flood study, because complex mechanisms can only be identified through field measurements spanning several weeks. They also 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 in analysing the data and supporting the preparation of an RFP. This could be the same consultant that carries out the flood study, a separate consultant engaged to develop the RFP, or the client engineer who reviews the study results as described the Overview.

- The consultant will examine the data collected by the municipality and offer recommendations to include additional flood mechanisms as necessary.
- On items decided on by the municipality, the consultant will provide clear recommendations supported by professional expertise and analyses.
- The consultant should be able to defend their analyses against questions from the public, other consultants, and agencies.
- The consultant must have a team that is appropriately qualified and completes the analysis in a defensible manner.
- The consultant will identify items in the Technical Specifications and Guidance that are not appropriate to the study area, making the study 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 be detected by analyzing water levels at coastal sites. These measurements are compared to expected peak tide levels from the nearest harbour, based on tidal information from the Canadian Hydrographic Service. Furthermore, rainfall data may be limited, and water course levels are often unavailable from flow gauging stations, which only provide flow measurements. Consequently, rainfall and water level data from upstream areas, beyond tidal influence, are also highly valuable.

To supplement anecdotal information and support model calibration, the following measurements must be 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), 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 studied watercourse.
- 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 (below mid-tide level or lower).

If preliminary historical and anecdotal evidence indicates that the watershed does not include riverine flooding risks, the rainfall gauge and 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 water levels within the tidal influence are collected and graphed, they should be converted from Chart Datum to CGVD2013 and compared to the nearest tidal predictions from Fisheries and Oceans Canada. If the peak water levels are different, this indicates the presence of tidal amplification or seiching. Increased tidal height peaks indicates tidal amplification while oscillations outside of tidal peaks indicates seiching. If these mechanisms are detected, they will need to be included in the scope of work for the flood study.

A review of the data and presence of tidal amplification or seiching by the selected consultant will confirm if 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 extent. 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 1 in 100 year event) and 5% AEP (equivalent to 1 in 20 year event) should be used by the municipality and consultant during the flood study and engagement with stakeholders and the public.

2.2 Projection Horizons for the analysis of future flood events

In developing the specifications, the province collaborated with academic institutions on a standardized framework for selecting scenarios and incorporating climate change into flood mapping. Literature reviews were conducted in various fields. The results were discussed with the province through workshops and the outputs were summarized in a set of specifications: 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 along 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. To account for climate change, any adjustments of rainfall measurements and coastal water levels should follow this document.

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

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), in both current and future conditions.

2.3.1 Precipitation:

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 should be investigated. Since winter conditions in Nova Scotia (i.e., December 1st to April 1st) include many freeze-thaw cycles, the likelihood of rainfall during the winter is high and 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 (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 should be taken as there is a risk of diminished public confidence in flood extents 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. These zones are known to be poorly resolved in oceanographic models.

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

CHAPTER 3 LIST OF POTENTIAL FLOOD MECHANISMS

This section provides information on additional mechanisms that might 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 cannot 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.

<table>
<tr><td rowspan="6">Potential Flood Mechanisms</td><td colspan="3"></td><td colspan="2">Future Scenarios</td></tr>
<tr><td rowspan="5">Current Scenarios</td><td></td><td>Mechanisms Relevant in Estuarine Floodplains</td><td rowspan="5">Land Use Change</td><td rowspan="5">Climate Change</td></tr>
<tr><td>Mechanisms Relevant in Riverine Floodplains</td><td>Ice jamming
Snowmelt during a rainfall event
Dam operation
Changing risks according to season
Hydraulic structure operation
Debris jamming</td></tr>
<tr><td>Mechanisms Relevant in Coastal Floodplains</td><td>Wave setup
Wave run-up and overtopping
Tidal amplification
Seiching</td></tr>
<tr><td>Joint Probability Analysis</td><td>Storm surge and rainfall
Other combination of events</td></tr>
</table>

3.1 Criteria and Roles for Selecting Mechanisms

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

The steps 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 informs the scope of work for the flood study 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 identify flood mechanisms. Any data gathering, or meetings with staff, stakeholders, community groups, interested parties, and the public would support the identification of additional flood mechanisms.

