Newfoundland Labrador

Technical Guidelines for Flood Hazard Mapping Studies

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Water Resources Management Division
Department of Environment and Climate Change
Government of Newfoundland and Labrador

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1 Study Outline

This document was prepared by the Water Resources Management Division (WRMD), Department of Environment and Climate Change (ECC). The document is to guide the consultant through the hydrologic, hydraulic, hydrodynamic and mapping components of the flood study. It is the intent of the Flood Mapping Study Technical Committee that the consultant adheres to the document. Additional direction will come from the following:

- The technical guidelines, *Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation* developed by Natural Resources Canada, Environment and Climate Change Canda and Public Safety Canada. Available at: https://ostr-backend-prod.azurewebsites.net/server/api/core/bitstreams/a2f61bd9-8a09-4042-8f93-eaba7fdd6424/content

- Previous Flood Mapping Studies that are publicly available on the Department's website. The Technical Committee recommends that the consultant refers to recent studies to ascertain the Technical Committee's expectations for this study. All studies are available at https://www.gov.nl.ca/ecc/waterres/flooding/frm/.

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

2 Information Review

The RFP issued for a flood mapping study in Newfoundland and Labrador may include requirements for different types of flood-generating mechanisms including:

- Fluvial or riverine (inland) flooding
- Coastal flooding
- Ice jam flooding
- Pluvial or stormwater flooding in urban areas
- Flooding due to the failure of flood protection infrastructure

The RFP will include written descriptions and mapping to identify the watersheds, rivers, streams, and shoreline to be included in the study for flood modelling and mapping.

2.1 Collection

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

- Streamflow data collected under the Canada - Newfoundland Water Quantity Surveys Agreement.
- Meteorological data collected under the Canada - Newfoundland Climate Stations and Programs Agreement.

- Meteorological and streamflow data collected by third parties.
- Records of historical floods from various information sources including the WRMD's updated Flood Events Inventory.
- Drawings for any hydraulic control structures in the study area.
- Operating rules and curves from dam owners to determine how these structures would operate during high flow events.
- High Resolution elevation data.
- Aerial/satellite photographs.
- Mapping data.
- Lake and sea levels.
- Stream cross-sections.

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

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

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

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

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

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

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

2.2 Analysis

2.2.1 Data

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

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

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

The climate change condition will include both precipitation increase and sea level rise. The climate change precipitation increase will be defined by the climate change IDF curves presented in the 2015 report “Intensity-Duration-Frequency Curve Update for Newfoundland and Labrador” available at https://www.gov.nl.ca/ecc/files/publications-idf-curve-2015.pdf and the report “Projected Impacts of Climate Change for the Province of Newfoundland & Labrador: 2018 Update” available at https://www.turnbackthetide.ca/tools-and-resources/whatsnew/2018/Final_Report_2018.pdf. If a newer version of “Projected Impacts of Climate Change for the Province of Newfoundland & Labrador” is available at project award, then that report will be used.

2.2.2 Historical Flooding

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

WRMD's Flood Events Inventory and an analysis of its records are available at https://www.gov.nl.ca/ecc/files/Fall-2014-Flood-Inventory-1.pdf.

Quantitative and qualitative information, such as the areal extent of flooding, high water marks, and location of buildings flooded and damaged, can be used to verify the results of the flood hazard analyses. Based on the compiled information, the consultant is to then evaluate the significance of the various factors contributing to flooding in the study area. The consultant is to consider all collected data and the limitations in the database and other constraints. The consultant is to design a strategy to produce the required flood profiles considering the following factors:

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

2.2.3 Flooding Mechanism

Based upon collected data and the records of historical flooding events, the consultant shall identify the most probable flooding mechanism for each system (watershed, river, stream, shoreline) to be modelled and mapped, and proceed with hydrological, hydraulic and hydrodynamic analysis for that flooding mechanism. Possible types of flooding mechanisms common in Newfoundland and Labrador include:

- Rainfall
- Rain on snow
- Spring freshet or snowmelt
- Convective storm
- Ice jam
- Storm surge
- Storm waves

A river or stream system that has a history of ice jam flooding should be analyzed for both open water and ice jam flooding mechanisms.

Coastal communities in Newfoundland and Labrador are frequently exposed to powerful Atlantic storm systems that can trigger the co-occurrence of coastal and inland flood processes. The consultant shall jointly consider coastal and fluvial or riverine flooding in order to quantify the overall flood risk for these coastal communities.

3 Field Program

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

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

3.1 Ground Survey

- The field program must include ground surveys to determine the nature and extent of the features which affect the exchange of water between the river and the flood plain.
- The consultant must relate all surveyed data including cross-sections, measured water data, simulated water surface profiles, and high-water marks to the Geodetic Survey of Canada geodetic control datum.
- All files are to be provided in provincial MTM Zone 1-6 NAD83 CSRS projections, as appropriate (e.g., MTM Zone 3 for the west coast of Newfoundland).
- All elevations are to be provided in the CGVD2013 vertical datum.
- The consultant must use standard surveying equipment and methods.

3.1.1 Cross Sections and Hydraulic Structures

Hydraulic structures shall include culverts, bridges, and instream structures (e.g., dams, weirs).

- Cross-sections must be surveyed at the upstream and downstream ends of the river reach to be modelled and at all locations where there can be expected changes in discharge, slope, shape, or roughness. This can include contractions and expansions of the channel and/or floodplain, upstream and downstream of tributary inflow locations, and natural drops in the stream bed profile. The cross-sections must include the below water portion of the channel.
- Sufficient surveyed sections must be obtained to adequately define representative river geometry and the interval between them should be such that the assumption of uniform flow within a section should be reasonable. Surveyed cross-sections should be taken at 100 m intervals. If the mean slope of a river reach is less than 1.0 m/km the section can be considered flat and the length between surveyed cross-sections can increased to a maximum of 500 m intervals. If the mean slope of a river reach is more than 1.0 m/km, the section can be considered steep and the distance between surveyed cross-sections may need to be decreased.
- The number of river cross sections to be collected/used must be identified.
- A surveyed cross-section must be collected at any federal or provincial hydrometric station monitoring water level or flow, whether the station is active or discontinued. A surveyed cross-section must also be collected at the natural outlet of any lakes, ponds or significant wetland complexes to be included in the models.
- All cross-sections must be photographed. Water levels, flows where possible, and time of measurement must also be recorded for each cross-section.
- Sufficient points along each cross-section must be established to accurately define the geometry of the cross-section. To ensure an accurate depiction of the cross-section geometry, the horizontal or vertical offset for each surveyed point must not exceed 0.5 meters, whichever comes first.

- The consultant will be responsible for surveying the river cross-sections extending to the full extent of the flooding of the main channel and any tributaries that are likely to experience backwater effects.
- The consultant must ensure adequate overlap with the LiDAR data, surveyed cross-sections are to extend a minimum of five meters from the river's edge on either side of the riverbank.
- To aid with HEC-RAS modelling, additional cross-sections can be derived from the LiDAR data. The consultant can augment surveyed cross-sections with sections derived from LiDAR data where the below water portion of the channel is expected to be uniform to a nearby surveyed cross section. It is recommended to survey as many cross-sections as possible from the field program, rather than augmenting them by interpolating or extracting from a digital elevation model.
- A minimum of two surveyed cross-sections upstream and two downstream must be obtained at all hydraulic structures.
- All hydraulic structures must also be surveyed, photographed, and captured in the hydraulic model. The photograph should be attached in the HEC-RAS model.
- In the final report or its appendices, the consultant must present a table of all the hydraulic structures assessing their current flow capacity to determine whether the structures will be overtopped for the following flow conditions:
    - the 1:20, 1:100 and 1:200 AEP for current climate and current development conditions
    - the 1:20 and 1:100 AEP for climate change and current development conditions

  Overtopped structures should be flagged in RED. The table should include the name of the structure, waterbody, id, type, latitude, longitude, road elevation, whether overtopped or not, and water levels for the above scenarios.
- In the final report or its appendices, the consultant must provide flow and water level through each river cross-section as well as through the hydraulic structures in a tabular format extracted directly from the hydraulic model.
- In the final report or its appendices, the consultant must present stream cross-sections and hydraulic structures cross-sections directly from the hydraulic model.
- The consultant must include survey datasheet for all hydraulic structures showing location coordinates, size of the structure, upstream and downstream invert elevations, low chord elevation, road top elevation over the structure, structure condition, water level during the survey, and upstream and downstream photos.

3.1.2 Water Level and Flow Monitoring

For the purposes of calibrating and verifying the hydrologic and hydraulic models, the consultant must undertake additional water level and flow monitoring

- The consultant's proposal must indicate where additional water level and flow monitoring locations, considering any existing Water Survey of Canada hydrometric stations, are required. Hourly water level recordings are to be undertaken continuously on the ponds, streams, and tributaries in the study area, at locations agreed upon by the Technical Committee, for a minimum period of 30 days and which must capture at least one significant rainfall event (greater than 20 mm).
- It is strongly recommended that the consultant consider deploying flow meters for all ungauged streams/rivers to accurately capture the actual flow of the waterways during various storm events.

- Flow meters must be deployed along the thalweg of the river, taking safety concerns into account, to obtain continuous flow measurements for all types of flow conditions.
- All precipitation and level/flow events recorded must be included in the calibration and verification of the hydrologic and hydraulic models.
- For calibration and validation of the hydraulic models, surveyed water surface profiles must be obtained at key cross-sections on multiple occasions spanning a range of low to high flow conditions. The exact time the water surface profile was obtained must be accurately recorded.
- Accurate elevations of high-water marks and the time of measurement must be recorded in a safe manner. Measurements are to be synchronized with the flow monitoring.
- The consultant must provide a field survey plan with details for the Technical Committee's review and approval before initiating the field program which also includes the site selection and deployment of flow monitoring instruments. If some cross-sections are extracted from a LiDAR survey for any river reach, it should be highlighted in the survey plan with sufficient detail.

The Technical Committee must be informed in advance of the installation schedule. Members of the technical committee will accompany installers for some of the sites and will inspect some of the sites after installation.

3.1.3 Flood Protection Infrastructure

Flood protection infrastructure shall include any built systems used to protect property and other infrastructure from either coastal or inland flooding. This may include berms, flood wall, dykes, seawalls, sea dykes, breakwaters, jetties, and revetments.

- All flood protection infrastructure must be surveyed, photographed, and captured in the hydraulic model. The photograph should be attached in the HEC-RAS model.
- In the final report or its appendices, the consultant must present a table of all the flood protection infrastructure to determine whether the structures will be overtopped for the following flow conditions:
    - the 1:20, 1:100 and 1:200 AEP for current climate and current development conditions
    - the 1:20 and 1:100 AEP for climate change and current development conditions

  Overtopped structures should be flagged in RED.
- The consultant must include survey datasheet for all flood protection infrastructure showing location coordinates, type of infrastructure, size and dimensions of the structure (e.g., length, height), crest elevation, material, material size, structure condition, water level during the survey, and upstream and downstream photos.

The provincial flood protection infrastructure layer can be referenced to help identify known coastal and inland flood protection infrastructure. This layer is available upon request to WRMD.

4 Watershed Characteristics

4.1 Topography

The consultant is to create an accurate digital elevation model (DEM) of the flood watershed for use in the hydrologic modelling component of the study. The DEM is to be based on the best available data. The 1:50,000 Canadian Digital Elevation Data (CDED) can be used. Using LiDAR data acquired by the federal government, the consultant is required to verify the LiDAR data for the entire watershed of the study area and where available, the consultant should use the LiDAR data for hydrological modelling instead of CDED data.

For the hydraulic modelling component of the study, the consultant is to create an accurate DEM of the entire flood plain using only LiDAR. LiDAR data for the study areas is expected to be available from the Federal Government: https://open.canada.ca/data/en/dataset/957782bf-847c-4644-a757-e383c0057995. Any collected and processed LiDAR data will be the property of the WRMD.

4.1.1 Flood Plain DEM

The consultant will be responsible for processing LiDAR mapping of the entire above-water floodplain. Described below are the LiDAR requirements:

- The consultant will use data available from Natural Resources Canada's High Resolution Digital Elevation Model (HRDEM) product for the flood plain DEM. HRDEM is part of the CanElevation Series created in support of the National Elevation Data Strategy implemented by NRCan. The product is derived from Lidar data and includes a Digital Terrain Model (DTM) and Digital Surface Model (DSM).
- Additional information on the HRDEM product can be found at https://open.canada.ca/data/en/dataset/957782bf-847c-4644-a757-e383c0057995
- Data for the project areas can be obtained directly from the link above or from WRMD once available.
- The HRDEM data has a spatial resolution of one meter (i.e. a one meter by one meter cell size). If the consultant feels that the spatial resolution is not adequate in certain areas or circumstances, they may reprocess the data as required. Lidar point data (e.g. LAS files) can be obtained for this process if required but will have to be requested.
- Site visits and real-time kinematic global positioning system (RTK GPS) check surveys to confirm the accuracy of the DEM are needed to ensure accuracy in key locations of the DEM. The consultant will be responsible for ensuring that LiDAR and surveyed data are in agreement, and field verification of the LiDAR mapping against the surveyed data is required. A report on this verification must be included in the report appendices. The average vertical accuracy of LiDAR data when compared to field surveyed data for vegetated and non-vegetated areas should be in the range of ± 5 to 20 cm.
- The consultant must ensure that the vertical and horizontal accuracy of the DEM data is sufficient to be used for plotting 1:20 and 1:100 AEP flood lines and for inundation mapping.
- The consultant must clearly document the match between the LiDAR data and ground-surveyed sections in a technical appendix to the report.

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

- The bare earth DEM used in the floodplain mapping in ESRI grid and GeoTIFF format.

- Vertical contours at 1-meter intervals in ESRI Geodatabase. Elevation data must be stored as a numeric data type, not text.
- Indexes, LiDAR index, and ortho index are to be provided for all delivery data types using the same index/tiling scheme.
- LiDAR survey accuracy report as an appendix by comparing the LiDAR elevation data with ground survey data. To do this comparison, random elevation points must be surveyed during the field program and compared with the LiDAR elevation points.

4.1.2 Flood Watershed DEM

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

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

4.2 Aerial Photography

The consultant will also be responsible for acquiring high-resolution ortho-photography. High-resolution ortho-photos for the study areas are available from the Provincial Department of Fisheries, Forestry, and Agriculture. If a better source of aerial imagery is available, this can be discussed further with WRMD. The primary purpose of aerial photography is for use as backdrop/base mapping for flood hazard mapping. The consultant must ensure that sufficient imagery is obtained for these purposes.

- Aerial photography should be obtained from the Provincial Department of Fisheries, Forestry, and Agriculture. An index of available air photos can be viewed at the following website https://gnl.maps.arcgis.com/apps/Styler/index.html?appid=370d91dfddf749b7964aae16e113a2c8
- Additional information on the provincial aerial photography program can be accessed at the following website https://www.gov.nl.ca/ffa/lands/maps/
- The approximate cost of air photos is $100 per tile. The consultant will be responsible for the cost of the air photos and should factor this into the project budget.
- Aerial photography must cover the entire municipal boundary/developed area that is surrounding the flood plain. The consultant will be responsible for ensuring that the required number of air photos are obtained to backdrop all flood hazard zones without any gap.
- To ensure the entire developed area is collected, the consultant should include a buffer on the perimeter of the developed area. The consultant must ensure the Trans Canada Highway, or any other major highway is shown on the flood hazard maps, if present.
- White space on the flood hazard maps resulting from uncollected aerial imagery will not be accepted.
- All imagery is to be colour balanced.
- For small areas, imagery is to be provided as a single mosaic.
- For larger areas, provided imagery is to be tiled. Tiled data will be in one-square kilometer (1kmx1km) tiles. Tile numbering will start at min x, max y (upper left), and end at max x, min y (lower right) (see below). Starting tile grid coordinates will be rounded to the nearest 1000 meters (x and y).

1	2	3
4	5	6

4.3 Satellite Imagery

In some cases, the provincial aerial photography may not reflect current ground conditions and updated imagery must be acquired for use as backdrop or base mapping for flood hazard and risk maps to reflect the current conditions. For example, in the Town of Channel-Port aux Basques, over 100 homes were deconstructed following Hurricane Fiona in 2022.

The consultant is responsible for commissioning any new capture of the study area using available satellites that can produce high resolution imagery (e.g., WorldView-3, SPOT). The imagery will be presented in GeoTIFF in GIS Raster format, in 1 km^2 tiles, and will be acquired so that no white space or clouds are present on the flood risk maps. The imagery will be used as background on flood maps prepared at a scale of 1:2500 to 1:5000. Overview maps will also be developed using the imagery that will allow for the complete sub-basin to be shown. The consultant should use whatever imagery is most current whether that be satellite imagery or aerial photography.

4.4 Flood Watershed: Curve Number

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

Soil Type

Soil type is to be based on soil surveys from the National Soil DataBase (NSDB): https://sis.agr.gc.ca/cansis/nsdb/index.html.

NSDB soil classes are:

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

NRCS soil types have been defined as follows:

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

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

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

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

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

Land Cover

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

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

Antecedent Runoff Conditions (ARC)

Assume ARC condition III.

Curve Number

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

Land Cover	A	B	C	D
Forest	50	74	85	89
Residential	78	88	94	96
Commercial	96	97	98	98
Deforested areas	75	87	92	94

Barren land	89	94	97	98
Fields/pastures/open spaces	59	78	88	91
Swamps/wetlands/waterbodies	100	100	100	100
Unclassified	NA	NA	NA	NA

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

The modelling and mapping of future development conditions in communities without a zero-net runoff policy, and with expected growth and/or development in currently undeveloped areas can be achieved by adjusting the CN number appropriately for these areas of planned future development.

4.4.1 Flood Watershed: Land Cover

The consultant must undertake a new land cover classification using high-resolution optical satellite imagery. The consultant has to acquire the required imagery for the land cover classification. The tentative specification of the imagery resolution is 1.5 meter for panchromatic and 6 meters for, orthorectified and mosaicked from SPOT-6 and 7 satellites. However, the consultant has the option to select more suitable imagery for land cover classification in consultation with the technical committee providing reasonable justification. The extraction of land cover categories shall include appropriate methods for atmospheric and geometric correction.

Once the satellite imagery is collected and used for land cover classification, it will become the property of the WRMD, and the consultant has to submit the imagery and resulting land cover to the WRMD with the final report.

Aerial photography, where it was collected, is acceptable for use for the land cover analysis.

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

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

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

4.4.2 Flood Watershed: Soil Type

The following are the requirements for soil classification:

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

5 Hydrology

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

The consultant is required to also undertake hydrologic modelling to determine the peak flows based on the 1:200 AEP for current climate and current development conditions. The 1:200 AEP peak flows are to be used in hydraulic modelling. Flood mapping for the 1:200 AEP is not required.

5.1 Stochastic Analysis

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

5.1.1 Flood Frequency Analysis

Based on good engineering judgment, the consultant is to determine the most suitable distribution for the estimate of the 1:20 and the 1:100 AEP. The preferred method of estimating distribution parameters is that of maximum likelihood. The theoretical probability distributions that the consultant is to consider are extreme-value distribution (Gumbel 1), lognormal distribution, three-parameter lognormal distribution, the generalized extreme value, log Pearson type-III, Pearson type-III, and generalized logistic. It has been observed that the generalized extreme value distribution generally has the best-fit distribution for most rivers in Newfoundland and Labrador followed by the log normal distribution. If no maximum likelihood solutions can be found, the method of moments should be used, computed or graphical estimates on empirical plotting positions should be avoided.

As part of the flood frequency analysis for each individual station, peak data should be visually analyzed to determine if the majority of peak flows occurred due to precipitation, a combination of snowmelt and precipitation, or both in order to help determine the most likely flooding mechanism.

The consultant should consider methods of naturalizing flow records for stations that may be classified as having regulated flows where there are upstream dams or other control structures, so that this data can be considered for inclusion in the flood study.

5.1.2 Regional Flood Frequency Analysis

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

The consultant shall make use of the most recent regional flood frequency analysis tools for Newfoundland and Labrador made available by WRMD. If data from these tools is stale, the consultant shall provide any updated Regional Flood Frequency Analysis (RFFA) examination and equations.

5.2 Hydrologic Modelling

For simulating the hydrologic behavior of the study area, the consultant is to use the non-proprietary US Army Corps of Engineers Hydrologic Engineering Center's Hydrologic Modelling System (HEC-HMS) version 4.8 or higher, which includes GIS tools that allow modelers to delineate elements, define a discretization, compute subbasin and reach characteristics, and estimate model parameters.

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

The consultant shall develop a hydrologic model for each community included in the study. Sub-basins shall be defined within the model based on the watersheds of all the streams and rivers included as part of the study.