If mechanisms are 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 in the 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, in the scenarios identified in the checklist, the rainfall amount and sea levels are increased by values prescribed in the **Climate Change Standard**.

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

During the preparation of the RFP the checklist provided will be filled out by the municipality and supporting consultant and appended to the RFP document. It will then be reviewed and confirmed by the consultant. One checklist should be filled out for current climate conditions, with an additional two items being added for future conditions, including climate change impacts.

Table 3.1: Checklist of Potential Flood Mechanisms

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

More detailed descriptions of potential flood mechanisms are presented below. They are primarily for the use of the consultant but are presented here to support the selection of flood mechanisms if needed.

3.3 Mechanisms Relevant in Riverine Floodplains

There are many other scenarios in addition to extreme precipitation that might 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 mechanism is important to include if snow accumulation can reach high depths (more than one metre), 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 are often subject to ice jams. Ice jam modelling should be considered if ice jams have been historically noted in developed areas. 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 subject to debris jams. Debris jam modelling should be considered if debris jams have been historically noted in developed areas. Since debris jams can be different each time they form, the analysis must rely on as much field and anecdotal data as possible.

4. Dam Operation, where Present

Where dams are present, the owner of the structure should be contacted, and the operational procedures should be obtained for various weather conditions. The Dam Safety Review reports should also be obtained and reviewed. The scenarios that produce 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 have many different configurations, and can include operated weirs, gates, orifices, penstocks, flow diversions, pumps, and other components that may impact flows or water levels. If parts of the operational procedure of a hydraulic structure have the potential to increase flood risk, this mechanism be considered in the analysis. Similarly, if there is any likelihood that a structure could become stuck (such as a gate), this mechanism should be considered in the analysis.

6. Seasonal Conditions

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

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

7. Short Wave Processes
Short wave processes need to be evaluated where vulnerable infrastructure exists because they can increase water levels at the coastline. 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 defenses 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.

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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 lager 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 retreat[2].

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 scope of work in the original RFP.

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

After the flood mapping study is completed, the next step will be to develop a flood mitigation plan. Understanding the causes of flooding through the identification and analysis of flood mechanisms is crucial. By addressing these root causes, mitigation efforts can be more effective, targeting the source of flooding rather than just its symptoms. Therefore, the results of the flood study will be essential in preparing a comprehensive 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 floodplain's layout and the watershed's level of development, a Stormwater Management Plan can be an effective tool for reducing flood risk. These plans are crucial for identifying flood risks within the stormwater conveyance system at street level, a task that relies on first defining the floodplain.

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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

An analysis of public comments regarding inland and coastal flooding reveals that while most Canadians consider mapping an important issue, there is also significant opposition highlighted in various articles. A common concern expressed by Canadians is the potential negative impact of flood mapping on current home values and community development. Systematic media analysis helps to gauge public reactions to flood mapping and understand these responses through the lens of social theory.

Method

By reviewing local, regional, and national newspapers (via a database), we identified 112 articles from the past five years that included keywords such as "resident," "flood map," and "coastal." Of these, only 47 articles (42 percent) contained direct quotes from residents. The majority of the articles (65 out of 112, or 58 percent) featured direct quotes from local experts and representatives of municipal, provincial, and federal governments.[3]

Using qualitative data software NVivo and Excel, we organized and analyzed the articles to identify themes in residents' comments. We first categorized the comments based on support for or opposition to flood mapping, then further refined them into themes such as personal safety and high insurance rates.

Thematic Coding Results

Flood mapping support

Most of the articles (87/112 or 78 percent) 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. Experts in these articles note that federal, provincial, and municipal governments are failing their citizens with their lack of coordination and implementation of flood mapping.[i] Only 22 of the 87 articles that approve of flood mapping include quotes from residents who are supportive of the action. In these articles, citizens often state their desire to know whether their financial security is at risk <u>before</u> 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

[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.

In all 22 of the articles that convey flood mapping support, people want to know about potential loss as a result of flood mapping. For example, an article about rising rivers across Canada points out the need for flood mapping, with a resident stating that if she knew the risk of living near the Ottawa River, she “wouldn't have bought the home”.[iii]
While the majority of 2019 media articles from Quebec focused 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 purchasing property. 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” of flooding.[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 saves four dollars in repair and rebuilding costs”.[viii] The article later notes that the province is well equipped for mapping work and coastal land-use planning, which could potentially create much-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 stating, “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 is 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. These residents have experienced flooding in their homes, but will not risk another flood experience. 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

Most of the supportive articles cite the need for help from government to perform necessary flood mapping. They are also 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

A smaller portion (25/112 or 22 percent) of the resulting articles include direct quotes – some 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 building or renovations, or resale challenges. A flood map that dissuades development means that people cannot live on or near some desirable waterfront properties. Nova Scotians, like many Canadians, have lived near the water for centuries, so waterfront homes or properties are often handed down in families. The following themes emerged 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 rezoning plan due to concerns over property values. A resident notes that designating his home as high flood risk meant that his property would drop in value by 30 to 40 percent.[xvi] Similarly, new designations being applied to properties after mapping in some provinces (including Quebec) has led to construction freezes after a flood – leaving residents homeless.[xvii]

Residents are concerned that flood mapping could lower their property values or result in the loss of their homes. Most comments emphasize the difficulty of selling a property, or taking government buyouts, and being forced to move at a financial loss. An article quoting a couple in New Brunswick notes that they lived in their house since 1987, with a mortgage, and 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]

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 in the province's recent 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 or 20 percent) that oppose flood mapping also mention loss or potential loss of an individual's property through increasing insurance rates or lack of insurance.[xx] Although insurers offer products for overland and coastal flooding, four of these articles 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 opposing articles reference their lived history at their location, noting 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. One article notes that farmers reclaimed land from tidal marshes using ancient drainage systems, first constructed by Acadian settlers in 1671. A farmland owner in Amherst 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 articles 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, 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. Government officials and experts highlight the need for flood mapping, while some residents wish mapping had occurred earlier, and some oppose the idea entirely. This problem becomes intractable when all individuals—current residents and potential future ones—are treated the same. However, it can be resolved in favor of maintaining the status quo (no mapping) within a democratic system that prioritizes the interests of 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, making System 1 more prone to 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 biases our perceptions [xxxi] and affects our ability to make connections, analyze information, and draw conclusions.[xxxii] **Bounded rationality** refers to the tendency to use shortcuts in our thinking, such as relying on the opinions of similar individuals (normative bias), applying heuristics like political values, or ignoring gradual changes in our surroundings that we perceive as unnecessary.

In social science*,* **loss aversion** is the 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 they do not is uncertain. This uncertainty is also most of what drives **status quo bias**.

Someone experiencing **cognitive dissonance** 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 they can rebuild without worry.

Solution aversion works much the same way, and like cognitive dissonance it is 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 entirely. 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 opinions of 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, and 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; a sense that they are 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 designing interactions for the kind of knowledge and relationships that attendees have, rather than expecting them to engage in unfamiliar or uncomfortable activities. This also champions engagement that is meaningful rather than tokenistic.

Leveraging the reasonable person model requires an understanding of **trust ecology**. This is 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 conditions trust ecology with the characteristics of the entity being trusted. This includes **ability** (technological competency), **integrity** (moral competency), **benevolence,** and the subjective variable of **charisma**, which can only be attributed to an individual not 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;
- Citizens perception of their municipalities intentions in carrying out flood mapping and whether they feel their municipality is seeking to 'do the right thing'; and,
- The personal characteristics of those individuals with whom citizens interface in the process of flood mapping.