5.2.1 Hydrologic Inputs

The Technical Committee requires that the consultant must use the latest fully functional version of HEC-HMS, but not a beta version, which integrates or is embedded within ArcGIS. The best available data is to be used and where the consultant had collected data, this is to be used.

5.2.2 Modelling Methods

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

- The best available data and good engineering judgment are to be used.
- Storage in lakes, ponds and dammed reservoirs is to be taken into account. Dam operators are to be contacted for reservoir operating levels and procedures for high-flow events. Storage curves should be developed for other storage elements such as lakes, ponds and significant wetland complexes. Storage curves can be developed from the DEM. Initial model water levels for storage elements should

be set to at least the full pool level or maximum water level that the waterbody can hold before water begins to overflow at a natural outlet or reservoir spillway. Measured water levels or water levels determined using LiDAR data, if above the full pool level, may also be used as initial model water levels. The consultant must include a table summarizing the technical methods used for the various components of the HEC-HMS model (e.g. loss method, transform method, base flow method, routing method, and precipitation method).

- Technical methods that the Technical Committee has accepted are SCS Curve Number, SCS Unit Hydrograph, and the Muskingum-Cunge routing method. The consultant may use other methods after justifying the need to the Technical Committee.
- All model parameters, their values, and method of estimation must be thoroughly explained in the reports for review by the Technical Committee.

5.2.3 Precipitation

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

- In the absence of site-specific rainfall data and studies, the synthetic rainfall distribution to be used is the alternating block method.
- Similar to the Huff curves, dimensionless mass curves using data from locations across Newfoundland and Labrador have been developed and are presented in Appendix A.
- The consultant is to evaluate the dimensionless mass curves presented in Appendix A along with a synthetic rainfall distribution based on the alternating block method.
- For the flood hazard mapping the consultant is to use the hyetograph that results in the greatest flow hydrograph to ensure that the flood hazard mapping is conservative.
- Rainfall durations including the 6, 12, and 24 hours are to be considered in determining the most severe event.
- Hyetographs for all events considered are to be provided in tables and graphed in the report or the technical appendices.

6 Hydraulics

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

The consultant is required to also undertake hydraulic modelling to determine the inundation depths of flooding based on the 1:200 AEP for current climate and current development conditions. The 1:200 AEP water levels and streamflow are to be provided in tabular format for each cross-section of the river reach. Flood mapping for the 1:200 AEP is not required.

6.1 Hydraulic Modelling

For simulating the hydraulic behavior of the study area, the consultant must use the non-proprietary HEC-RAS model. The consultant must use the latest fully functional version of HEC-RAS, but not a beta version, and the results must be able to be exported from HEC-RAS into GIS applications or embedded with RAS

Mapper. If a proprietary model has to be used for any hydraulic analysis that cannot be undertaken using HEC-RAS, the consultant must provide a copy of the model to the Technical Committee.

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

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

With the Draft and Final Report, the consultant is to provide all input and output files for all computer models used in the study, and all documentation required to operate the models must be provided in digital format. A mixed flow simulation must be used unless there is a valid reason for assuming sub-critical or supercritical flow.

The consultant shall develop a hydraulic model for each independent stream or river network.

6.1.1 Steady State and Unsteady State Model

A steady state model is run with a steady or constant flow and is generally not suitable when there is tidal influence, the flood events being modeled are dynamic (flash floods), the flow network is complex or flat, or the river flow is regulated (dam). In these cases, an unsteady state model should be used. Steady state conditions can be represented in an unsteady state model by integrating constant flows and water levels into the model.

2D or coupled 1D/2D models should be unsteady state models.

The consultant should provide both steady state and unsteady state versions of hydraulic models, as appropriate.

6.1.2 1D or 2D Modelling

The consultant will decide where to use a 1D or 2D HEC-RAS model and inform the Technical Committee with the justification of using a 1D or 2D model. 2D modelling should be considered when:

- Flow patterns are complex and 1D model assumptions are significantly violated
- Where backwater effects are expected such as in tidal areas, bays and estuaries
- Around wetland complexes
- Where there may be large variation in the flow distribution and depth
- Where there may be large variation in the velocity distribution, magnitude and direction
- Where the floodplain is wide and extensive
- Where the river is comprised of sinuous channels, braided streams, multiple channels, abrupt bends and confluences
- Around bridges and roadway crossings

1D models are generally best suited for in-channel flows where the flow path is known and expected floodplain flows are minor to moderate.

Coupled 1D/2D models may also be considered depending on the hydraulic characteristics of the rivers or streams.

6.1.3 Boundary Conditions

The model boundary conditions will consist of inflow boundary conditions at the upstream ends of the extents of the rivers and creeks considered in the hydraulic models. For the downstream end, water level boundary conditions will be at the end of the reach for the study area in question or at the river outlet to the Atlantic Ocean. Oceanic boundary condition water levels will be defined as follows:

1. With the aid of water level statistics derived from the regional coastal modelling analysis results undertaken as part of the creation of the 2023 NL Atlas of Storm Surge and Wave Climates (completed by DHI Group).
2. Using data from an active real time (not predictive) tidal station water level gauge if within 3 km of the study area or river outlet.

The appropriate water level boundary conditions (considering tide, storm surge and sea level rise, as appropriate) will be used to derive current climate and future climate change 20 and 100-year AEP flood maps for the study areas.

6.1.4 Stormwater Inputs for Hydraulic Modelling

When undertaking river flood modelling for urban watersheds with highly developed stormwater infrastructure (e.g., hard infrastructure such as piped storm sewer networks, stormwater detention ponds, storm sewer outfalls), inputs from such systems need to be considered. In Newfoundland and Labrador, management of stormwater is the responsibility of the city, municipality or LSD. Where policies are in place for stormwater management, the focus is typically on ensuring that post-development stormwater runoff rates are equal to or less than the pre-development runoff rates. The first communities to develop stormwater policies in the province were Mount Pearl and St. John's in 2015.

Many peri-urban and rural areas of the province rely on open ditching for stormwater management, which does not need to be separately considered in the hydraulic river model.

The consultant shall gather information on stormwater management policies for the community of interest in addition to information on stormwater infrastructure. Information on stormwater infrastructure shall include storm sewer catchments; outfall pipe sizes, materials, and alignments; flows, hydrographs or other data on relevant stormwater infrastructure outlets (e.g., outfalls, detention ponds, catch basin locations and capacities, etc.) for input into the integrated flood model.

Stormwater infrastructure inputs should be integrated into the hydraulic river model through the use of appropriate modelling tools. The model selected must be able to integrate both stormwater catchment inputs from urban infrastructure and hydrologic watershed inputs. These combined inputs are to be used to model water surface profiles used to create floodplain mapping. The PCSWMM model has been used to develop flood hazard and risk mapping for the City of St. John's.

Larger communities in the province may have municipal stormwater models already developed. The consultant must check with the community for the availability of existing stormwater models, where outputs from such models can be used as stormwater infrastructure inputs into the hydraulic river model. Where municipal stormwater models do not exist for the stormwater system, the consultant must determine the magnitude of the stormwater flows for each identified stormwater system infrastructure output location that may contribute to river flood flows in the watershed. This information can be obtained from hydraulic calculations or by developing a stormwater model specific to the stormwater infrastructure outlet of interest. These stormwater inflows will define the boundary conditions of the inputs from the municipal stormwater system. The consultant is not expected to develop a detailed model of the stormwater collection system network.

Flood modelling and mapping of future development conditions must reflect the stormwater management policy for that community, if such policy exists. Communities in the province with a known zero net runoff policy include: St. John's, Paradise, Mount Pearl, Portugal Cove-St. Phillips, Logy Bay-Middle Cove- Outer Cove, Torbay, Clarenville, Flatrock, Harbour Grace, Bauline, Marystown, and Conception Bay South.

6.1.5 River Ice Modelling

If a river has had historical flood events linked to ice jams, the consultant must undertake an analysis of maximum water levels under ice jam conditions. The consultant shall make a determination of the 1:20 and 1:100 AEP flood profiles under ice jam conditions and compare these to open water 1:20 and 1:100 AEP flood levels to determine which poses the more significant flood event scenario for integration into flood hazard mapping.

Ice jam analysis should include consideration of the river reaches that have experienced historical ice jam flood events or that exhibit characteristics typical of ice-jamming. Backwater effects must also be considered when analyzing for ice jams. Modelling and analysis of ice-related flooding is a specific technical discipline and may require the involvement of experts in this field.

RIVICE is an example of an existing non-proprietary river ice model that can be used to model flooding during ice generation and ice break up.

6.1.6 Lakes and Ponds

Where lakes and ponds of significant size in the flood watershed have a shoreline next to infrastructure such as roads and bridges or developed property with homes or cabins that could be impacted by flooding, the consultant must assess the impact of lake and pond shoreline flooding as a result of wind driven storm surge and waves. This additional water height and elevation from storm surge, wave setup and runup should be determined for 1:20 and 1:100 AEP wind speeds and provided in tabular format for points of interest along the shoreline. Maximum storm surge, wave setup and runup should be determined using the maximum fetch distance, average water depth for that fetch, and associated wind direction for that fetch for each point of interest. The 1:20 and 1;100 lake or pond water elevation should be used in the analysis with the corresponding AEP wind speed. Current climate conditions should be used for this analysis. Simplified methods are adequate for smaller lakes and ponds in the province.

The consultant shall provide a digital GIS layer of the shoreline points of interest and the associated maximum storm surge, wave setup and runup water height and elevation for the 1:20 and 1:100 AEP events.

7 Calibration and Verification

All models must be calibrated and verified, to the fullest extent possible, using a split-sample technique. The consultant must ensure the collection of adequate field data/observation for this purpose. Documentation on recent floods must be used to the fullest extent possible. All models must take into consideration the level of accuracy required to produce flood hazard mapping. Floodplain models and the delineated floodplain may be deemed unacceptable unless they are calibrated based on field-measured river flow monitoring data, and the models have been calibrated for at least two extreme rainfall/runoff events each with an 85% accuracy or better.

The Technical Committee accepts that calibration for the hydrologic model will be undertaken primarily on the CN values if using HEC-HMS. Other models such as PCSWMM may require calibration be undertaken on different model input parameters (e.g., Green-Ampt parameters). The consultant must ensure that all calibrated values are within an accepted range of published values.

8 Climate Change

The consultant is to undertake an analysis of the impacts of climate change projections on the flood profiles. To undertake this analysis, the consultant must evaluate climate change scenarios for both the 1:20 and the 1:100 AEP flood profiles. The most recent versions of the "Projected Impacts of Climate Change for the Province of Newfoundland & Labrador" (see Section 2.2.1), "Relative sea-level projections for Canada" (see section 13.3.1), and the "NL Atlas of Storm Surge and Wave Climates" (see Section 13.4.1) are to be used to help determine the climate change flood hazard. The following climate change projection information is to be used in developing provincial flood maps:

- Global climate model: CMIP5 or CMIP6
- Climate change assessment report: IPCC AR5 or IPCC AR6
- Scenario: RCP8.5 or SSP5-8.5 (median values)
- Timeframe: 2100 (or late century period – from 2071 to 2100)

The "Projected Impacts of Climate Change for the Province of Newfoundland & Labrador" and the "Relative sea-level projections for Canada" are based on CMIP5 models, while the "NL Atlas of Storm Surge and Wave Climates" uses CMIP6.

The requirements for the climate change flood hazard mapping are the same as those for the current climate case. The climate change floodplains will be in accordance with the 1:20 and 1:100 AEP flood lines in terms of map formatting. The climate change flood maps must include a note on the map indicating the climate change scenario and projected timeframe being used.

9 Flood Hazard and Risk Mapping and GIS Products

As per the *Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation*, the following definitions are being implemented for flood hazard and flood risk mapping:

Flood Hazard Maps: Engineering maps that display the results of hydrologic and hydraulic investigations that show areas that could be flooded under different likelihoods. These maps are used for regulatory planning purposes related to land use planning and flood mitigation.

Flood Risk Maps: Maps that indicate the potential adverse consequences associated with floods, including but not limited to social, economic, environmental and cultural consequences to communities during a specific potential flood event and the overall risks to the community from a range of potential flood scenarios.

9.1 Flood Hazard Maps

Based on the modelling results, the consultant is to produce the following flood hazard maps:

- Flood hazard maps indicating flood plains associated with the following scenarios:
    - the 1:20 and 1:100 AEP for the current climate and current development conditions
    - the 1:20 and 1:100 AEP for current climate and a fully developed watershed condition
    - the 1:20 and 1:100 AEP for climate change and current development conditions
    - the 1:20 and 1:100 AEP for climate change and a fully developed watershed condition

- Flood hazard maps indicating the change of flood plains associated with the historical 1:20 AEP and the new 1:20 AEP for the current climate and current development conditions (where applicable).

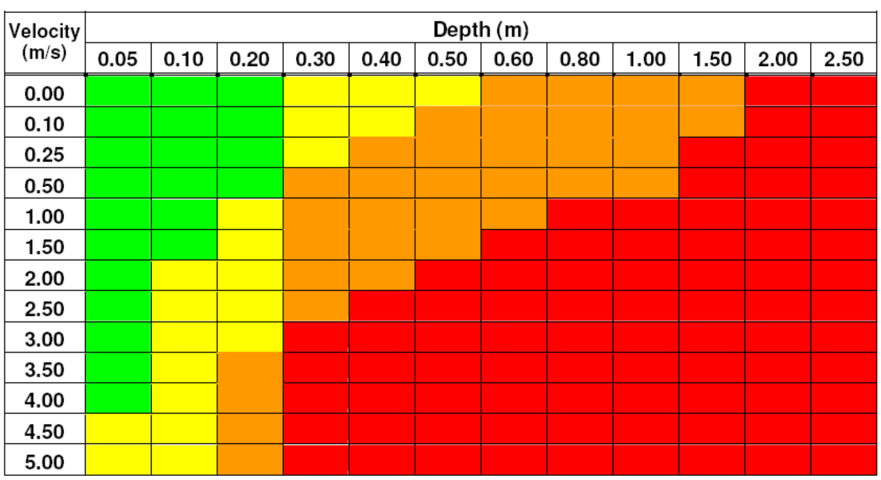
- Flood hazard maps indicating the change of flood plains associated with the historical 1:100 AEP and the new 1:100 AEP for the current climate and current development conditions (where applicable).

- Flood hazard maps indicating the change of flood plains associated with the 1:20 AEP for the current climate and current development conditions and the 1:20 AEP for climate change and current development conditions.

- Flood hazard maps indicating the change of flood plains associated with the 1:100 AEP for the current climate and current development conditions and the 1:100 AEP for climate change and current development conditions.

9.2 Flood Risk Maps

The consultant is to undertake an analysis of the flood risk associated with the 1:20 and the 1:100 AEP flood profiles for the current climate and current development conditions, and climate change and current development conditions using the flood risk matrix presented in Figure 1.



Degree of Risk	Colour Code	Description
Low		**Caution**
Moderate		**Danger for Some** Includes children, the elderly and the infirm.

Significant		**Danger for Most** Includes the general public.
Extreme		**Danger for All** Includes emergency services.

Figure 1: Flood Risk Matrix (Uden et al, 2007)

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

The extreme water level and depth averaged current statistics at selected discrete points in the local coastal model domains shall be interpolated for integration into flood risk mapping products.

Based on the modelling results, the consultant is to provide flood depth, flood velocity, and flood risk maps associated with the 1:20 and 1:100 AEP scenario for the current climate and current development conditions and for climate change and current development conditions.

9.3 Mapping Specifications

Maps are to be provided at community level scale and an overview level scale. Community scale maps should be suitable for identifying if individual properties are within the flood risk zones and would be at an approximate scale range of 1:2000 to 1:5000. Community scale maps should include the high-resolution ortho-photos, contours at a 1 m interval, and relevant street names where applicable. Overview maps are intended to give a broader view of the complete sub-watershed/watershed. Overview maps should include an index of the community scale maps.

The consultant must delineate the coastal shoreline for each study area community within the domain of the municipal boundary or limits of development for the community. Municipal and plaining area boundaries can be downloaded from the Department of Municipal Affairs and Community Engagement: https://www.gov.nl.ca/mpa/municipal-boundaries/

For flood mapping of coastal communities, riverine and coastal storm surge flooding pdf maps must be merged for 1:20 and 1:100 current climate and climate change scenarios as these will be considered “regulatory flood maps”. Where riverine and coastal flood areas overlap in the mapping they should match and be seamless. Separate digital flood mapping layers must be provided for riverine and storm surge flood areas. A combined digital flood mapping layer of riverine and storm surge must be provided as well.

A set of wave flood pdf maps using the same coastal map frames to be used for the merged riverine and storm surge flooding maps must be provided. Wave flood maps should be provided for 1:20, 1:100 for current climate and climate change scenarios.

The set of one community scale and overview maps to be delivered by the consultant is summarized below:

Current Climate Hardcopy/PDF Map Sets:

1. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Community Flooding Overview Map

   a. For inland communities: riverine
   b. For coastal communities: riverine + tides + storm surge
2. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Flood Zones (FZ)
   a. For inland communities: riverine
   b. For coastal communities: riverine + tides + storm surge
3. Current Climate and Fully Developed Condition (CC-FD) 1:20 and 1:100 AEP Community Flooding Overview Map
   a. For inland communities: riverine
   b. For coastal communities: riverine + tides + storm surge
4. Current Climate and Fully Developed Condition (CC-FD) 1:20 and 1:100 AEP Flood Zones (FZ)
   a. For inland communities: riverine
   b. For coastal communities: riverine + tides + storm surge
5. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Community Wave Flooding Overview Map
6. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Wave Flood Zones
7. Current Climate and Fully Development Condition (CC-FD) 1:20 and 1:100 AEP Community Wave Flooding Overview Map
8. Current Climate and Fully Developed Condition (CC-FD) 1:20 and 1:100 AEP Wave Flood Zones
9. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Inundation Depth Overview Map
   a. For inland communities: riverine
   b. For coastal communities: riverine + tides + storm surge
10. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Velocity Overview Map
   a. For inland communities: riverine
   b. For coastal communities: riverine + tides + storm surge
11. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Risk Overview Map
   a. For inland communities: riverine
   b. For coastal communities: riverine + tides + storm surge
12. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Wave Risk Overview Map

Current Climate Digital Map Sets:

1. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Flood Zones (FZ)
   a. For inland and coastal communities: riverine
   b. For coastal communities: tides + storm surge
   c. For coastal communities: riverine + tides + storm surge
2. Current Climate and Fully Developed Condition (CC-FD) 1:20 and 1:100 AEP Flood Zones (FZ)
   a. For inland and coastal communities: riverine
   b. For coastal communities: tides + storm surge
   c. For coastal communities: riverine + tides + storm surge
3. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Wave Flood Zones
4. Current Climate and Fully Developed Condition (CC-FD) 1:20 and 1:100 AEP Wave Flood Zones

5. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Inundation Depth
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + storm surge
6. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Velocity
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + storm surge
7. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Risk
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + storm surge
8. Current Climate and Current Development Condition (CC-CD) 1:20 and 1:100 AEP Wave Risk

Climate Change Hardcopy/PDF Map Sets:

1. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Community Overview Map
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + sea level rise + storm surge
2. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Flood Zones (FZ)
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + sea level rise + storm surge
3. Climate Change and Fully Developed Condition (CLC-FD) 1:20 and 1:100 AEP Community Flooding Overview Map
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + sea level rise + storm surge
4. Climate Change and Fully Developed Condition (CLC-FD) 1:20 and 1:100 AEP Flood Zones (FZ)
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + sea level rise + storm surge
5. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Community Wave Flooding Overview Map
6. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Wave Flood Zones
7. Climate Change and Fully Development Condition (CLC-FD) 1:20 and 1:100 AEP Community Wave Flooding Overview Map
8. Climate Change and Fully Developed Condition (CLC-FD) 1:20 and 1:100 AEP Wave Flood Zones
9. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Inundation Depth
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + sea level rise + storm surge
10. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Velocity
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + sea level rise + storm surge
11. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Risk
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + sea level rise + storm surge
12. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Wave Risk

Climate Change Digital Map Sets:

1. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Flood Zones (FZ)
    a. For inland and coastal communities: riverine
    b. For coastal communities: tides + sea level rise + storm surge
    c. For coastal communities: riverine + tides + sea level rise + storm surge
2. Climate Change and Fully Developed Condition (CLC-FD) 1:20 and 1:100 AEP Flood Zones (FZ)
    a. For inland and coastal communities: riverine
    b. For coastal communities: tides + sea level rise + storm surge
    c. For coastal communities: riverine + tides + sea level rise + storm surge
3. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Wave Flood Zones
4. Climate Change and Fully Developed Condition (CLC-FD) 1:20 and 1:100 AEP Wave Flood Zones
5. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Inundation Depth
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + sea level rise + storm surge
6. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Velocity
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + sea level rise + storm surge
7. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Risk
    a. For inland communities: riverine
    b. For coastal communities: riverine + tides + sea level rise + storm surge
8. Climate Change and Current Development Condition (CLC-CD) 1:20 and 1:100 AEP Wave Risk

Comparison Hardcopy/PDF Map Sets:

1. Comparison of Current Climate and Current Development Condition (CC-CD) with historical Flood Zone for 1:20 and 1:100 (if applicable) - to be provided only if/where previous floodplain mapping is available

In producing the flood hazard and risk maps identified above, the following requirements must be met:

- Flood lines, or other lines digitized as geo-referenced polygons. All digital files are to be provided in provincial MTM Zone 1-6 NAD 83 CSRS projections, as appropriate, in an ESRI Geodatabase and as AutoCAD DWG Files.
- Overlaying the flood lines on high-resolution ortho-photography with contours at a one-meter interval.
- Providing an overview map for each case of the community scale maps. The overview maps will include an index of the associated set of community scale maps.
- Providing the area of the 1:20 and 1:100 AEP flood plains and where old flood hazard mapping is available, comparing the change in the area and percentage change. Where old flood hazard mapping is not suitable for digital analysis a visual analysis is to be undertaken. The report must discuss how the old and new profiles compare.
- Providing the area of the climate change 1:20 and 1:100 AEP flood plains and comparing the change in the area and percentage change with the base case 1:20 and 1:100 AEP flood profiles. The report must discuss how the base case and climate change flood profiles compare.
- A comparison of the historical floodplain and climate change current development condition flood zone to the current climate current development condition flood zone for the 1:20 and 1:100 AEP must also be provided. A summary table of the change in area between the two comparison cases is to be provided in the report.

- The delineated shoreline must be shown in coastal flood maps and the river centerline must be shown on inland flood maps.
- The location of hydrometric stations must be identified on flood maps.
- Inland riverine cross-section lines (1D) and/or points (2D), and coastal transects (1D) and/or points (2D) with cross-section, point or transect identification number and the 1:20 and/or 1:100 flood water levels for both current and climate change scenarios.
- For climate change flood maps, include the climate change scenario and projected timeframe being used.
-
- Maps should be provided in digital format as PDFs with an 11x17 page size.
- The pdf overview map frames for inland riverine and coastal flooding should match.
- If landscape overview map frames are used, all maps should use this same template. If portrait overview maps are used, all maps should use this same template. The North arrow should be pointing up.
- Maps should have all standard map features including, but not limited to, north arrow, scale bar, legend, grid lines with coordinates and key map. See sample maps on the WRMD website at: https://www.gov.nl.ca/ecc/waterres/flooding/frm.
- **The consultant must field verify (on the ground) all flood profiles before submission of the draft reports.**
- **On completion of the draft flood hazard mapping, prior to submitting to WRMD for review, the consultant must have the flood hazard maps reviewed by the communities to identify any obvious issues. Issues that can be rectified must be rectified prior to submitting to WRMD.**

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

a) ESRI Geodatabase:
   i. All files must be compatible with the latest version of the software.
   ii. Polygons on separate layers for each of the flood zones.
   iii. Polygons on a separate layer for the contributing drainage area (watershed).
      a) Inland riverine cross-section lines (1D) or points (2D) on a separate layer with cross-section or point number and the 1:20 and 1:100 flood water levels for both current and climate change scenarios as attribute information.
      b) Coastal transect lines or blocks (1D) or points (2D) on a separate layer with transect or point number and the 1:20 and 1:100 flood water levels for both current and climate change scenarios as attribute information.
      c) Historical map information is required as a separate layer.
      d) Projection files to be included. The projections should match what is stated on the pdf maps.
   iv. Raster datasets are to be provided in GeoTIFF format. GeoTIFFs are to be formatted as outlined in section 9.3.2.

b) AutoCAD DWG Files:
   i. All files must be compatible with the latest version of the software.
   ii. Polygons on separate layers for each of the flood zones.
   iii. Inland riverine cross-section lines (1D) or points (2D) on a separate layer with cross-section or point numbers and the corresponding flood water levels as attribute information.
   iv. Coastal transect lines or blocks (1D) or points (2D) on a separate layer with transect or point number and the 1:20 and 1:100 flood water levels for both current and climate change scenarios as attribute information.

v. Section lines on a separate layer with the following attribute information – cross-section number, 1:20 and 1:100 AEP elevations.
vi. Index of community scale maps as digital layer.
vii. Historical map information is required as a separate layer.

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

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

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

Flood zones along shorelines of water bodies and/or coastlines must NOT use these features as the edges of polygons. Shorelines and coastlines are prone to erosion and/or deposition over time and updates to historical mapping can result in significant changes in water features. As well, flood zones are often required to be viewed at scales smaller (e.g. 1: 50,000) than the community scale mapping used to produce flood risk mapping. Polygons which begin or end at shorelines and coastlines must extend past these features far enough to account for positional changes in features created by changes in the scale of mapping that may be used by end-users.

The flood lines, or other lines, must not be edited to ensure they totally include or exclude buildings or other structures. The positions and shapes of buildings or other structures on digital mapping are not precise enough to make such determinations and are often outdated. In such cases, 1:20 year and 1:100-year flood lines must be drawn through these features until field visits can be made in order to determine the threat of flooding posed to these structures. Refer to Figure 2.

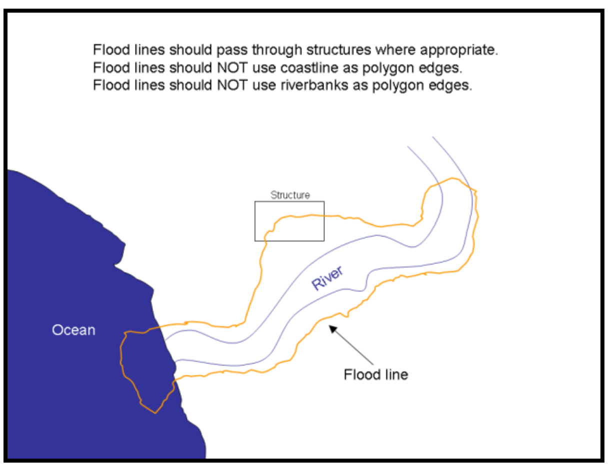


Figure 2: Flood Line Editing

Isolated or disconnected flood plain polygons must be removed from the flood plain mapping unless providing reasonable justification for the isolated or disconnected flood plain polygons.

9.3.1 Inundation Depth, Velocity, and Risk raster coverage requirements

All raster layers must include the river and brook channels. This applies to ESRI grid and GeoTIFF file types.

9.3.2 GeoTIFF formatting requirements

GeoTIFF datasets of flood depth, velocity, and risk must be classified such that the particular classification of each category is identifiable independent of the legend and suitable for analysis in GIS. For example, flood depth raster grid cells will be classified using the specific category (e.g. 0.5 – 1.0 meter, 1.0 – 1.5 meter, etc.) rather than a generic grid code (e.g. 1 -5) with the categories only available in the legend. Refer to Figures 3, 4, and 5 for illustrations of the required format. This format is not compatible with the ESRI Grid datatype.

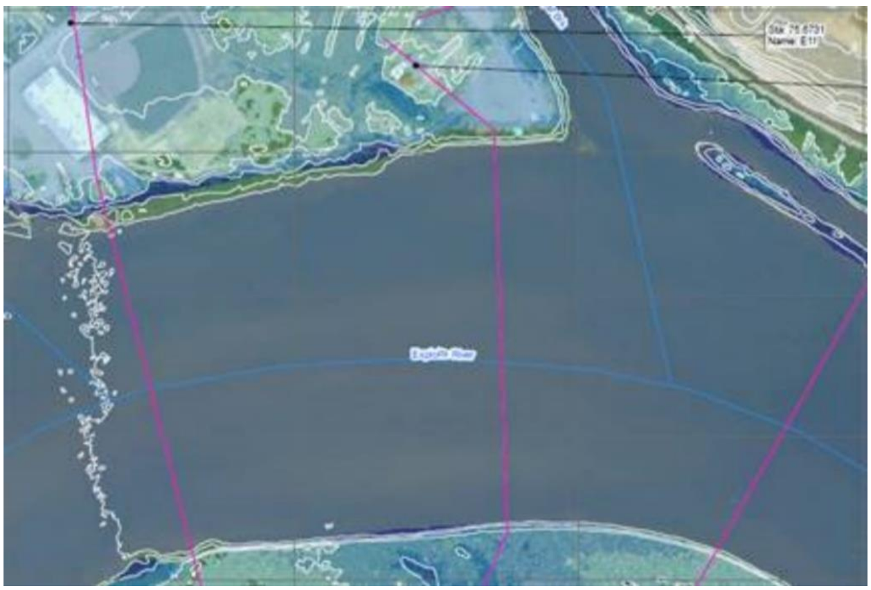


Figure 3: Incorrect coverage – depth does not include the river and brook channels

Figure 4: Incorrect coverage – risk does not include the river and brook channels

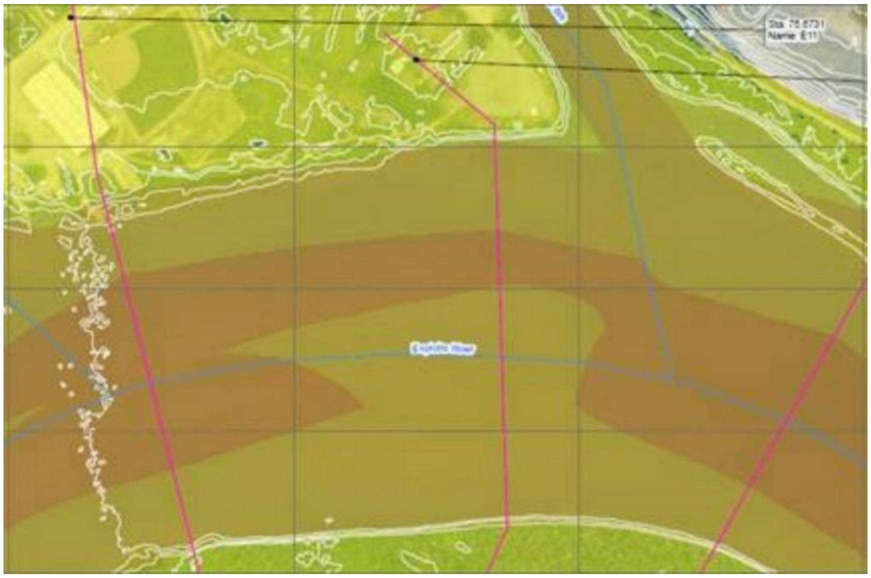


Figure 5: Correct coverage – velocity includes the river and brook channels

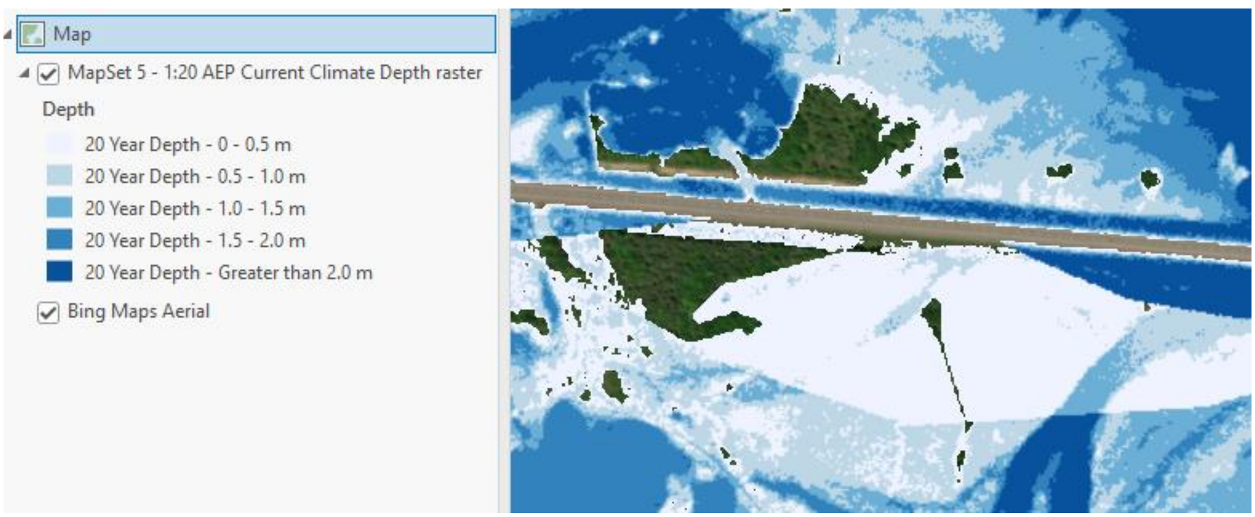


Figure 6: Correct raster format

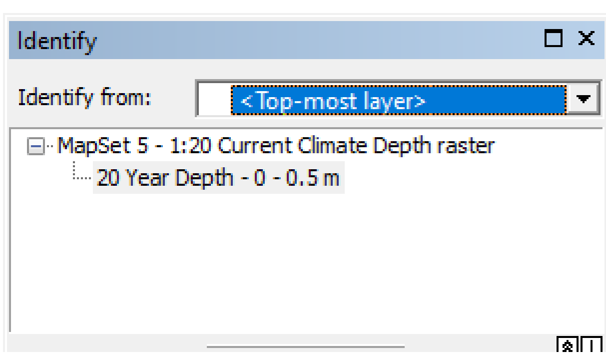


Figure 7: The grid cell value should return the class range, not the individual value

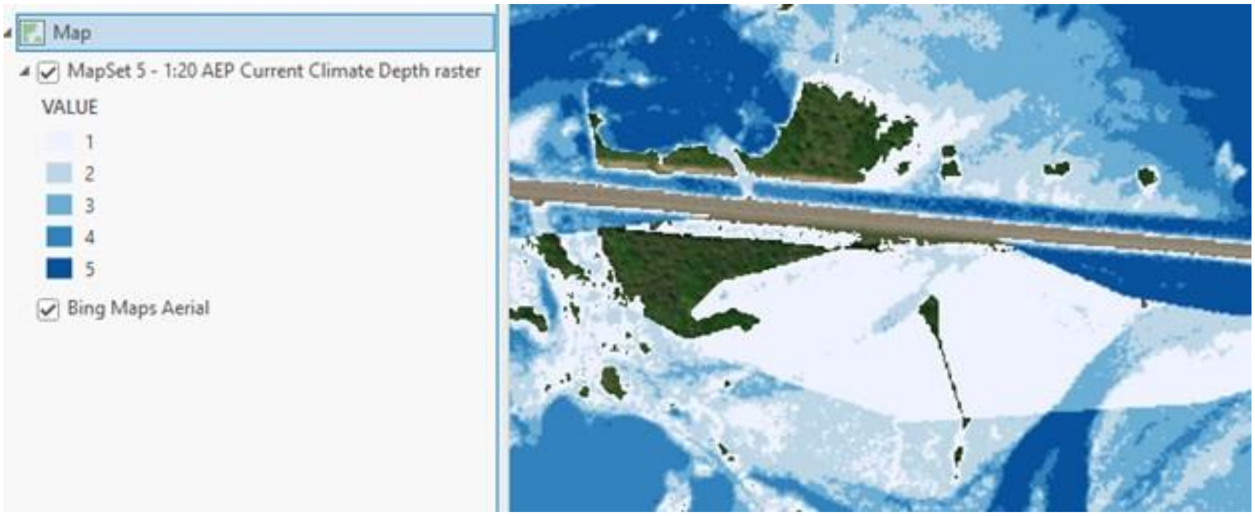


Figure 8: Incorrect raster format

GeoTIFFs can be reclassified using the Reclassify geoprocessing tool in ArcGIS. Using inundation depth as an example, reclassify the raster into 5 classes (Figures 8 and 9).

lowest – 0.5 is 1
0.5 – 1.0 is 2
1.0 – 1.5 is 3
1.5 – 2.0 is 4
2.0 – highest is 5

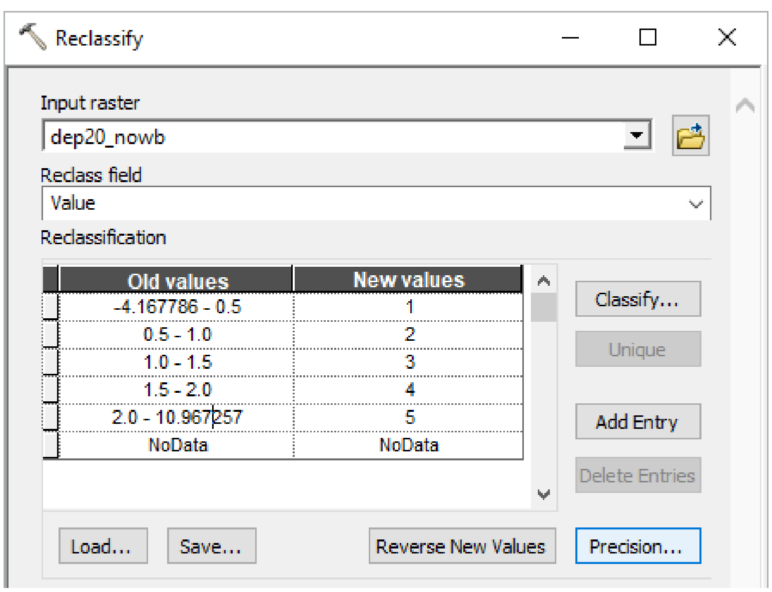


Figure 9: reclassify raster into 5 classes

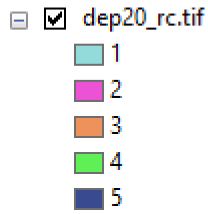
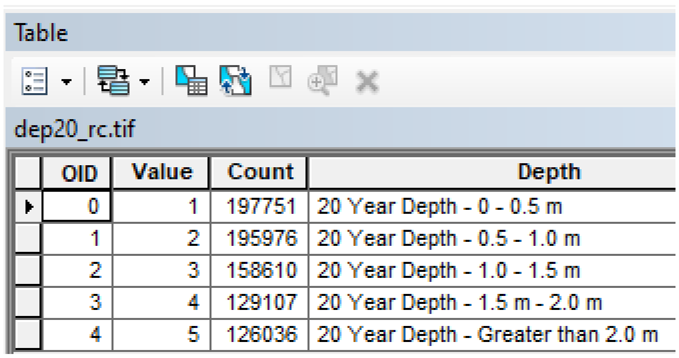


Figure 10: reclassified geo tiff with 5 classes

Open the GeoTIFFs attribute table and add a text field (Depth). Populate the depth field where 1 is “20 Year Depth – 0 – 0.5 m”, 2 is “20 Year Depth – 0.5 - 1.0 m”, etc.



Table

dep20_rc.tif

OID	Value	Count	Depth
0	1	197751	20 Year Depth - 0 - 0.5 m
1	2	195976	20 Year Depth - 0.5 - 1.0 m
2	3	158610	20 Year Depth - 1.0 - 1.5 m
3	4	129107	20 Year Depth - 1.5 m - 2.0 m
4	5	126036	20 Year Depth - Greater than 2.0 m

Figure 11: Correct attribute table format for geo tiff raster files

The geo tiff can be symbolized using the depth field.

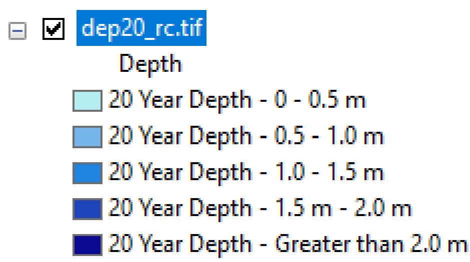


Figure 12: Correct format for inundation depth geo tiff

Use this workflow to reclassify the Risk and Velocity GeoTIFFs keeping in mind that Risk will have 4 classes and Velocity will have 6 classes.