Researchers have found that **social trust** (interpersonal trust) can be more important to behaviour change than **institutional trust**. Whether people accept flood mapping may depend on their feelings about their fellow citizens and who they perceive as benefiting or losing from the process. It can be just as important as their opinions of municipal representatives or hired consultants.

Finally, studies indicate that people often think in terms of unconscious structures called **frames**.[xxxix] Social scientists often use **communicative frames** to convey information and elicit specific responses. Often, we can influence responses by changing the language of a message but, framing must work emotionally and be relatable to the reader. 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 distinct types of moral framing increase citizen's perceptions of when to act: 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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Nova Scotia Municipal Flood Line Mapping

Appendix B: Technical Specifications

Contents

CHAPTER 1 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. 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 Teir Method for mapping and data collection

All primary watersheds in the province are expected to be mapped using a Tiered Mapping Method. The tiered mapping method prioritizes reaches of the watershed based on the potential for hydraulic influence and impact on vulnerable populations or infrastructure and consists of three tiers of accuracy reflecting different applications or the maps and levels of potential risk.

1.1.1 High Priority Reaches

Consisting of highly developed areas and areas designated by municipalities for future development. These areas would require intensive survey and data collection efforts. All watercourses in the reach with depths greater than one metre would require bathymetric data and there should be a high degree of confidence in the accuracy of the flood lines in the current condition scenarios. The resulting maps are considered regulatory and municipalities would be expected to use them to ensure their Municipal Planning Strategies and Land Use Bylaws are reasonably consistent with the Statement of Provincial Interest Regarding Flood Risk Areas. The maps should allow municipalities to accurately determine properties and infrastructure at risk of flooding.

1.1.2 Medium Priority Reaches

Consisting of areas where essential buildings or infrastructure are present or critical road/highway crossings are identified. These areas would require targeted field surveys at key locations along the reach. River cross sections would be required to supplement terrestrial lidar with consideration given for bathymetric surveys in watercourses with depths greater than one metre where additional accuracy in the model would be valuable. The resulting maps are not considered regulatory, however, municipalities would be encouraged to use them to ensure their Municipal Planning Strategies and Land Use Bylaws are reasonably consistent with the Statement of Provincial Interest Regarding Flood Risk Areas.

1.1.3 Lower Priority Reaches

Consisting of areas with minimal development and generally flow through wooded and/or agricultural areas. Flood mapping in these areas will be based on strictly desktop analysis using the available DEM. The resulting maps are not considered regulatory. These maps may be useful for municipalities for long range land use planning, especially considering climate change scenarios in 2050 and 2100. These maps map also be useful for municipalities to determine if there are other high or medium priority areas that should be studied in the future.

1.2 Return period or frequency of flood events to analyse

1.2.1 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.

1.2.2 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.

1.3 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.

1.4 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.

1.4.1.1 Winter Rainfall Event

In addition to the scenarios prescribed by the Province through the **Climate Change Standard**, winter rainfall events shall be investigated. Precipitation needs to be monitored for at least 3 months between October and May if there is no existing data. 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).

1.4.2 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., 2016). 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 Geological Survey of Canada (James et al., 2021).

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.

CHAPTER 2 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.

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

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)
	Existing Climate Conditions	
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 events[1]:		

[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
	Future Climate Change Conditions	
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 defenses 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 retreat[2].

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.

CHAPTER 3 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.

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

CHAPTER 4 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.