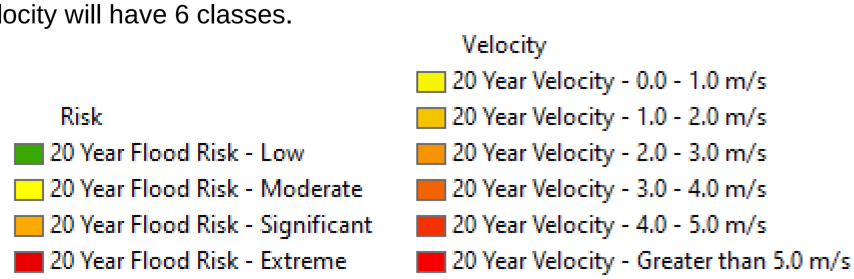


Figure 13: Correct format for Risk and Velocity GeoTIFFs

9.4 GIS Data Outputs

Other GIS data output products to be provided by the consultant for flood mapping studies as shapefiles or as layers in a geodatabase, where not otherwise indicated, shall include:

- Bare earth DEM in GIS raster format
- 0.25 -1 meter contour
- Raw data for LiDAR cloud point data (if outside the HRDEM program with NRCan)
- Satellite imagery- GeoTIFF in GIS Raster format
- Imagery- Aerial photography index
- Aerial photography - GeoTIFF
- Main watershed and sub-watersheds layers
- River network layer
- Land use/land cover layer
- Soil type layer
- Subbasin SCS curve number layer, if applicable
- Land surface roughness, if applicable
- Hydraulic structures, riverine flood protection, coastal flood protection location layer
- Delineated shoreline
- Bathymetric data
- Cross sections with all scenario flood elevations

10 Consequence Assessment

The consultant is to evaluate the consequences of a flood event using the mapping produced and any infrastructure assessment conducted. Assessments should be made on a community basis for the following conditions:

Climate Condition	**AEP**
Current Climate	20-Year
Current Climate	100-Year
Climate Change	20-Year
Climate Change	100-Year

If coastal flood mapping is produced separately from riverine flood mapping this should also be assessed separately.

Consequence assessments should evaluate:

- The area of flooded land (ha)
- Number of buildings flooded (source used for determining buildings should be documented- e.g., LiDAR building)
- Estimate of the number of people directly impacted by flooding
- Identify any critical infrastructure other than bridges and culverts that may be impacted by a flood event
- Estimate of potential economic losses with respect to direct impacts on buildings and infrastructure

Consultants can use the Federal Flood Damage Estimation Guidelines for Buildings and Infrastructure, 2021, to help determine estimates of potential damage costs.

11 Sensitivity Analysis

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

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

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

12 Flood Forecasting

The consultant is to evaluate the application of a flood forecasting service for the study area and propose a strategy for the development and implementation of a flood forecasting service using the hydrologic, hydraulic, and hydrodynamic models implemented in this study. The flood forecasting service must factor in all meteorological, hydrological, hydraulic and hydrodynamic factors that trigger flooding. This shall include consideration of coastal flood forecasting.

13 Coastal Flood Hazard Analysis and Mapping

The coastline of Newfoundland and Labrador is extensive and inclusive of many bays, fjords, peninsulas and offshore islands. The estimated length of Newfoundland's coastline is approximately 17,542 km, while the estimated length of Labrador's coastline is approximately 7,886 km. There are approximately 276 coastal communities located in the province, between 7 and 12% of the province's population lives within 30 m of the coastline, and there are approximately 24,000 building structures located within 30 m of the coastline.

The pattern of human settlement in Newfoundland and Labrador has predominately been along the coast. Historically, fishing and maritime activities played a significant role in the economy, leading to the establishment of hundreds of coastal communities some dating back to the early 1600s. The densest level of development in many rural coastal communities is often concentrated at low elevation beach areas of the community bay or cove.

The main objectives in developing coastal flood mapping for communities along the coast of Newfoundland and Labrador is for land use planning, emergency management and engineering design in the face of increasing climate change. Coastal flood mapping study areas are limited to coastal areas within municipal boundaries or planning areas for municipalities or the extent of coastal development for a Local Service District (LSD). Coastal flooding processes of interest for hazard mapping include sea level rise, tides, storm surge and wave effects (see Figure 14). The contribution of these various coastal flood hazard components vary in magnitude and relative importance by location. Climate change is expected to have a major impact on future coastal flooding and must be assessed as part of any coastal flood mapping study.

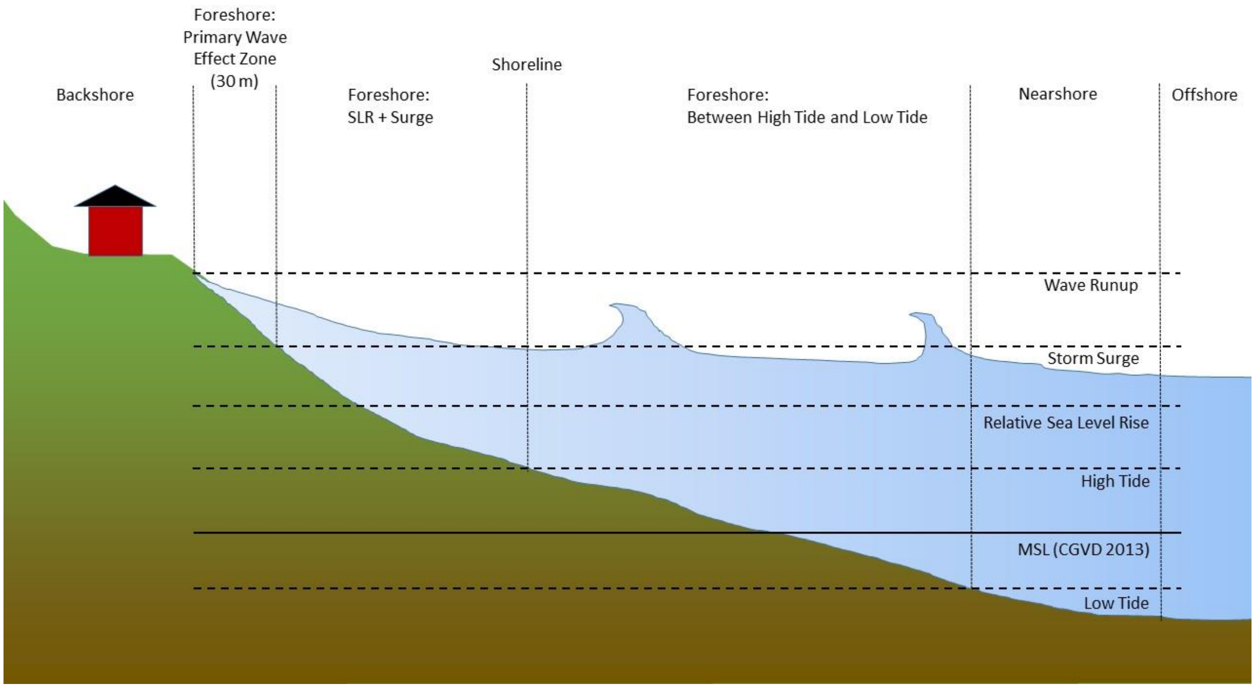


Figure 14: Coastal flooding processes and coastal profile

The principal objective of a coastal flood study is to provide legible and accurate mapping with appropriate coastal flood levels including the contributions of wave effects. It is not only important that the mapped results of the flood hazard study be technically correct, but also that the mapping be easy for the community to use for emergency and land use planning decisions.

The analytical complexity of the coastal flood mapping work must meet the minimum requirements set out in this section of the Technical Document.

All deliverables produced are to be referenced to Canadian Geodetic Vertical Datum 2013 (CGVD2013).

Coastal flooding triggered by tsunami hazards are not to be evaluated.

13.1 Shoreline Delineation

The consultant must delineate the coastal shoreline for each study area community within the domain of the municipal boundary or limits of development for the community. Coastal flood mapping should extend across the shoreline contained within a community's municipal boundary where such a boundary exists. Where no municipal boundary exits, coastal flood mapping should extend across the occupied or developed shoreline of the community to be mapped.

The existing shoreline should be determined using the high-resolution DEM based on the most recent LiDAR data collected for that area. The shoreline break lines defined based on the LiDAR data can help to seamlessly merge the coastal bathymetry DEM into the HRDEM, establish proper slopes along the shoreline and to infill any below-water portions of the HRDEM.

A visual check of the shoreline must be made to ensure that the product is consistent with other sources of data (e.g., satellite/aerial imagery, field survey).

13.2 Level of Analysis

Coastal flood analysis and mapping for Newfoundland and Labrador will be community based, mostly for numerous small rural communities along the coast ranging in population from 100-1500 residents. As such, a moderate level of analytical detail is acceptable in order to balance computational demand with the need for multiple community scale results.

To assist consultants in the development of coastal flood mapping, the province developed an Atlas of Storm Surge and Wave Climates (see Section 13.4.1) with the assistance of DHI in 2023. This Atlas provides nearshore total water levels from tide and storm surge, along with wave conditions, and will be made available to the consultant. The consultant is expected to make use of the data provided in the Atlas to develop community based coastal flood mapping.

Atlas data point locations are located in the nearshore. When located on an open coast, the reporting point is located near the community location on the coast, but far enough out to avoid land boundary effects. Where a community is located in a relatively sheltered area, in the lee of some islands, or there are other topographic features which have not been resolved in the regional model used to generate data points for the Atlas, the reporting point has been moved further offshore.

The consultant shall develop a localized hydrodynamic model domain to resolve total extreme storm surge water levels at the foreshore. Data from the Atlas can be used to establish boundary conditions for this modelling.

The consultant shall use the Atlas to determine extreme wave conditions at the shoreline. A local hydrodynamic wave model domain shall be used to transform wave conditions to the foreshore using data from the Atlas as boundary conditions.

The consultant shall transform foreshore waves in combination with storm surge and sea level rise to onshore wave runup water levels on land. Analytical complexity for undertaking this should at a minimum use one-dimensional hydrodynamic modelling techniques along representative transects to provide a moderately-realistic representation of the coastal flood hazard, as well as additional information pertaining to flood propagation and flood depth. Wave runup analysis must be incorporated into the coastal flood hazard.

Coastal flood hazard mapping shall include two sets of mapping for both current development and fully development conditions as follows:

- Flood hazard maps indicating coastal floodplains associated with coastal flooding from storm surge, tides and sea level rise, as appropriate, for the following scenarios:
    - the 1:20 and 1:100 AEP for current climate conditions
    - the 1:20 and 1:100 AEP for climate change conditions

- Flood hazard maps indicating the inland extent of wave uprush (wave setup and runup) beyond the coastal floodplain associated with the following scenarios:
    - the 1:20 and 1:100 AEP for current climate conditions
    - the 1:20 and 1:100 AEP for climate change conditions

Static mapping of peak nearshore water levels onto digital elevation models (i.e., bathtub modelling) is not a sufficient approach for coastal flood mapping. Dynamic modelling approaches are required as they provide increased accuracy and improved insight to flood pathways. The level of effort, resources, and specialist expertise to be used with the selected dynamic modelling approach must be commensurate with objectives for developing multiple community based coastal flood maps.

13.3 Climate Change

The effects of climate change must be incorporated into the assessment of the coastal flood hazard to ensure that long-term climate impacts are accounted for in the flood mapping products. This includes an assessment of:

- Relative sea level rise
- Seasonal ice cover

Because climate change is a key factor in coastal flooding the following timelines are to be assessed:

- Current climate conditions
- End of century with a range between 2071-2100

The global emissions scenario that should be used for coastal flood analysis is RCP 8.5/SSP5-8.5.

In 2023, WRMD commissioned an Atlas of Storm Surge and Wave Climates to assist with the development of comprehensive coastal flood mapping. The Atlas also includes future storm surge and wave climates based on regional numerical models. A multi-model ensemble was used to provide a comprehensive understanding of potential future impacts in order to deal with the uncertainties associated with climate change projections, particularly for wind. The Atlas provides downscaled offshore storm surge residual and offshore wave conditions for the future climate out to 2100. Future climate change storm surge and wave climate data from the Atlas is to be used for information purposes only due to general uncertainty in the climate projection models. Future climate change coastal flood mapping will incorporate sea level rise and changes in seasonal ice cover.

Climate change scenarios for coastal flooding will incorporate relative sea level rise in the local, community specific model domains.

The robustness of these downscaled climate projections used in the Atlas will be revisited periodically as uncertainties to changes in future storm behavior are resolved, better climate models and multi-model ensembles are developed, and model time horizons change.

13.3.1 Sea Level Rise

Sea level rise refers to the increase of sea levels for a specified time horizon relative to a specified base year, while relative sea level rise denotes a local rate of increase of sea levels measured relative to the local land surface and takes into account effects of local land subsidence and uplift.

Climate change sea level rise will be defined by the projections in “Relative sea-level projections for Canada based on the IPCC Fifth Assessment Report and the NAD83v70VG national crustal velocity model”, Geological Survey of Canada, Open File 8764, 2021, available at https://ostrnrcan-dostrncan.canada.ca/entities/publication/0f1ac750-8381-4bda-84f9-620dc00f07fc. If a newer version of “Relative sea-level projections for Canada” from the NRCan Geological Survey of Canada is available at project award, then that report will be used.

Projected sea-level changes in the NRCan dataset include the effects of changes in glacier and ice-sheet mass loss, thermal expansion of the oceans, changing ocean circulation conditions, and human-caused changes in land water storage. A new land motion model developed by the Canadian Geodetic Survey was also incorporated into the data. The RCP 8.5 climate scenario was adopted to define sea level rise and sea level rise was considered from present day to the year 2100. The RCP 8.5 median relative sea level rise projections, including land subsidence should be adopted.

For the current climate scenario used in the flood study, a sea level rise value must be applied to the applicable baseline year to account for sea level rise up to the current year. For the climate change scenario, future sea level rise must be accounted for.

The anticipated sea level rise values are to be added to the current climate and climate change scenarios as appropriate in order to assess the full coastal flood hazard. The effects of sea level rise on waves can be incorporated when wave transformation modelling is employed to assess climate change effects on nearshore wave conditions.

An enhanced scenario for future sea level rise for 2100 should also be examined that incorporates potential additional contribution from the Antarctic Ice Sheet and the slowing or collapse of the Atlantic Meridional Overturning Circulation (AMOC). The enhanced scenario should add a further 65 cm of global sea-level rise from Antarctic melting, and up to one meter from AMOC collapse, to the median projection of the SSP5-8.5 climate scenario at 2100.

13.3.2 Ice Conditions

Many communities in the province, particularly along the coast of Labrador, the north coast of the Island and extending down the west coast in the Gulf of St. Lawrence experience sea ice during the winter which can help to mitigate some coastal flood processes. Depending on conditions, ice can either reduce, contribute to, or exacerbate coastal flood hazards. Shorefast ice and large regions of continuous (or near-continuous) ice cover acts as a barrier at the ocean surface, preventing or limiting momentum transfer from winds to the sea surface, and therefore reducing the potential for large waves and storm surges. The Avalon Peninsula typically does not experience sustained shore fast sea ice, which could dampen or reduce storm surge potential.

The Canadian Ice Service (CIS) monitors ice conditions around Newfoundland and Labrador and produces daily ice charts that can provide information on long-term trends in sea ice presence for coastal communities in the province.

The impact of sea ice cover on storm surge and wave conditions at the nearshore has been incorporated into the regional models used in the development of the Atlas of Storm Surge and Wave Climates. Both current climate and climate change sea ice conditions should be assessed as part of the community based coastal flood hazard assessment modelling and mapping.

13.4 Available Data and Data Collection

The main data inputs for coastal flood mapping studies include, but are not limited to:

- NL Atlas of Storm Surge and Wave Climates
- Elevation data
- Bathymetry data
- Coastal transects/profiles and shoreline type
- Tidal and wave monitoring data
- Historic storm-related water level information
- Land cover information
- Information on built coastal protection structures
- Data on riverine flooding where relevant

This section highlights some key data sources available to consultants who undertake coastal flood mapping studies for communities in Newfoundland and Labrador, and key data that will need to be collected for such studies by the consultant.

13.4.1 NL Atlas of Storm Surge and Wave Climates

Estimates of storm surge have traditionally been completed using the analysis of historical data records at gauging stations. Often these records are incomplete, unreliable, and only available near larger urban coastal communities. To resolve this data gap, in 2023 the province commissioned DHI to develop a NL Atlas of Storm Surge and Wave Climates (hereafter referred to as the "Atlas") to assist with the development of community level coastal flood mapping. The Atlas was created by leveraging numerical modelling tools (Mike 21 HD) to simulate North Atlantic regional level domain storm surge and wave climates to derive a comprehensive dataset which can be leveraged to address present and future flood risk planning and management activities.

The provincial coverage provided by the North-Atlantic regional hydrodynamic model domain is shown in the figure below. Model grid resolution varies from 1-20 km and has been divided into four main regions: Newfoundland East, Newfoundland South, Newfoundland West and Labrador. The domain was developed to capture the evolution of regional storm surge events that develop in the Atlantic at distances over 1000 km from Newfoundland and Labrador. The North Atlantic regional model water level is static and set to mean sea level (MSL), thereby only producing the storm surge residual of the total coastal water levels. The North Atlantic regional model was calibrated against long-term storm surge monitoring records. The purpose of the NA regional model is to provide boundary conditions for further downscaling.

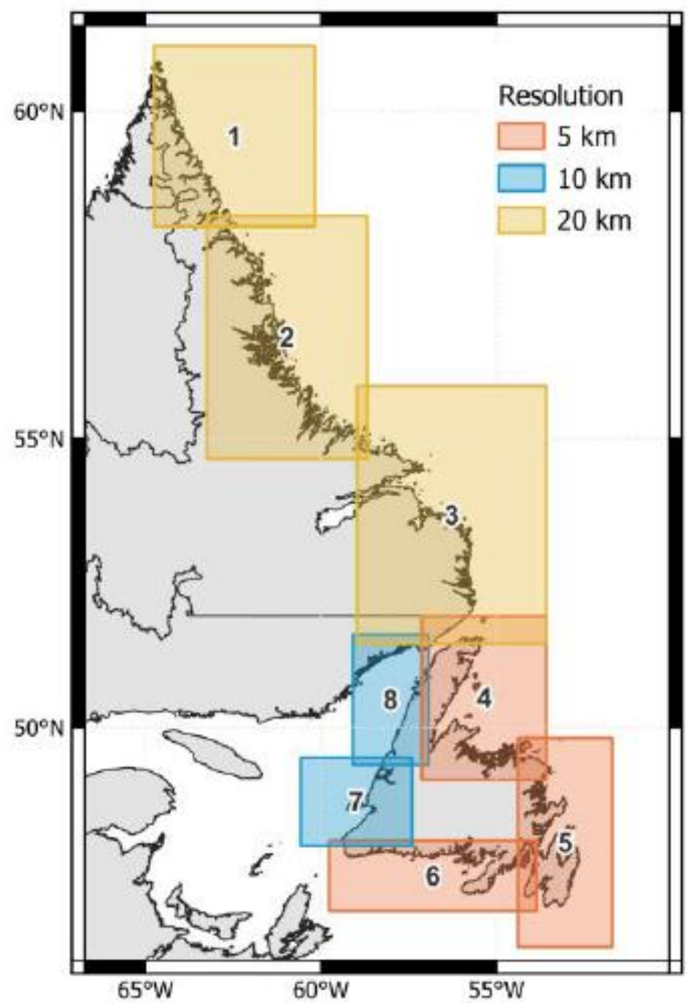


Figure 15: NL coverage from the North Atlantic regional domain model

The NL Atlas of Storm Surge and Wave Climates includes discrete points of interest along the entire coast of the province with time series of key metocean parameters, statistical parameter analysis maps presented as GIS raster files, and tables containing extreme storm surge and water levels at selected locations for various return periods. For points of interest, results can be extracted from a high-density of available points along the coast and offshore (up to at a maximum distance of about 100 km from the coastline) with higher resolution of data points near the coast. Different tools and data types are available for the hindcast period and for the climate change projections as follows:

General

- How information in the Atlas can best be used.

- Limitations on the use of the Atlas dataset.

Hindcast:

- Time series of offshore storm surge and wave conditions in an hourly hindcast from 1980-2020.
- Extreme value analysis at 78 points of interest for storm surge and wave conditions for various return periods.
- GIS mapping of hindcast storm surge and wave height statistics at various approximate resolutions (5km, 10 km, 20 km) as GeoTIFF raster files in EPSG 4326 - WGS84.

Climate Change:

- 3-hourly time series of storm surge and wave parameters for a historical baseline forced by two Global Climate Models (EC-Earth3 and ACCESS-CM2) for the period from 1984 to 2014.
- 3-hourly time series of projections, which incorporate future climate change, of storm surge and waves for the SSP5-8.5 scenario forced by two Global Climate Models (EC-Earth3 and ACCESS-CM2) for the period 2015 to 2100.
- Maps of projected relative changes to storm surge and wave height statistics relative to the historical baseline for mid and late century, considering the SSP5-8.5 climate change scenario and two Global Climate Models (EC-Earth3 and ACCESS-CM2) in GIS raster format.