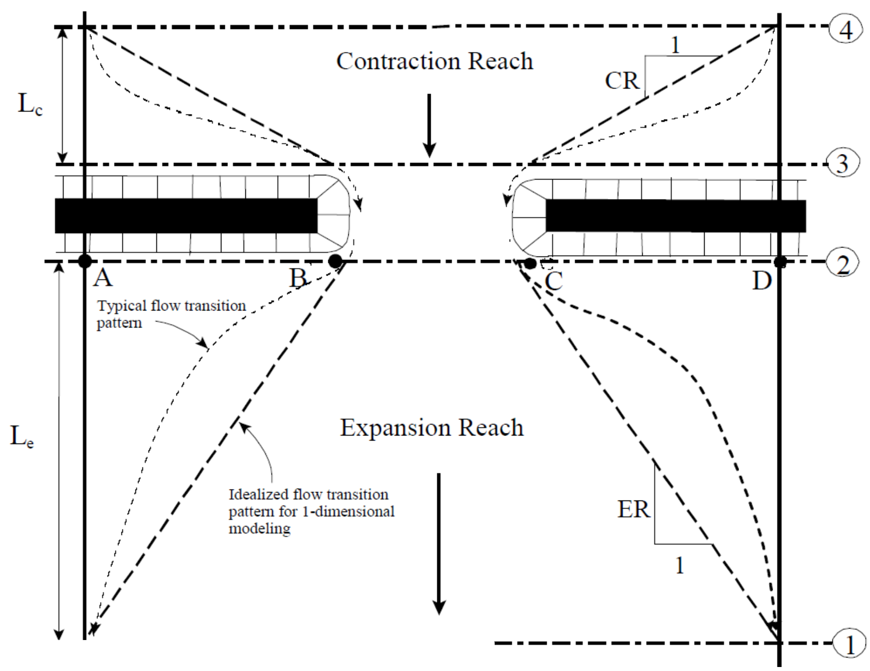

Figure 4.2 - Cross Section Locations at a Bridge or Culvert (Table 5.1 from the HEC-RAS Hydraulic Reference Manual)[3]

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, 2016 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.

CHAPTER 5 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.

CHAPTER 6 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.

	Hydrology	Hydraulic Modelling
Hydrologic and Hydraulic Modelling Requirements	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 Velocity-area Discharge Measurement Collection

Where velocity-area discharge measurements are required the Water Survey of Canada (WSC) methodology should be used. If the specific circumstances require another methodology this should be rationalized and clearly articulated in the reporting.

Spacing of the verticals
• Collect at least 20 observation verticals (stations) in any cross section (25-30 verticals is ideal). • Each station should account for about 5% of the total flow and no station must account for more than 10% of the total discharge. • Where depths and velocities are greater, verticals are closer together. Where depths and velocities are smaller, the distance between verticals increases. • Keep the distance between verticals greater than 5 cm. It may not be possible to obtain 20 verticals and 5% of flow per vertical on narrow streams. Adjust the total number of verticals according to this minimum criterion for distance.

Depth of observation
• If the depth of vertical is less than 0.75 m, observations are made at a 0.6 depth. • If the depth is equal to or greater than 0.75 m, the two- point method with observations at 0.2 and 0.8 depth is used to obtain the mean velocity. • If a non-standard velocity profile is suspected with the two-point method, a third observation is taken at 0.6 of the depth and the three-point method is then applied.

Time of exposure
• Under normal measurement conditions, each point velocity must be sampled for a minimum of 40 seconds. • If velocities at a location appear highly variable, a longer sampling time should be used. Ensure the probe remains stable during the sampling time. • Under extreme conditions, such as rapidly changing stage, a shorter sample time may be used to lessen the overall measurement time. However, it would be advisable to conduct one or more additional measurements consecutively under such conditions.

Flow angle
• Position the probe perpendicular to the tag line while holding the wading rod vertically.

Interference from technologist
• The technologist should stand in a position that least affects the velocity of water in the sampling volume. • Hold the wading rod firmly and close to the tagline. • Stand downstream of tagline, and as far from the probe as possible (this may require standing to the side of the wading rod). • For very small streams or near shore measurements, avoid standing in the water if feet and legs would occupy a considerable percentage of the cross-section or station.