The NL Atlas of Storm Surge and Wave Climates also includes information on how the Atlas dataset can be used and its limitations. The Atlas is available on the WRMD website: https://www.gov.nl.ca/ecc/waterres/flooding/coastal-flooding/. Any data not publicly available can be made available to consultants upon request to WRMD.

Atlas results account for the joint probability of occurrence of all the different processes contributing to coastal flooding: sea level rise, tide, local and regional surge and wave effects (setup and runup), and seasonal, interannual, and intradecadal factors.

Summary offshore wave statistics from regional wave hindcasts provide an assessment of offshore wave conditions and insight to potential upper bounds of wave exposure at a given site. Offshore wave time series can be further analyzed to provide useful summary statistics including:

- Return values of significant wave height (Hs) and wave period (Tp), sorted by directional sector.
- Joint Hs-Tp scatter diagrams, illustrating the range of peak wave periods associated with different significant wave heights.
- Wave persistence tables (duration of wave height-period combinations by direction).
- Wave roses (directional/compass plots of the frequency of occurrence of wave height classes).

The methodology used to generate current climate storm surge and wave conditions is outlined in Figure 16.

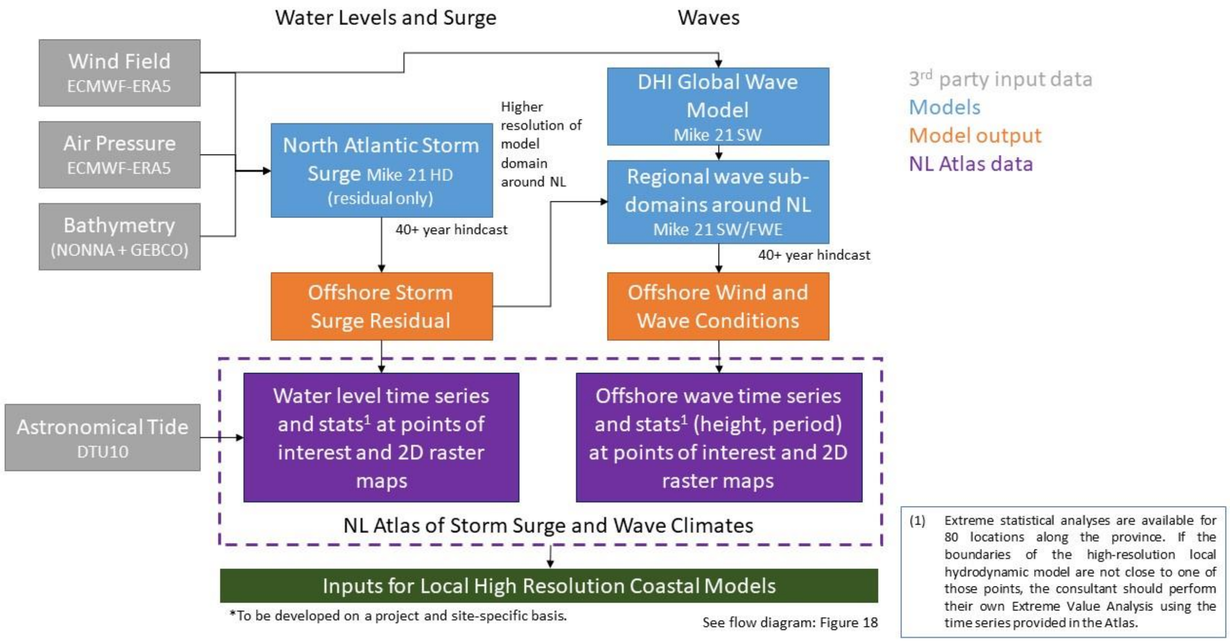


Figure 16: Atlas methodology for current climate conditions

Two climate models were used to provide an overview and understanding of potential future climate scenarios and their impacts. The atlas provides downscaled offshore storm surge levels and nearshore wave conditions for the future climate out to 2100. Climate projections were developed using two climate models at three (3) hourly intervals (for wind) using a baseline of 1984 to 2014 for comparison. Due to the high degree of uncertainty in future climate projections, the future climate information for storm surge and waves is for information purposes only. The model results should not be directly applied in engineering design and should be treated as indicative of potential future climate change scenarios. The methodology used to generate future climate change storm surge and wave conditions is outlined in Figure 17.

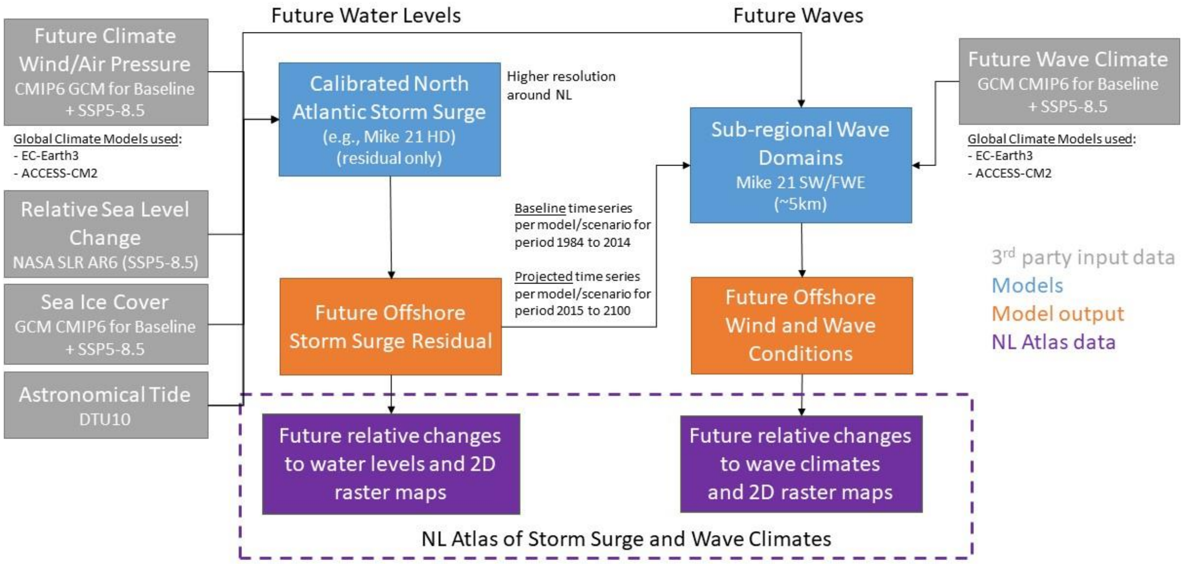


Figure 17: Atlas methodology for future climate change conditions

The North Atlantic Regional Model is of lower resolution than the primary study area of interest and establishes parameters for higher-resolution local models in the Atlas. Data from the Atlas can serve the following purposes:

- Boundary conditions at the offshore for riverine overland flood modelling.
- Boundary condition input for local community storm surge and wave modelling for coastal flood hazard assessment.
- To support a regional understanding, and rapid initial assessment, of coastal hazards in Newfoundland and Labrador.
- To help inform potential climate response options, regional planning, education and capacity building, and to inform decisions on climate policy, sustainable design, and adaptation planning.

13.4.2 Elevation Data

Topography (LiDAR) data are required for all coastal flood modelling and mapping projects in order to produce a High-Resolution Digital Elevation Model (HRDEM) of the project area. The HRDEM, which is openly available on Canada's Open Government portal, provides open access to currently available high-resolution elevation data across Newfoundland and Labrador and includes both digital terrain models (DTMs) and digital surface models (DSMs). Please refer to Section 4.1.

The bare earth DEM shall be used in the coastal flood mapping and shall not include buildings or other obstacles.

All elevations are to be in the CGVD2013 vertical datum.

Accurate representation of topographic and bathymetric elevations is of crucial importance to the reliable modelling of coastal hydrodynamics. Care is therefore required when quality-checking, merging (and referencing to common datums), and integrating topography and bathymetry datasets in a numerical model. Particular care should be given to linear features, such as culverts, road embankments, and dikes.

13.4.3 Bathymetry

Bathymetry data is required for all coastal flood modelling and mapping projects. High-resolution bathymetric data is needed to support detailed storm surge and wave simulation at the coast, community-scale flood hazard assessment, and simulation of overland flooding. There are several sources for available bathymetric data sets including:

- Global General Bathymetric Chart of the Oceans (GEBCO) data of the Atlantic Ocean supplied by the British Oceanographic Data Centre (BODC)
- Canadian Hydrographic Service (CHS) bathymetric data intended for non-navigational (NONNA) use that can be downloaded via their online portal
- Locally collected bathymetric data collected as part of the flood study

The consultant may need to conduct a bathymetric survey on the foreshore-nearshore areas of communities selected for coastal flood modelling and mapping to supplement existing bathymetric data available from the CHS. The survey crew will collect depth measurements via boat using the latest hydrographic survey grade sounding equipment interfaced with Real Time Kinetic (RTK) Global Positioning System (GPS). The survey crew shall navigate and collect bathymetric data based on pre-determined transect lines that are to be uploaded into a RTK dual frequency GPS. All bathymetric survey information will be in CGVD2013. The number of coastal transects to be collected should be identified.

When possible and safe to do so, additional RTK/GPS shots shall be captured along the shoreline and up the banks to the crest of the backshore. These shots are to extend bathymetric transects into the existing HRDEM coverage and to provide more detail of the existing bank geometry. Spot checks of any coastal defenses (e.g., breakwater, sea wall) shall also be taken.

Bathymetry data is required for the community-scale storm wave and water-level modelling, nearshore wave transformation modelling and wave runup calculations. In general, the best available data that meets the resolution requirements of the modelling effort should be used. For transect analyses, the extent of bathymetry depends on the magnitude of incident storm wave conditions. For most shore types and open coast settings, bathymetry out to water depths of approximately 12 m is required for wave transformation evaluations. In more sheltered areas with less energetic storm wave conditions, bathymetry out to water depths of 3 m or even less might suffice.

Accurate representation of topographic and bathymetric elevations is of crucial importance to the reliable modelling of coastal hydrodynamics. Care is therefore required when quality-checking, merging (and referencing to common datums), and integrating topography and bathymetry datasets in a numerical model. The average vertical accuracy of bathymetry data when compared to field surveyed data should be in the range of ± 5 to 20 cm.

The consultant shall provide a 2D raster map of coastal bathymetry integrating all sources of data as an ESRI_Grid or GeoTIFF file.

13.4.4 Transects and Shoreline Type

Transects are straight lines that begin out in the foreshore waters and cut across the land. Each transect is defined by an elevation profile which extends in a straight line from a point in open water to a point on land, perpendicular to the bathymetric contours, to the degree possible. The elevation profile of the transect can be defined from the project DEM including both bathymetric and LiDAR data or manually surveyed. Transects should be strategically placed to represent segments of the coast with similar features. Transects must be marked on coastal food maps and can be used to identify the physical location for the wave hazard analyses and how waves behave as they move along the transect and interact with land.

Instead of single transects, the consultant is encouraged to develop a transect profile to represent a block of coastline. These transect profiles should represent a broader section of the coastline and be simplified and schematized in order to minimize the influence of minor local features, such as small bumps or depressions in the profile. To generate these schematized, transect profiles, the following approach can be applied:

- Delineate a representative block where the coastline is uniform, and transect variations are expected to be minimal.
- Extract a transect every 2 m along this representative block and aligned to the zero-meter contour.
- Average the elevations from all transects within the same block to generate an initial transect profile.
- Run a simplification algorithm to produce the final representative transect profile for the block.

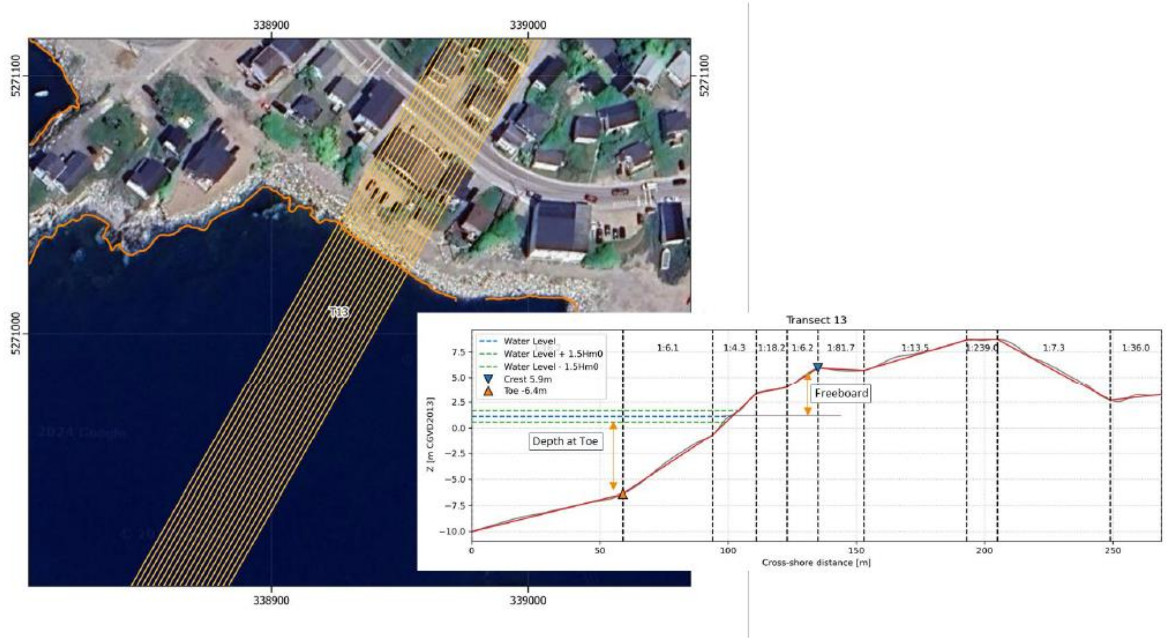


Figure 18: Example of a schematized (average) profile

Transects do not need to be manually surveyed unless available topographic and bathymetric data are unsuitable or incomplete. Manually surveyed transects should be used to verify the accuracy of transects derived from available topographic and bathymetric data. The consultant should field-check shore topography to note any changes caused by construction, erosion, coastal engineering, or other factors. The consultant should document any significant changes with location descriptions, drawings, and/or photographs.

The number of transects required will be dictated by factors such as slope, coastline orientation, whether the shoreline is sheltered or not, irregularity of the shoreline, nature of coastal features (e.g., beaches, man-made structures, cliffs), changing profile characteristics, population density and variable upland development patterns. These factors may dictate a reduced transect spacing and may require many more transects than might be used along an open coast shoreline of the same overall length. The consultant should be able to interpolate between transects using topographic, shoreline structure, land cover, and backshore development information, thereby significantly reducing the number of transects required where possible. In relatively uniform sections of coastline, transects can be spaced between 150 and 600 m apart. In sections of coastline with complex topography, significant development, or rapidly changing shoreline features, transects may need to be spaced between 30 to 150 m apart. Wider spacing between transects of more than 600 m can be used in sections of the coastline that are homogeneous, unpopulated or undeveloped as long as the interpolation between transects remains accurate. The number of proposed coastal transects to be collected/used should be identified.

An effort should be made to site transects and map results in a way that avoids large changes in flood water levels from one reach of shoreline to the next, particularly in areas dominated by wave runup. Spatial resolution must be high enough to capture important topographic and/or bathymetric features of relevance to simulating overland flooding and to capture flow pathways. This may require sensitivity testing to identify the coarsest resolution that can be adopted without compromising accuracy.

Shoreline type will help with the models and methodologies selected for analysis of wave setup, runup, overtopping and overland propagation to be used for wave analysis and mapping the coastal flood zones. General shoreline settings near communities in NL include, but are not limited to:

- Erosion-resistant beach profile having a small lens of mobile sand
- Cobble, gravel, shingle beach or mixed grain size beach
- Shorelines with piers and wharves affecting sediment transport
- Erodible coastal bluffs and cliffs
- Non-erodible coastal bluffs and cliff

The type of shoreline profile (e.g., sloped, positive slope plateau, negative slope plateau, cliff) will govern the approach to determining wave runup.

Information on the susceptibility of parts of coastal Newfoundland and Labrador to coastal erosion can be gathered from the provincial Geoscience Atlas (https://geoatlas.gov.nl.ca/Default.htm) or:

- Catto (2011) - https://geoatlas.gov.nl.ca/Custom/help/Coastal_Monitoring/Catto_2011%20-%20Nfld%20Coastal%20Erosion.pdf
- Catto (2019) - https://geoatlas.gov.nl.ca/Custom/help/Coastal_Monitoring/Catto_2019%20-%20Coastal%20Labrador.pdf

The consultant shall provide a coastal transects layer as an ArcGIS file.

13.4.5 Tide and Wave Monitoring Data

The consultant may want to use historical tide and wave monitoring data as part of the coastal flood hazard assessment, however, there is limited data available for Newfoundland and Labrador. The Marine Environmental Data Section (MEDS) of the Department of Fisheries and Oceans (DFO) has several permanent tide and water level stations with available data that can be accessed from their website: https://www.tides.gc.ca/en/tides-and-water-levels-data-archive

The Bedford Institute of Oceanography (BIO) Government of Canada WebTide model can provide tidal boundary conditions for high resolution models.

DFO has 2 buoys that collect wave data off the coast of Newfoundland and Labrador with data available from the following website: https://meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/waves-vagues/index-eng.htm

SmartAtlantic also has data from several tide and wave monitoring stations publicly available: https://www.smartatlantic.ca/index.html

Wave data can be taken from the MSC50 Atlantic wave hindcast product from ECCC.

13.4.6 Historic Storm Related Coastal Water Levels

The consultant will need to collect information on historic coastal flood events in order to help validate any coastal flood mapping produced. Sources of information may include:

- Archival records
- NL Flood Events Inventory: https://www.gov.nl.ca/ecc/waterres/flooding/flooding/
- Information from the community and residents
- NRCan Historic Flood Events: https://open.canada.ca/data/en/dataset/fe83a604-aa5a-4e46-903c-

685f8b0cc33c
- Public Safety Canada NASP Imagery: https://pscanada.maps.arcgis.com/apps/MapSeries/index.html?appid=fad7ab607dab4b3cb8f433c42460338a
- Field observations

13.4.7 Land Cover and Roughness

Depending on the type of analysis used, some (hydrodynamic) models may require input regarding the land surface roughness in order to drive computational processes that simulate friction between the land surface and the water. Refer to Section 4 on watershed characteristics, which should also apply to the coastal zone to be mapped. Roughness depends, in part, on the surficial material, as well as vegetation. Roughness is often represented using the Manning's n coefficient. Often, roughness coefficients are treated as a calibration parameter and are adjusted during the model calibration process to optimize model performance.

The consultant shall provide a land surface roughness layer as an ArcGIS file.

13.4.8 Buildings, Infrastructure and Coastal Flood Defense

The consultant may need to incorporate the impacts of buildings, infrastructure, flood defences, and hydraulic and hydrologic connectivity into the coastal flood modelling and analyses. In developed areas, consultants may need to consider the impacts of infrastructure on the propagation of floodwaters and hazard pathways. For example, infrastructure, such as buildings, walls, roads, and flood defences, may obstruct flow, whereas drainage infrastructure (e.g., culverts) may facilitate flood propagation across connected land parcels.

The consultant should obtain documentation for significant coastal structures that may provide protection from the 1% AEP flood or affect propagation of storm surge and wave action, including coastal armoring, breakwaters, piers, and wharves. Documentation should include basic layout, crest elevation, construction material, present condition, owner, construction date, design documentation, and date and type of any repairs.

Linear features such as dikes, road embankments, or culverts may have a significant impact on flood propagation and distribution. Drainage infrastructure, such as culverts and ditches can be incorporated into elevation datasets (and, by extension, flood modelling) via hydro-enforcement, or incorporated in two-dimensional hydrodynamic models as sub-grid scale features/structures.

As part of the CanElevation Series, the federal government has made available a layer of Automatically Extracted Buildings from the HRDEM dataset where coverage is available.

Shoreline protection work that has been permitted along the coastline of the province is documented in permits issued under Section 48 of the Water Resources Act and may be found online (going back to 2014) including a mapping application of issued regulatory permits:
https://www.gov.nl.ca/ecc/waterres/permits-licenses/permits/water-alt/

13.4.9 Riverine Flood Levels

Riverine flood levels may also impact coastal flood water levels. In cases where river flood modelling has also been undertaken, the coastal flood water levels must tie into the riverine flood levels at the coast. In cases where river flood modelling has not been undertaken data from hydrometric stations should be used to determine high riverine water levels at the coast.

13.4.10 Atmospheric Data

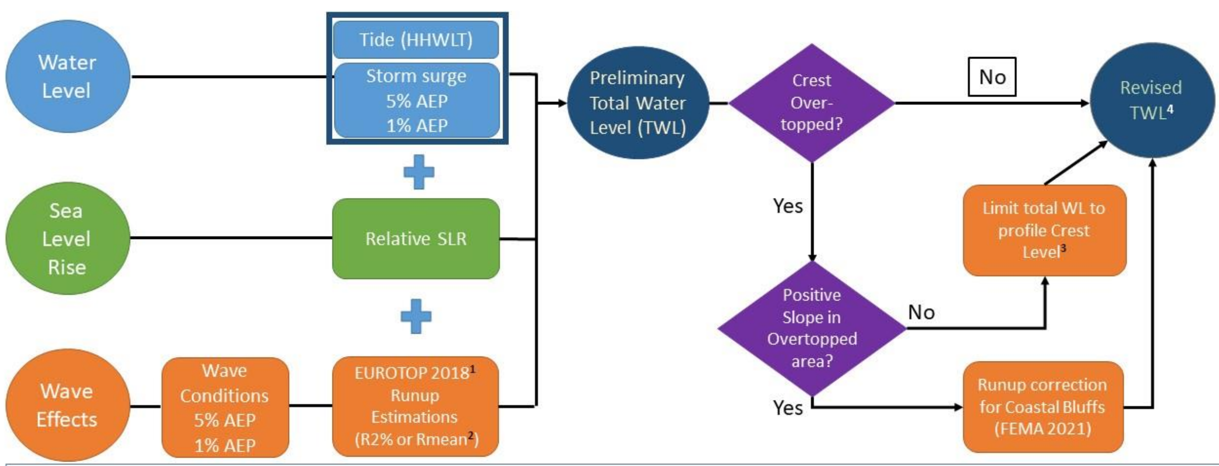
The storm surge models require robust historical spatially and temporally varying wind and pressure fields across the entire model domain. The best available data set is the global Climate Forecast System Reanalysis (CFSR) model administered by the National Centre for Atmospheric Research (NCAR). CFSR data has been validated to measured wind and atmospheric pressure records at climate stations located across the province whose data is publicly available from ECCC.

13.5 Modelling and Analysis Methods

The following section provides minimally acceptable guidance and techniques for modelling and analysis of various coastal flood hazard–generating sources related to total water levels and waves. Distinct approaches for assessing coastal flood hazard include:

- Transect (1D) analysis at locations of interest
- Detailed inundation (2D) modelling at locations of interest

Transect analysis involves extracting a one-dimensional profile from the foreshore, perpendicular to the coastline, and estimating the expected total water level at that location using numerical techniques. This method of analysis is technically robust, and is suitable when project scope, schedule and budget does not allow for detailed inundation modelling throughout each reach. The following figure outlines the transect analysis methodology at a high level.



(1) EUROTOP 2018 methodology applied after careful consideration of each profile characteristics and geometry. Note that not all profiles are within the applicability range of those equations.
(2) Reduction Factor from R2% to Rmean based on FEMA 2021 recommendations.
(3) No detailed overtopping calculations were considered at this stage. The proxy considered for mapping when facing downward slopes is likely to provide a conservative estimate of flooded areas.
(4) Final total WL does not consider the joint probability of wave-tide-surge. Each variable is analyzed separately and combined afterwards. The associated AEP for the Revised TWL cases are likely to be less than those of the individual variables. Consequently, the TWL values provided in this assessment are likely to be conservative but indicative of potential flooding.

Additional notes:

- The applicability of the results for a particular transect into neighboring areas will depend on the similarity between those areas morphological features and those of the profile, e.g., depth slopes, foreshore slope, crest levels, coastline orientation, amongst others.
- For very flat profiles, specially those that show rock outcrops, the methodology for runup estimation (based in EUROTOP 2018) would no longer be valid. Other methods, such as direct modelling of the profiles should be considered for a precise estimation on total water levels and associated flooding.

* FEMA 2021, Guidance for Flood Risk Analysis and Mapping Coastal Wave Runup and Overtopping.

Figure 19: Transect methodology for the estimation of total water levels

Because continuous hindcast simulations were used to generate data for the NL Atlas of Storm Surge and Wave Climates, the joint probability of occurrence of all the different processes contributing to coastal flooding (sea level rise, tide, storm surge and wave effects) is accounted for taking a probabilistic approach. The resultant time series datasets were used as input to extreme value analyses (EVA) to determine the 5% and 1% AEP total water levels. This probabilistic approach also allows for direct comparison against observed, ‘real-world’ flood events for verification purposes.

To derive AEP storm surge flood levels, total water levels with a defined AEP are required throughout the flood mapping area of interest. Producing AEP statistics at each node in the model is not required, however, a representative selection of a minimum of 6 nodes shall be chosen for analysis and interpretation for each community. These number and locations of the nodes selected for further analysis shall be defined at the toe of each transect used to calculate the wave runup to best integrate the total water level AEP and the wave runup results. At each data extraction point, time series of total water levels and depth-averaged velocities shall be extracted for integration into the flood risk, riverine flood hazard maps, and coastal flood maps. Statistical analysis will be performed for each time series, and the AEP for total water levels and depth averaged currents will be defined by fitting representative statistical distributions to the data.

Detailed (2D) inundation modelling must be carried out using software specifically designed for that purpose (e.g., MIKE 21 products) for local model domains of interest. Use of 2D modelling that incorporates wave effects should be evaluated for areas of low elevation with exposed populations, and coastal areas with dense development.

The consultant must provide a rationale in justifying any methods used for coastal flood mapping outside the scope of this technical document. The decision and rationale justifying the use of any alternate method should be clearly documented. Alternate methods must have been instituted by experts in the field of coastal flood mapping and should be documented in studies that detail the process/procedure that can be replicated in this instance as a Best Practice.

13.5.1 Scenarios for Analysis

The following scenarios must be included in the coastal flood hazard analysis:

Return Period (year)	20	100
Annual Exceedance Probability (AEP)	5%	1%

Total water levels are to be produced for the two different probability events for:

- current climate conditions
- climate change conditions

A high-level overview of the methodology for deriving current climate and climate change local domain coastal flood mapping is outlined in Figure 20. Water levels for future climate change scenarios are accounted for by the incorporation of sea level rise.

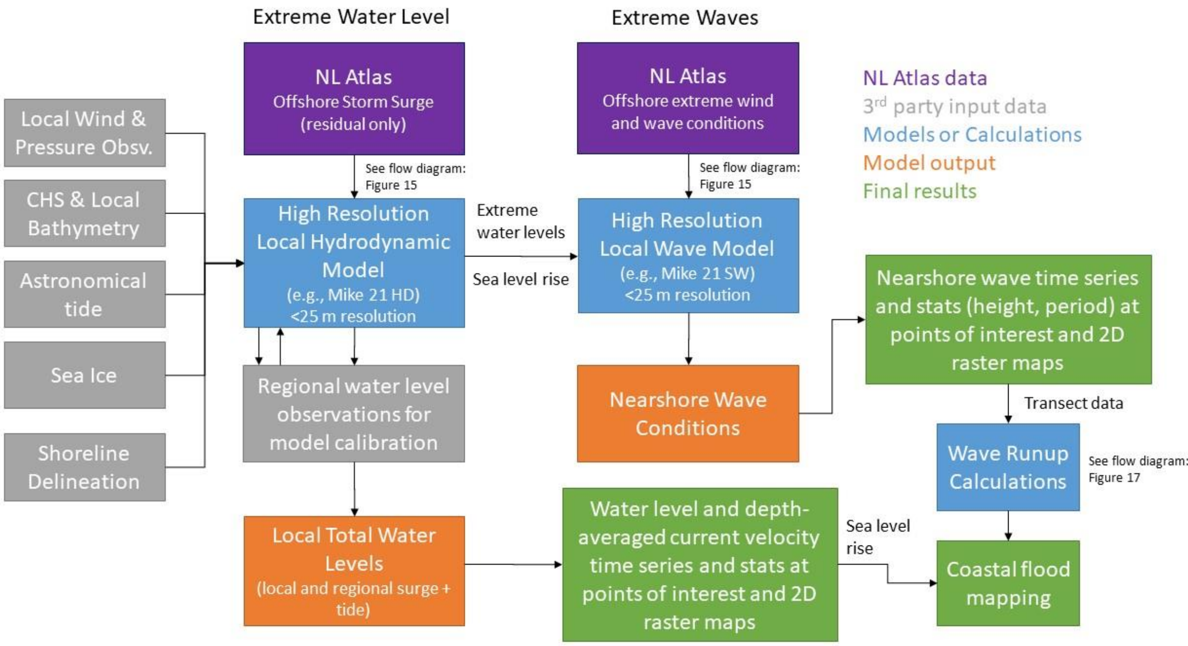


Figure 20: Current climate and climate change methodology for local coastal flood mapping

13.5.2 Storm Surge Water Levels

Sustained elevated water levels along the coast are driven by storm surge, sea level rise and tides. The height of the storm surge is affected by many factors, including the intensity, path, and speed of the storm; the depth of water offshore; and the shape of the shoreline. Offshore total water levels (surge and tides) can be taken from the NL Atlas of Storm Surge and Wave Climates. Coastal models are then needed to investigate local community storm surge effects in more detail using the outputs from the larger regional model used to provide data for the Atlas. The local community coastal model must be adjusted to accurately represent historical storm surge events. Statistical analyses must be completed to determine the 20 and 100-year AEP local storm surge events.

Steps to take to derive high-resolution detailed local community storm surge models shall include the following:

- The high-resolution detailed local community models should have a resolution down to 25 m. Best available bathymetric data should be used in the models.
- Boundary conditions for the local models are derived from the Atlas for storm surge and from the Bedford Institute of Oceanography Government of Canada WebTide model for tides.
- Spatially and temporally varying wind and pressure fields are to be included to simulate local surge processes. Local models should be calibrated to water level observations from monitoring stations.
- The high-resolution local model should simulate water level (combined tide and surge effects) throughout the model domain.
- Points of interest are to be selected at key locations and total water levels and depth averaged current data extracted as continuous, hourly time series over at least 40 years.
- Model data at points of interest will be evaluated for required AEP events representative of the joint probability of tidal conditions and storm surge events occurring simultaneously.
- Total water level and depth averaged current statistics are interpolated for the development of flood extent and risk mapping products.

The local, community high-resolution model results should be available at hourly intervals at every node in the domain model for the hindcast period. This data set can be interpreted either at hourly intervals in 2D or as a time series at individual nodes.

Local, community model domains should be validated against data from nearby tidal gauges and for several past flood events (e.g., Hurricane Igor, Hurricane Fiona) to ensure accuracy.

13.5.3 Waves

Waves are an important component of the coastal flood hazard because they increase the elevation of the flood hazard and have the potential to cause significant structural damage to buildings. Flood hazards related to wave action include wave setup, wave runup and overtopping, and overland wave propagation. Waves have been identified as a significant hazard in past coastal flood events in Newfoundland and Labrador. As such, the analysis of wave effects is an important component of coastal flood mapping studies requiring localized dynamic modelling of waves. Coastal flood studies must examine contributions of both wave setup and runup.

The objective of wave effects assessment is to simulate the wave-driven flooding processes (wave setup, runup and overtopping) and to delineate 2D horizontal wave impact flood lines. The extreme wave conditions used as input for the wave-driven flood calculations are obtained by propagating to the shoreline extreme offshore wind and wave conditions combined with extreme water levels (joint action of tides and storm-surge). To consider climate change impacts, sea level rise projections and projected changes in significant wave height are incorporated in the discrete extreme scenarios. To appropriately characterize wave effects across a diverse range of coastal environments, a tiered methodology should be adopted:

1. **Advanced 3D Modelling**: In high-priority areas with dense population, complex terrain (e.g., diffraction around islands and coastal embayment's), critical infrastructure, high infrastructure density and significant flood hazard, advanced 3D numerical models can be used to simulate detailed hydrodynamic interactions and wave overtopping which can result in pooling, ponding and localized flood effects.
2. **1D Transect with Detailed Mapping Interpretation**: In moderately complex or partially developed areas, a hybrid approach based on a large number of 1D transects and detailed mapping interpretation between 1D transects can be employed, incorporating expert judgment to interpret potential water pathways to define the primary wave effects zone, and more refined profile analysis to capture wave-driven flood extents with greater accuracy. Suitable for uniform coastlines with minimal variation, as well as for structures and features well-documented in the literature (e.g., sea dikes with constant slopes).
3. **Standard 1D Transect**: In lower-priority areas with simpler coastal features and limited or no infrastructure, standard 1D transect methods can be applied using a smaller number of representative shoreline profiles and automated procedures without considering water pathways. The primary wave effect zone is defined automatically as 30 m from the shoreline.

This approach integrates regional numerical models, detailed local wave runup and flood assessments, empirical wave runup models, advanced mapping techniques, and expert judgment.

High-quality wave modelling includes analysis of local wind direction, collection of localized shoreline profiles or a gridded bathymetric digital elevation model (DEM), and specific hydrodynamic modelling. Wave transformation modelling is employed to assess nearshore wave conditions. Steps to take to derive high-resolution detailed local community wave models shall include the following:

- Wave model is completed using a sufficient computational grid for the local domain to allow for the capture of extreme offshore wave conditions derived from the Atlas. Model parameters are defined based on regionally appropriate settings to simulate extreme local wave runup conditions.
- Discrete multidirectional extreme nearshore wave conditions at a high resolution (down to 25 m) along the community shoreline is modelled using offshore wind and wave conditions and total water levels (surge and tide) from the Atlas, and relative sea level rise.

- Outputs from the wave model along the shoreline are used to perform 1D wave runup calculations along coastal transects. Outputs include time-series of hourly wave parameters (i.e. significant wave height Hm0, peak wave period Tp and mean wave direction MWD) at the offshore point of each transect for the hindcast period.

The local, community high-resolution model results should be available at hourly intervals at every node in the domain model for the hindcast period. This data set can be interpreted either at hourly intervals in 2D or as a time series at individual nodes.

Evaluation of wave contributions to coastal flooding requires an understanding of offshore wave conditions, wave propagation and transformation processes in nearshore areas, and wave interactions with shore-based features and structures. Techniques with varying levels of complexity may be applied to characterize waves at a particular location.

Onshore wave effects are typically constrained to a relatively narrow strip along the foreshore, where waves runup, overtop and splash. This is referred to as the 'Primary Wave Effect Zone'. Outputs from the high-resolution local wave models are used in combination with the storm surge, sea level rise, and coastal cross sections to complete wave runup calculations.

Multiple transect analysis must be undertaken in order to determine the water levels for the 1:20 and 1:100 AEP and for current climate and climate change conditions.

The consultant shall provide WRMD with a digital GIS layer of the Primary Wave Effect Zone for each community.

13.5.3.1 Advanced 3D Modelling

3D wave models offer a more precise and detailed assessment to accurately represent wave flood hazards. 3D wave modelling is capable of simulating different processes like wave breaking, setup, runup and overtopping and provides advantages such as accurate wave propagation, detailed inundation modelling, and enhanced communication and engagement. However, 3D wave modelling has high computational costs, is dependent on the availability of high-resolution bathymetry and topographic data, and takes significant time for setup, calibration and to run scenarios. The use of 3D wave modelling should only be considered for priority areas and smaller domains (i.e., shoreline reaches of less than a few kilometers).

$R_{2\%}$ is the wave runup elevation exceeded by 2% of waves and is a well-established and widely used metric for establishing wave flood levels. When using 3D wave models, the $R_{2\%}$ is estimated using a proxy derived from the 3D model outputs ($R_{2\%,Proxy}$), which represents the horizontal extent of wave runup rather than a direct elevation. The corresponding wave runup height is then inferred from this extent by comparing with the elevation from the DTM. A 3D wave model determines flood extents directly, with wave runup elevations inferred afterwards.

The 3D wave model simulation represents the peak of a storm event, defined by a single high-water level and a representative wave spectrum characterized by the significant wave height, peak period, and mean wave direction. A standard duration for reliable spectral wave analysis is a 30-minute simulation run. The model outputs should consist of a time series of water levels and wave conditions at each grid cell representative of peak storm conditions.

The horizontal extent of wave runup ($R_{2\%,Proxy}$) and wave runup height ($R_{2\%}$) can be extracted as follows:

- The number of peaks in each model grid cell is calculated from the water surface elevation time series for the entire simulation time. These peaks represent both the number of individual waves reaching the coastline and the number of wave runup events at the adjacent emerged land areas.
- The total number of waves at the interface between the static water level and the land (the "toe", see Figure 21) is used to determine the number of wave runup events that correspond to the top 2%. For example, if 100 waves reach certain point along the coastline, the $R_{2\%,Proxy}$ threshold for

the adjacent emerged areas is defined as 2 events. This threshold is used in the following step to determine which areas are within the wave runup zone and which areas are not reached by 2% of the waves.

- Moving from land to sea, land cells with a total number of peaks greater than the $R_{2\%,Proxy}$ threshold at the land-sea interface are retained within the $R_{2\%,Proxy}$ contour, while land cells with fewer peaks are excluded (indicating that these areas are reached by less than 2% of the individual waves within the peak of the storm).
- Polygons are generated to encompass all land cells where the number of wave peaks exceeds the $R_{2\%,Proxy}$ threshold identified at the land–sea interface. The outer edge of this polygon defines the proxy wave runup extent, $R_{2\%,Proxy}$.
- Wave runup elevations are then extracted at selected locations by comparing the maximum elevation from the Digital Terrain Model within the flooded zone (i.e. within the $R_{2\%,Proxy}$ polygon).

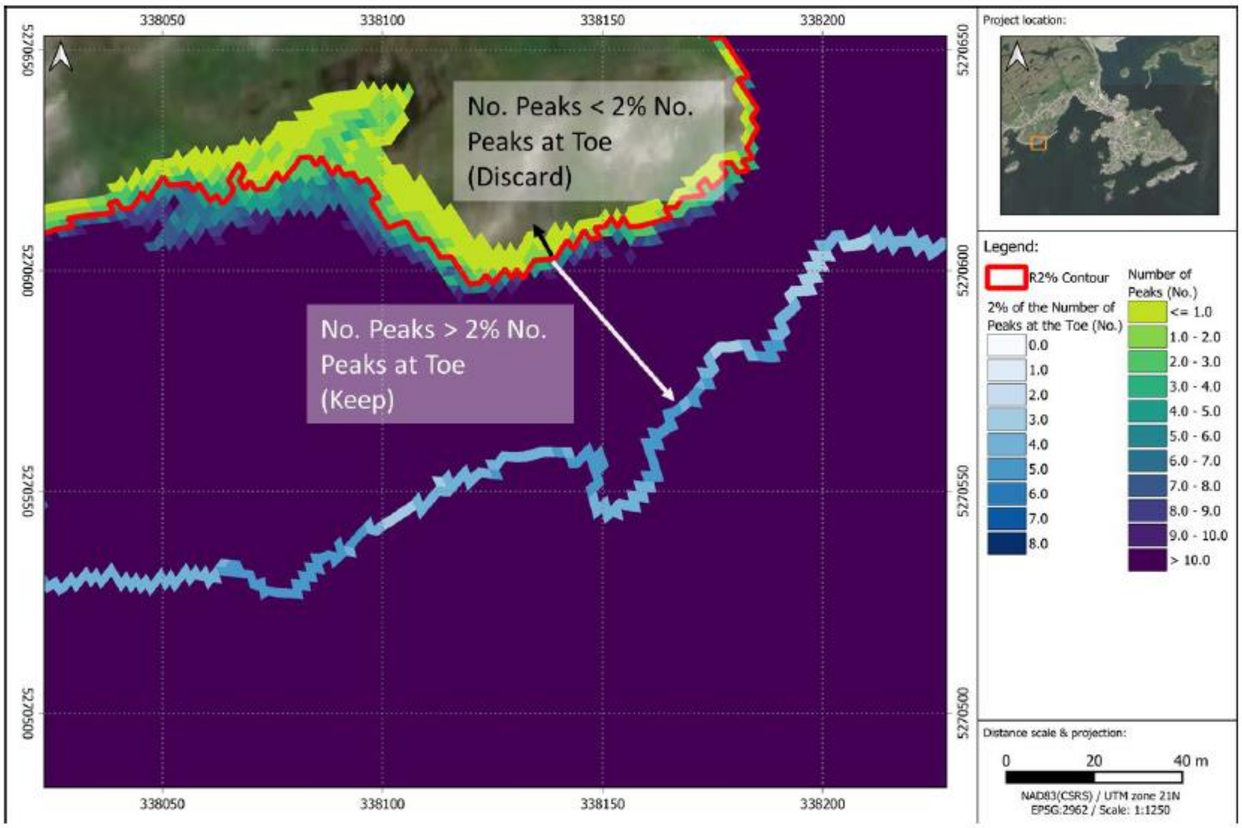


Figure 21: $R_{2\%}$ contour line based on the number of wave peaks extracted from 3D wave model

13.5.3.2 1D Transect Based Method

1D transect-based methods should be used to estimate wave runup and flood extents in areas not covered by the 3D wave models typically in locations with simpler coastal geometries and/or limited wave impacts, or remote areas without significant infrastructure at risk. The 1D transect method requires much reduced computational resources and is based upon well-established empirical formulas. The 1D transect method consists of calculating wave runup at individual transects or transect profiles using models or empirical equations, correcting these runup elevations if overtopping occurs, and interpolating these results along the shoreline.