6.1.2 Velocity-area Discharge Measurement Collection

Where stage-discharge curves are required the Water Survey of Canada (WSC) methodology should be used. If the specific circumstances require another methodology this should be rationalized and clearly articulated in the reporting. The stage-discharge curve development must be as follows[4]:

- Stage-discharge measurements must be collected over the entire duration of the monitoring period (minimum 3 months).
- Consultant must monitor water level reading and weather forecast continuously and be ready to take a field measurement during high flow events.
- The stage-discharge curve should include a minimum of 10 stage-discharge measurements spanning the range of flows observed over the monitoring period.
- The highest and lowest discharge measurements should be within 15% of the maximum and minimum discharges captured during the monitoring period.

[4] There may be difficulty achieving a minimum of 10 measurements within 15% of min-max discharge at scale over the monitoring season. On a site specific determination the consultant can propose a reduced requirement as long as it does not go below a minimum of 6 measurements and 25% of the maximum and minimum discharges captured during the monitoring period.

6.1.3 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 agreeance 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 km^2 to 1450 km^2).

- 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.

6.1.3.1 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.

6.1.3.2 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.

6.1.4 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).

6.1.4.1 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 used[5].

6.1.4.2 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)

[5] 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

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:

- Light forest
- Medium density forest
- Dense forest
- Light brush
- 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 example[6]. 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

[6] 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.

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

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 used[7].

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

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[7] 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

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.

CHAPTER 7 MODEL CALIBRATION REQUIREMENTS

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 Process		
	1. Selection of Calibration Events	
	2. Calibration Data Sources	Rainfall Coastal water levels River flows and water levels
	3. Minimum Calibration Standard	

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 temperature[8], 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

[8] 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 Canada[9] (James, T.S., Henton, J.A.,Robin C., & Craymer, M. 2021) and Richards and Daigle (2011).

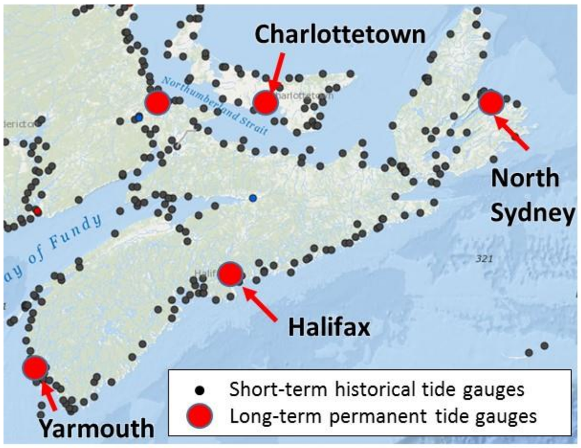

Fig. 1 DFO Tide Stations

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

[9] 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 an 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.

CHAPTER 8 STANDARDIZED MAPPING VISUALS

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. All maps should be stamped by a qualified engineering professional and be able to be cross-referenced with the GIS.

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.

CHAPTER 9 REPORTING / REQUIRED DOCUMENTATION

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, a GIS Geodatabase including all vector and raster data in a format that is retrievable with open-source software is required. The geodatabase should allow for mapping layouts and data links to be conserved. All maps (e.g. extents, velocity, depth, and hazard) should be delivered as both vector lines or polygons (as applicable) and 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).

The consultant should also work with stakeholders and rightsholders, including the Province, to identify locations that are of particular concern. These locations should be highlighted and discussed in the report. PDF maps of the locations should be included showing at minimum the flood extents for 1% and 5% AEP Current Climate and 1% and 5% AEP Future Climate at 2100.

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 Future Climate	Floodline_1_AEP_CC
	5% AEP Future 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 Future Climate	Depth_1_AEP_CC
	5% AEP Future 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 Future Climate	Velocity_1_AEP_CC
	5% AEP Future 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 Future Climate	Hazard_1_AEP_CC
	5% AEP Future Climate	Hazard_5_AEP_CC

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. The municipality may 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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