Wave runup ($R_{2\%}$) at each transect or transect profile should be estimated using wave models or empirical equations. If models are used, they should be validated across a range of coastal conditions and used only for those conditions. For conditions for which the model may not be applicable, empirical formulas should be used. Methodologies for wave runup calculations can include:

- FEMA, Guidance for Flood Risk Analysis and Mapping: Coastal Wave Runup and Overtopping, 2021: https://www.fema.gov/sites/default/files/documents/fema_coastal-wave-runup-overtopping_112021.pdf
- EurOtop, 2018: http://www.overtopping-manual.com/eurotop/downloads/
- USACE CEM, 2002: https://www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/u43544q/636F617374616C20656E67696E656572696E67206D616E75616C/

Transforming nearshore wave heights to onshore wave setup and runup water levels will involve the use of mean wave runup (Rmean) and wave runup (R2%) derived from the local wave model results. Wave runup and setup can be assessed at each transect using Rmean and R2%. The R2% wave runup is always higher than Rmean as it is estimated using a larger wave effect contribution only exceeded by 2% of waves. Corrections on the wave runup transect methodology may need to be applied for certain shoreline types where the shore crest is overtopped or where there is runup on a composite positive slope including:

- Runup on a plateau with a positive slope
- Runup on a plateau with a negative slope or ponding area

13.5.3.3 Primary Wave Effect Zone

The Primary Effect Wave Zone is the area influenced by wave runup and overtopping as defined by local topography and hydrodynamics. To enhance the accuracy of 2D flood mapping derived from 1D transect-based methods, a Primary Wave Effect Zone must be delineated. The purpose of this zone is to better represent the influence of wave-induced flooding and avoid unrealistic inland projections of wave runup. This delineation is particularly important in regions where the wave runup elevation exceeds the crest elevation of coastal barriers (e.g., dunes, berms, or seawalls). In such cases, flood extents are not solely determined by the runup elevation but are also influenced by wave overtopping dynamics. Simply projecting the crest elevation landward would overestimate the flood extent by assuming uniform flooding beyond the barrier.

To define the Primary Wave Effect Zone, a systematic approach should be used to evaluate coastal areas, taking into account multiple topographic and hydrodynamic factors, as well as engineering judgment, including:

- **Proximity to the coastline**: A 30-meter buffer from the High-Water Line (HWL) should be used as an initial guideline to delineate wave effects zones, with adjustments based on local topographic and hydrodynamic conditions. This buffer is illustrated in Figure 22 by an orange dashed line.
- **Profile characteristics**: Cross-shore profiles spaced every 5 meters should be analyzed to capture variations in coastal morphology and delineate crest elevations (if present). Relevant features of each profile, such as the location of the crest elevation before the profile plateaus or ponding areas, are illustrated in Figure 22.
- **Hillshade Digital Terrain Model (DTM)**: Used to visually interpret terrain features, slopes, and potential flow pathways.
- **DTM elevations and hydrological features**: Identification of ponding areas, low-lying depressions, and other local minima that could influence water retention.
- **Estimated wave runup elevations**: Runup estimates along selected profiles provides a basis for defining potential flooding extents.

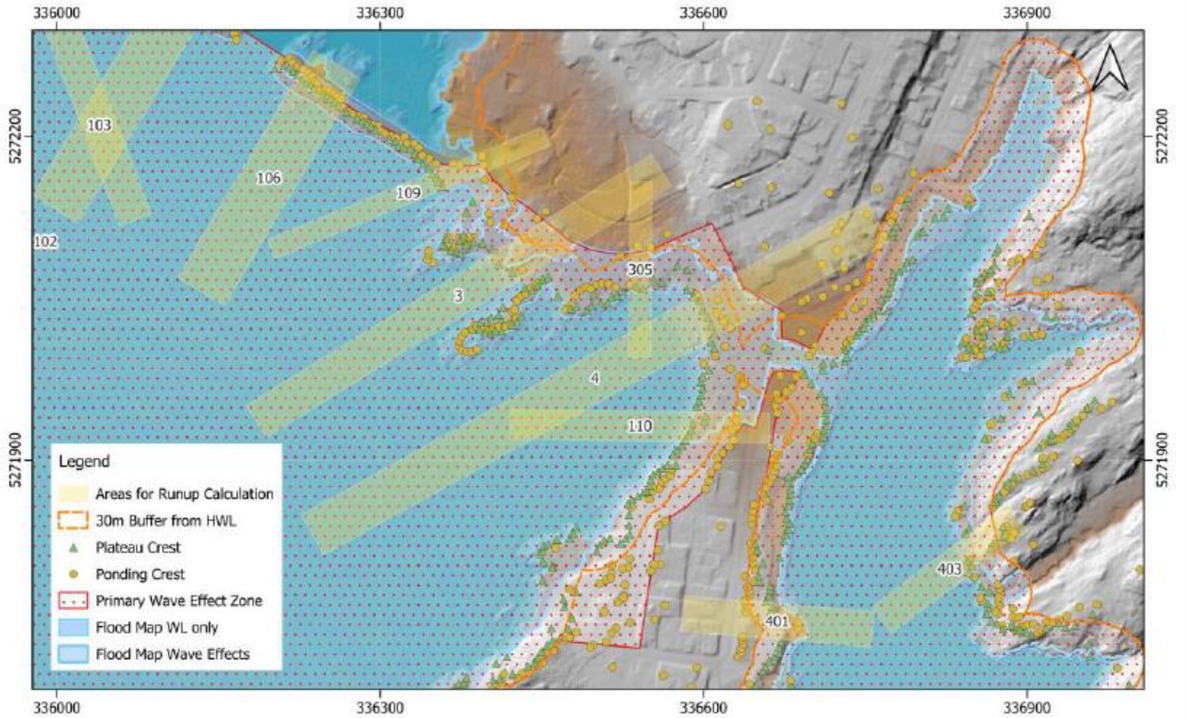


Figure 22: Example of the delineation of the Primary Wave Effect Zone

A detailed assessment of the Primary Wave Effect Zone should be conducted for priority areas covered by the 1D transect approach. In lower-priority regions, the Wave Effect Zone is approximated using a 30-meter buffer from the High-Water Level, with minor adjustments based on observed terrain characteristics and expected hydrodynamic behavior.

To estimate flood levels within the Primary Wave Effect Zone, the 2% exceedance runup elevation (R2%) is used. Beyond the Primary Wave Effect Zone, flood levels are estimated based on either:

- Mean Runup Elevation (R_{mean}), in areas immediately adjacent to the Primary Wave Effect Zone.
- Total Water Level (TWL), which includes contributions from tide, storm surge and sea level rise, as appropriate, in areas protected from wave action, such as inland lagoons and embayment's.

This approach ensures that wave-induced flooding is more realistically represented while minimizing overestimation or underestimation of flood extents in complex coastal environments.

13.5.3.4 2D Flood Mapping

Wave flood hazard maps must be created by integrating results from the various 3D and 1D wave runup methodologies. 2D maps based on 1D transects will carry inherent uncertainty as they rely on extending the results at specific transect locations over a broader area. The reliability of the wave flood mapping can be enhanced through the delineation of a primary wave effect zone, defining the alongshore extent of profile applicability, and adjusting the final flood maps where necessary.

The final 2D wave flood maps are to integrate results from the 3D model with 2D maps derived from 1D transects. Care is taken to ensure smooth transitions between different model areas. After merging of the different model maps, a smoothing algorithm should be applied to refine flood contours. The maps are then reviewed to remove spurious results and to ensure adequate representation of areas affected by wave overtopping.

Areas covered by the 3D models have a lower degree of uncertainty compared to those assessed with 1D transect-based methods. As a result, the accuracy of the flood maps will vary across different areas.

13.5.4 Models

Most models commonly used for coastal storm surge and wave analysis are commercially available software products. Examples of software that may be used in this study include, but are not limited to:

- MIKE21 Flow Model (FM) - Hydrodynamic Module(HD) developed by DHI
- MIKE21 FM Spectral Wave (SW) developed by DHI
- MIKE3 Wave FM developed by DHI
- SWAN wave modelling software developed by Delft University of Technology
- TELEMAC-2D developed by the Laboratoire National d'Hydraulique (LNH)
- TUFLOW developed by BMT and the University of Queensland
- TOMAWAC developed by the Laboratoire National d'Hydraulique (LNH)
- Coastal Modelling System (CMS) developed by USACE
- CSHORE developed by USACE
- XBeach developed by Deltares
- FUNWAVE-TVD developed by Shi et. al.
- NHWAVE developed by Ma et. al.

When selecting the geographic domain for the model, it is important to consider the mechanisms that drive elevated water levels associated with storm surge and waves. Nested grid models or unstructured (flexible) computational meshes can be used to reduce computational demands associated with the need for both large geographic extents and high spatial resolutions in coastal areas. High-resolution local models should have a resolution down to 25 m in the areas of interest. Boundary conditions for the local, community high-resolution models are to be taken from the NL Atlas of Storm Surge and Wave Climates. Models must also be tied into the CGVD2013 vertical datum.

Spatial resolution must be high enough to capture important topographic and/or bathymetric features of relevance to simulating tidal circulation, storm surges, gradients in free surface elevation, and/or overland flooding and to capture flow pathways, but must not be so detailed that it causes impractical computational burden. Unstructured grids and nested grid techniques may be leveraged to balance these competing requirements.

Model time-step selection should be 1 hour or sufficient to capture peak water levels and durations of storm events. The temporal resolution of driving input or boundary condition data (e.g., atmospheric fields) may also place practical limits on the temporal resolution of model output.

Use of 2D modelling that incorporates wave effects can be used to evaluate areas of low elevation with exposed populations, or and coastal areas with dense development, for which 1D transect analysis of wave runup onshore may be overestimating the inundation area. Most commercially available and open-source two-dimensional (shallow-water and depth-averaged) hydrodynamic models incorporate the important physical processes relevant to simulating overland flooding. The model should extend sufficiently far inland to exceed the reach and elevation of the most severe floods being simulated. Model output is driven by requirements to support the risk analysis, and may include inundated areas, water depths, and flow velocities.

Considerations in model selection shall include:

- Important processes, physics, or factors affecting coastal flooding are properly captured by the model, and may include wind and atmospheric pressure forcing, tide forcing, bed friction, Coriolis forcing, wetting/drying, turbulence, and physical processes relevant to simulating overland flooding.
- Model complexity and level of effort involved in developing, calibrating, and validating the model.
- Computational efficiency, cost, and resource demand of the model.
- Practitioner experience with applying the model.

- Dimensionality (e.g., 2D depth-averaged approaches are typically adequate for most tide, storm surge and overland flooding modelling applications; 3D modelling not required).
- Model has a successful track record, demonstrated by verification for relevant test cases and real-world applications.
- Model can produce required outputs.
- Needs for integration with mapping or GIS software.

While a non-proprietary software solution is preferred, if the consultant determines that a proprietary model has to be used for the analysis, the consultant must provide a copy of the model software to the Technical Committee Project Manager.

The consultant shall provide WRMD with a copy of all coastal flood modelling files.

13.5.5 Model Calibration and Validation

The consultant should review results from the coastal models and assessments from a common-sense viewpoint and compare them to available historical flood data to ensure mapping provides a reasonable result. Calibration and validation of the resulting coastal flood mapping will help to demonstrate the model accuracy.

To help calibrate and validate the coastal flood mapping produced, the modelled and mapped water levels should be compared to observed water levels that have occurred during past events at several locations in the community. Past coastal flooding events can be identified from the provincial flood event database, hindcast data, community historical records, photos, water level or weather records, post-flood high water mark survey data, debris/wrack line surveys or observations, community knowledge, sedimentary records, other physical indicators of floods or high-water levels, and high-resolution satellite imagery representing past floods.

Calibration is an iterative process in which model parameters (e.g., bed friction) are adjusted until a satisfactory agreement with observational data is achieved for a given storm surge or wave event. Once the consultant is satisfied with the performance observed from the calibration process, the optimized model is tested against an independent event, or events, (not included in the calibration process) to validate model performance. Both the calibration and validation processes provide a basis to compute model skill metrics, such as root-mean-square errors in water levels, which can help to convey model uncertainty. The consultant should make an assessment of the vertical and horizontal accuracy of the delineated coastal flood zones.

13.6 Mapping and Output Products

The type and frequency of recurrence of flood elevations for which coastal flood hazard mapping should be developed include:

- Flood hazard maps indicating coastal floodplains associated with coastal flooding from storm surge, tides and sea level rise, as appropriate, for the following scenarios:
  - the 1:20 and 1:100 AEP for current climate conditions
  - the 1:20 and 1:100 AEP for climate change conditions

- Flood hazard maps indicating the inland extent of wave uprush (wave setup and runup) beyond the coastal floodplain associated with the following scenarios:
  - the 1:20 and 1:100 AEP for current climate conditions
  - the 1:20 and 1:100 AEP for climate change conditions

Coastal storm surge flood maps for the above indicated scenarios should show the maximum flood extent and the depth of flooding. Coastal flood maps will be developed as a separate collection from the riverine flood mapping. Coastal floodplains and wave uprush areas must be indicated by a polygon on mapping.

Future development scenario flood mapping for coastal wave flooding is not required. Flood inundation depth, velocity and flood depth-velocity risk maps associated with the 1:20 and 1:100 AEP for climate change and current development conditions for coastal floodplains (tides + storm surge + sea level rise, as appropriate) shall be provided.

The consultant must determine the combined water elevation along each transect and interpolate water elevations between transects to delineate the coastal flood hazard area. The consultant should mark the location of the total combined water elevation and the storm surge (surge + tide + sea level rise) on the transect for both 1:20 and 1:100 flood levels. The flood contours should represent inundation extents at the transects and should be representative of areas of potential coastal flood hazard. The starting and end point for each transect should be clearly indicated on the maps. Good judgment and an understanding of typical flooding patterns are needed by the consultant to locate the area of transition (an area not exactly represented by either transect) on the map. The consultant should then delineate the floodplain boundaries for each transect up to this transition area. The consultant should examine how a transition can be made across this area to connect matching contours and still have the boundaries follow logical physical features. Sometimes the flood contours for the two contiguous transects are not the same; in such cases, the consultant may have to taper or feather the contours at their boundaries to an end or enlarge the zones and subdivide them in the transition area. The transitions between each transect contour should be smoothed, and not left staggered. A caveat can be added to the report that there may be some inaccuracies in the delineated coastal flood areas at the reach boundaries when applying a 1D transect to represent a coastal flood zone.

The context of each hazard scenario must be indicated on coastal flood map products, including sea-level rise assumptions. Otherwise, coastal flood hazard mapping should follow the requirements of Section 9.

13.6.1 Data Outputs

Other data output products to be provided by the consultant for coastal flood mapping studies shall include:

- Copies of the coastal modelling files
- Long-term hindcasts
- Peak and time series of water depths
- Peak and time series flow velocities
- AEP statistics at nodes of interest for water depth and flow velocities
- A quantified assessment of consequences and damages
- 2D raster maps of the maximum storm surge water level over the hindcast period for the local model domain
- 2D raster maps of extreme wave events over the hindcast period for the local model domain
- Offshore wave roses at key locations for each coastal area of interest (directional/compass plots of the frequency of occurrence of wave height and wave period classes including for the entire period of record and monthly).

14 Residual Flood Hazard Analysis and Mapping

A residual flood hazard area can be defined as the area which would be inundated by the failure of major flood protection infrastructure (e.g., berm, flood wall, dyke, sea wall, sea dyke, breakwaters). While existing flood protection infrastructure was put in place to help mitigate flood risk, there is always the chance that such infrastructure could fail. Mapping the residual flood hazard area can help identify vulnerable areas and also demonstrate the value of existing flood protection infrastructure. With climate change, the probability of occurrence of floods larger than the design flood will increase, meaning there is a higher risk of flooding in residual flood hazard areas nominally safeguarded by flood protection infrastructure.

In communities with some kind of major coastal or inland flood protection infrastructure, the consultant shall identify and map the residual flood hazard area that could be flooded in the case of such infrastructure completely failing during the 1:100 current climate and climate change design flood. The consultant shall provide a comparison table of the residual flood zone area to the regular 1:100 current climate and climate change flood zone areas.

15 Field Verification

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

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

16 Assumptions

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

17 Final Report

The consultant shall provide a finalized flood mapping study report documenting the work undertaken as outlined in the above sections, as appropriate. The final report shall contain sections for any special objectives identified in the RFP.

The finalized flood mapping study report shall be signed and stamped by a professional engineer.

Appendix A: Temporal Distributions Brief-Dimensionless Mass Curves

June 2021

Introduction

Similar to the Huff curves, dimensionless mass curves using data from locations across Newfoundland and Labrador have been developed. The locations used are grouped based on the micro-climates within the region. Using Bayesian clustering analysis, 8 types of temporal distributions were identified across the province. These were regrouped into 4 major types:

- **Advanced pattern (AP)** - more than half of the total precipitation occurs in the first half of the event duration.
- **Uniform pattern (AP-U)**- the ratio of total precipitation to the event duration is almost uniform (1:1 ratio)
- **Delayed pattern (DP)** - less than half of the total precipitation occurs in the first half of the event duration.
- **2-Peaked Delayed pattern (DP-2P)** - similar to the DP but with 2 peaks in the hyetograph.

(Full details of the development process and description of micro-climate conditions can be found in https://tspace.library.utoronto.ca/bitstream/1807/96943/1/cjce-2018-0563. pdf)

Steps

1. Identify climate zone in which study region is located and note the dominant temporal distribution assigned (Figure 1).
2. Identify rainfall amounts and duration for return period of interest.
3. The x-axis of the curves represents duration and the y-axis, depth. Both range from 0-1 with 10 quantiles for each event giving 10 time ordinates (Table 1). Interpolation was used to fit events with durations longer, or shorter, than the number of chosen time ordinates.

Table 1: Dimensionless mass curves for the 4 temporal distributions

Duration	AP	APU	DP	DP-2P
0	0	0	0	0
0.1	0.23	0.12	0.06	0.13
0.2	0.53	0.27	0.10	0.25
0.3	0.74	0.41	0.12	0.34
0.4	0.81	0.52	0.15	0.40
0.5	0.84	0.61	0.17	0.45
0.6	0.86	0.68	0.21	0.50
0.7	0.89	0.78	0.32	0.58
0.8	0.92	0.86	0.56	0.72
0.9	0.96	0.94	0.83	0.88
1	1	1	1	1

1. Convert 0-1 range into duration and depth based on the time increments required. For example, to convert 180mm rainfall for 24hr duration with 2-hour increments using the AP temporal distribution, see Table 2:

Table 2: 180mm rainfall distributed using AP temporal distribution

Increment(hr)	Dimensionless depth	Actual depth(mm)
0	0	0
2	0.18	32.4
4	0.44	79.0
6	0.65	116.5
8	0.77	138.6
10	0.82	148.2
12	0.84	151.3
14	0.85	153.8
16	0.88	158.1
18	0.91	163.8
20	0.94	168.8
22	0.96	172.2
24	1	180

Actual depth = Dimensionless depth x 180mm.

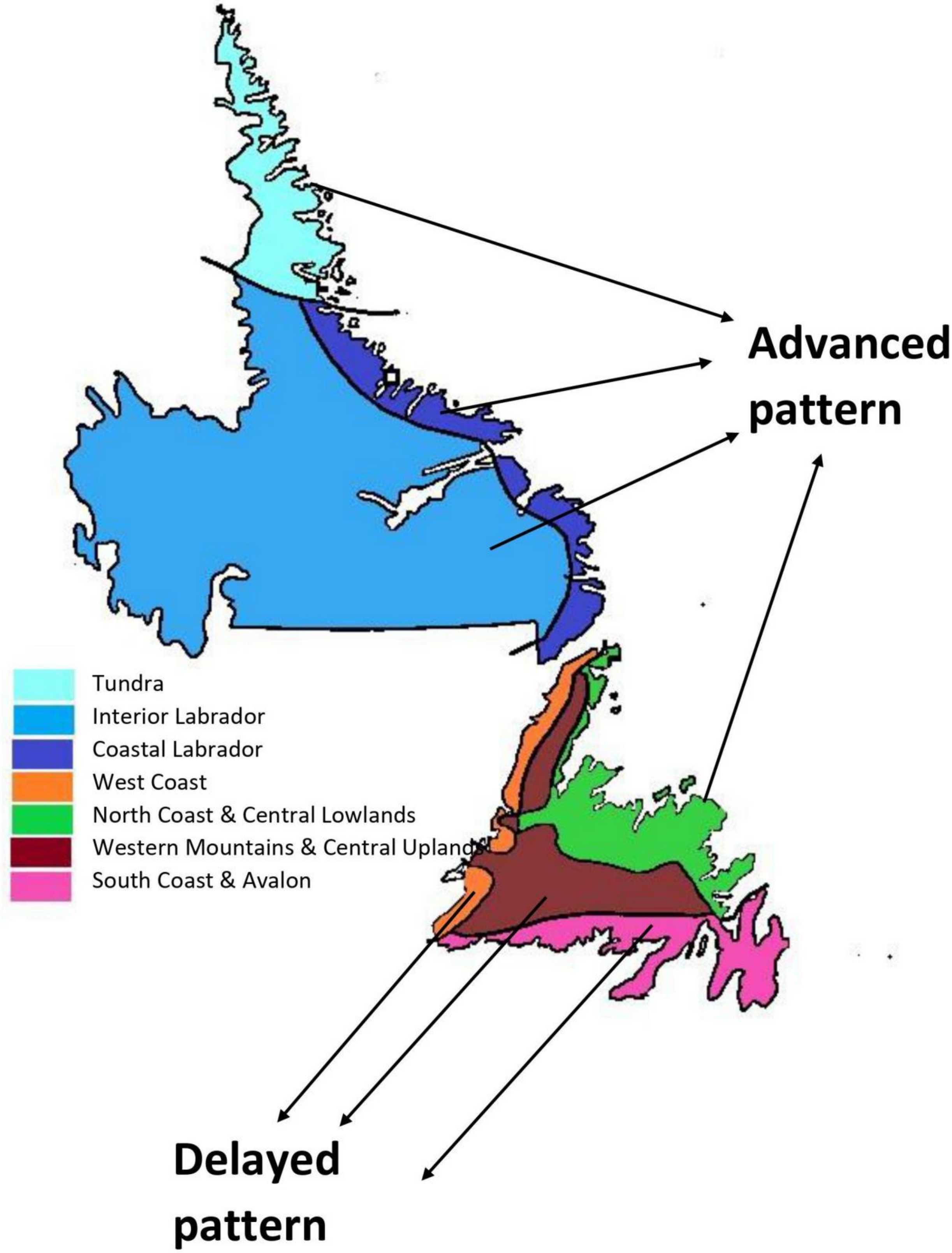


Figure 1: Map of dominant temporal distributions for Newfoundland and Labrador

Table 3: Temporal distributions for a 6-hour event

Increment(hour)	AP	DP
0	0.000	0.000
1	0.439	0.084
2	0.770	0.138
3	0.841	0.164
4	0.878	0.278
5	0.938	0.643
6	1.000	1.000

Table 4: Temporal distributions for a 12-hour event

Increment(hour)	AP	DP
0	0.000	0.000
1	0.180	0.047
2	0.439	0.084
3	0.647	0.115
4	0.770	0.138
5	0.823	0.151
6	0.841	0.164
7	0.854	0.197
8	0.878	0.278
9	0.910	0.428
10	0.938	0.643
11	0.957	0.876
12	1.000	1.000

Table 5: Temporal distributions for a 24-hour event

Increment(hour)	AP	DP
0	0.000	0.000
1	0.067	0.026
2	0.180	0.047
3	0.311	0.066
4	0.439	0.084
5	0.553	0.100
6	0.647	0.115
7	0.719	0.128
8	0.770	0.138
9	0.803	0.145
10	0.823	0.151
11	0.834	0.156
12	0.841	0.164
13	0.847	0.176
14	0.854	0.197
15	0.865	0.230
16	0.878	0.278
17	0.894	0.344
18	0.910	0.428
19	0.925	0.529
20	0.938	0.643
21	0.948	0.763
22	0.957	0.876
23	0.971	0.963
24	1.000	1.000

Appendix B: Detailed List of Flood Hazard Mapping Study Deliverables

Section	Deliverable	Sub-deliverable	Sub-deliverable 2	Sub-deliverable 3	Requirements
Information Review	Updated flood event inventory and source documents				Excel, PDF- part of final report
Information Review	Operating rules and curves for regulated rivers with dams/reservoirs				Table, graph
Field Program	Field survey plan				PDF
Field Program	Field program report and data (as part of final report or as separate field program report)				PDF-part of final report, Excel-monitoring site data
Field Program	Hydraulic structure infrastructure survey data- bridges, culverts, dams				Survey datasheets- type, dimensions, length, u/s and d/s invert elevation, low chord elevation, top of road height, coordinates, condition, photos (Provincial MTM Zone 1-6 NAD83 CSRS projections; CGVD2013 vertical datum)
Field Program	Riverine flood protection infrastructure survey data- berms, etc.				Survey datasheets- type, dimensions, length, height, material, coordinates, photos, condition (Provincial MTM Zone 1-6 NAD83 CSRS projections; CGVD2013 vertical datum)
Field Program	Coastal flood protection infrastructure survey data- breakwater, sea wall, sea dyke, etc.				Survey datasheets- type, dimensions, length, height, crest elevation, material, coordinates, photos (Provincial MTM Zone 1-6 NAD83 CSRS projections; CGVD2013 vertical datum)

Remote Sensing	LiDAR survey verification report (as part of final report or field program report)	PDF
Remote Sensing	Remote sensing report (as part of final report or field program report)	PDF
Remote Sensing	Bare earth DEM in GIS raster format	ArcGIS, AutoCAD, CGVD2013, NAD83
Remote Sensing	0.25 -1 meter contour GIS shapefile	ArcGIS
Remote Sensing	Raw data for LiDAR cloud point data (if outside the HRDEM program with NRCan)	LAS
Remote Sensing	Satellite imagery- GIS Raster format	GeoTIFF, date of imagery
Remote Sensing	Imagery- Aerial photography index GIS shapefile	ArcGIS, date of imagery
Remote Sensing	Main watershed and subwatersheds layers	ArcGIS
Remote Sensing	River network layer	ArcGIS
Remote Sensing	Land use/Landcover	ArcGIS
Remote Sensing	Soil types for the watershed, in tabular format and graphed, as well as GIS. Soil types are to be mapped and provided in final report/appendices	ArcGIS, Table, Graph, Map
Remote Sensing	Subbasin SCS curve numbers, in tabular format and graphed, as well as GIS. Subbasin CN numbers are to be mapped and provided in final report/appendices	ArcGIS, Table, Graph, Map
Remote Sensing	Land surface roughness	ArcGIS
Hydrologic Investigations and Modelling	HEC-HMS model(s), input/output files for all required scenarios	HEC files
Hydrologic Investigations and Modelling	Updated RFFA analysis and equations (if existing tools are based on stale data)	Tables
Hydrologic Investigations and Modelling	Updated IDF curves	Tables
Hydrologic Investigations and Modelling	Summary of HEC-HMS technical methods used	Table

Hydrologic Investigations and Modelling	Hyetographs of events				Tables, graphs
Other Models	Input/output files (PCSWMM, etc.)				Model files
Hydraulic Investigations and Modelling	HEC-RAS Model, input/output files (unsteady state model developed during calibration and simulation, and steady state model developed for all required scenarios)	Steady State	Unsteady State		HEC files- Background image of study area, photos of hydraulic structures, mixed flow simulation, model for each river/stream network, steady-state and unsteady-state model versions
Hydraulic Investigations and Modelling	Summary of HEC-RAS technical methods used				Table
Hydraulic Investigations and Modelling	Hydraulic structure capacity evaluation- CC-CD	1:20	1:100		Tables
Hydraulic Investigations and Modelling	Hydraulic structure capacity evaluation- CLC-CD	1:20	1:100		Tables
Hydraulic Investigations and Modelling	Hydraulic model cross-section elevation profiles from the 1D flow analysis				Profile graphs
Hydraulic Investigations and Modelling	Hydraulic model cross-section elevation profiles from the 2D flow analysis				Profile graphs
Hydraulic Investigations and Modelling	Water level, crest height and if riverine flood protection structures will be overtopped for CC and CLC	1:20	1:100	1:200	Tables. The table should include name, id, coordinates, type of infrastructure, dimensions, crest elevation, material, material size, condition, and photos.
Hydraulic Investigations and Modelling	Water level, road height and if hydraulic structure is overtopped for CC and CLC	1:20	1:100		Tables. The table should include the name of the structure, waterbody, id, type, latitude, longitude, road elevation, whether overtopped or not, and

					water levels for the scenarios.
Hydraulic Investigations and Modelling	Water level and streamflow through each cross-section of the river reach, and hydraulic structures- CC-CD	1:20	1:100	1:200	Tables, Coastal boundary conditions- tides+surge
Hydraulic Investigations and Modelling	Water level and streamflow through each cross-section of the river reach, and hydraulic structures- CLC-CD	1:20	1:100		Tables, Coastal Boundary conditions- tides+surge+sea level rise
Hydraulic Investigations and Modelling	Lakes and ponds- water height and elevation from storm surge, wave setup and runup for points of interest along lake/pond shorelines where infrastructure and property may be affected CC-CD	1:20	1:100		Tables, ArcGIS
Ice Jam Modelling and Mapping	Ice Jam model, input/output files				Model files
Ice Jam Modelling and Mapping	Water level and streamflow through each cross-section of the river- CC-CD, CC-FD, CLC-CD, CLC-FD	1:20	1:100		Tables
Ice Jam Modelling and Mapping	Ice Jam Flood Mapping (1:2500 scale)- CC-CD, CC-FD, CLC-CD, CLC-FD	1:20	1:100		PDF and Printed- orthophotography background, 1 meter contours, river centerline identified, hydrometric stations and tidal gauges identified, cross-sections with water levels (1D), points with water levels (2D)
Ice Jam Modelling and Mapping	Ice Jam GIS Flood Mapping Files- CC-CD, CC-FD, CLC-CD, CLC-FD	1:20	1:100		ArcGIS, AutoCAD

Hydrodynamic Storm Surge and Wave Investigations and Modelling	Offshore wave roses at key locations for each coastal area of interest (directional/compass plots of the frequency of occurrence of wave height and wave period classes including for the entire period of record and monthly)			Graphs
Hydrodynamic Storm Surge and Wave Investigations and Modelling	Coastal storm surge model, input/output filles			Model files
Hydrodynamic Storm Surge and Wave Investigations and Modelling	Coastal wave model, input/output files			Model files
Hydrodynamic Storm Surge and Wave Investigations and Modelling	Hydrodynamic model elevation profiles of coastal transects			Profile graphs
Hydrodynamic Storm Surge and Wave Investigations and Modelling	Coastal hindcast data, peak and time series of water depths and water velocities			Tables, Excel
Hydrodynamic Storm Surge and Wave Investigations and Modelling	AEP statistics at nodes of interest for extreme wave and storm surge water depth and flow velocities from local community model domains			Tables
Hydrodynamic Storm Surge and Wave Investigations and Modelling	Water level and velocity through each coastal transect- CC-CD (tide+surge)	1:20	1:100	Tables
Hydrodynamic Storm Surge and Wave Investigations and Modelling	Water level and velocity through each coastal transect- CC-CLC (tide+surge+sea level rise)	1:20	1:100	Tables
Hydrodynamic Storm Surge and Wave Investigations and Modelling	Water level through each coastal transect- CC-CD (waves)	1:20	1:100	Tables
Hydrodynamic Storm Surge and Wave Investigations and Modelling	Water level through each coastal transect- CC-CLC (waves)	1:20	1:100	Tables

Hydrodynamic Storm Surge and Wave Investigations and Modelling	Water level, crest height and if coastal flood protection structures will be overtopped for CC and CLC	1:20	1:100	1:200	Tables. The table should include name, id, coordinates, type of infrastructure, dimensions, crest elevation, material, material size, condition, and photos.
Sensitivity Analysis	Effects of sensitivity analysis at each cross-section				Tables
Flood Hazard Mapping: 1:2500	Current Climate and Current Development Condition (CC-CD) Flood Zone (FZ) a. For inland communities: riverine b. For coastal communities: riverine + tides + storm surge	1:20	1:100		PDF and Printed-orthophotography background, 1 meter contours, river centerline identified, hydrometric stations and tidal gauges identified, cross-sections with water levels (1D), points with water levels (2D)
Flood Hazard Mapping: 1:2500	Current Climate and Fully Developed Condition (CC-FD) FZ a. For inland communities: riverine b. For coastal communities: riverine + tides + storm surge	1:20	1:100		PDF and Printed-orthophotography background, 1 meter contours, river centerline identified, hydrometric stations and tidal gauges identified, cross-sections with water levels (1D), points with water levels (2D)
Flood Hazard Mapping: 1:2500	Climate Change and Current Development Condition (CLC-CD) FZ a. For inland communities: riverine b. For coastal communities: riverine + tides + sea level rise + storm surge	1:20	1:100		PDF and Printed-orthophotography background, 1 meter contours, river centerline identified, hydrometric stations and tidal gauges identified, cross-sections

				with water levels (1D), points with water levels (2D), CLC scenario and projected timeframe
Flood Hazard Mapping: 1:2500	Climate Change and Fully Developed Condition (CLC-FD) FZ a. For inland communities: riverine b. For coastal communities: riverine + tides + sea level rise + storm surge	1:20	1:100	PDF and Printed-orthophotography background, 1 meter contours, river centerline identified, hydrometric stations and tidal gauges identified, cross-sections with water levels (1D), points with water levels (2D), CLC scenario and projected timeframe
Flood Hazard Mapping: 1:2500	Comparison of Current Climate and Current Development Condition (CC-CD) with historical Flood Zone (only if/where previous flood mapping is available)	1:20	1:100	PDF and Printed-orthophotography background, 1 meter contours, river centerline identified, hydrometric stations and tidal gauges identified, cross-sections with water levels (1D), points with water levels (2D)
Flood Hazard Mapping: 1:2500	Current Climate and Current Development Condition (CC-CD) Wave Flood Zones	1:20	1:100	PDF and Printed-orthophotography background, 1 meter contours, river centerline identified, hydrometric stations and tidal gauges identified, cross-sections with water levels (1D),

				points with water levels (2/3D)
Flood Hazard Mapping: 1:2500	Current Climate and Fully Developed Condition (CC-FD) Wave Flood Zones	1:20	1:100	PDF and Printed- orthophotography background, 1 meter contours, river centerline identified, hydrometric stations and tidal gauges identified, cross-sections with water levels (1D), points with water levels (2/3D)
Flood Hazard Mapping: 1:2500	Climate Change and Current Development Condition (CLC-CD) Wave Flood Zones	1:20	1:100	PDF and Printed- orthophotography background, 1 meter contours, river centerline identified, hydrometric stations and tidal gauges identified, cross-sections with water levels (1D), points with water levels (2/3D), CLC scenario and projected timeframe
Flood Hazard Mapping: 1:2500	Climate Change and Fully Developed Condition (CLC-FD) Wave Flood Zones	1:20	1:100	PDF and Printed- orthophotography background, 1 meter contours, river centerline identified, hydrometric stations and tidal gauges identified, cross-sections with water levels (1D), points with water levels

				(2/3D), CLC scenario and projected timeframe
Flood Hazard Mapping: 1:2500	Residual Flood Hazard Mapping for Current Climate Current Development (CC-CD) and Climate Change and Current Development (CLC-CD) Conditions	1:100		PDF and Printed- orthophotography background, 1 meter contours, river centerline identified, hydrometric stations and tidal gauges identified, cross-sections with water levels (1D), points with water levels (2D), CLC scenario and projected timeframe
Flood Mapping: Comparison	Comparison of Current Climate and Current Development Condition (CC-CD) with Climate Change and Current Development Condition (CLC-CD) Flood Zone	1:20	1:100	Table
Flood Mapping: Comparison	Comparison of Current Climate and Current Development Condition (CC-CD) with historical Flood Zone	1:20	1:100	Table
Flood Mapping: Comparison	Comparison of Residual Flood Area with CC-CD and CLC-CD Flood Zones	1:100		Table
Flood Risk Mapping	Current Climate and Current Development Condition (CC-CD) Inundation depth a. For inland communities: riverine b. For coastal communities: riverine + tides + storm surge	1:20	1:100	PDF- overview map
Flood Risk Mapping	Current Climate and Current Development Condition (CC-CD) Velocity a. For inland communities: riverine	1:20	1:100	PDF- overview map

	b. For coastal communities: riverine + tides + storm surge			
Flood Risk Mapping	Current Climate and Current Development Condition (CC-CD) Risk a. For inland communities: riverine b. For coastal communities: riverine + tides + storm surge	1:20	1:100	PDF- overview map
Flood Risk Mapping	Climate Change and Current Development Condition (CLC-CD) Inundation Depth a. For inland communities: riverine b. For coastal communities: riverine + tides + sea level rise + storm surge	1:20	1:100	PDF- overview map
Flood Risk Mapping	Climate Change and Current Development Condition (CLC-CD) Velocity a. For inland communities: riverine b. For coastal communities: riverine + tides + sea level rise + storm surge	1:20	1:100	PDF- overview map
Flood Risk Mapping	Climate Change and Current Development Condition (CLC-CD) Risk a. For inland communities: riverine b. For coastal communities: riverine + tides + sea level rise + storm surge	1:20	1:100	PDF- overview map
Flood Risk Mapping	Current Climate and Current Development Condition (CC-CD) Coastal Wave Risk	1:20	1:100	PDF- overview map
Flood Risk Mapping	Climate Change and Current Development Condition (CLC-CD) Coastal Wave Risk	1:20	1:100	PDF- overview map
Flood Mapping: Overview maps	Current Climate and Current Development Condition (CC-CD) Flood Zone (FZ) a. For inland communities: riverine b. For coastal communities: riverine + tides + storm surge	1:20	1:100	PDF- overview map

Flood Mapping: Overview maps	Current Climate and Fully Developed Condition (CC-FD) FZ a. For inland communities: riverine b. For coastal communities: riverine + tides + storm surge	1:20	1:100	PDF- overview map
Flood Mapping: Overview maps	Climate Change and Current Development Condition (CLC-CD) FZ a. For inland communities: riverine b. For coastal communities: riverine + tides + sea level rise + storm surge	1:20	1:100	PDF- overview map
Flood Mapping: Overview maps	Climate Change and Fully Developed Condition (CLC-FD) FZ a. For inland communities: riverine b. For coastal communities: riverine + tides + sea level rise + storm surge	1:20	1:100	PDF- overview map
Flood Mapping: Overview maps	Current Climate and Current Development Condition (CC-CD) Wave Flood Zone	1:20	1:100	PDF- overview map
Flood Mapping: Overview maps	Current Climate and Fully Development Condition (CC-FD) Wave Flood Zone	1:20	1:100	PDF- overview map
Flood Mapping: Overview maps	Climate Change and Current Development Condition (CLC-CD) Wave Flood Zone	1:20	1:100	PDF- overview map
Flood Mapping: Overview maps	Climate Change and Fully Development Condition (CLC-FD) Wave Flood Zone	1:20	1:100	PDF- overview map
Flood Hazard Mapping: GIS	Current Climate and Current Development Condition (CC-CD) Flood Zone (FZ) a. For inland and coastal communities: riverine b. For coastal communities: tides + storm surge c. For coastal communities: riverine + tides + storm surge	1:20	1:100	ArcGIS, AutoCAD
Flood Hazard Mapping: GIS	Current Climate and Fully Developed Condition (CC-FD) FZ a. For inland and coastal communities: riverine b. For coastal communities: tides + storm surge	1:20	1:100	ArcGIS, AutoCAD

	c. For coastal communities: riverine + tides + storm surge			
Flood Hazard Mapping: GIS	Climate Change and Current Development Condition (CLC-CD) Flood Zone (FZ) a. For inland and coastal communities: riverine b. For coastal communities: tides + sea level rise + storm surge c. For coastal communities: riverine + tides + sea level rise + storm surge	1:20	1:100	ArcGIS, AutoCAD
Flood Hazard Mapping: GIS	Climate Change and Fully Developed Condition (CLC-FD) Flood Zone (FZ) a. For inland and coastal communities: riverine b. For coastal communities: tides + sea level rise + storm surge c. For coastal communities: riverine + tides + sea level rise + storm surge	1:20	1:100	ArcGIS, AutoCAD
Flood Hazard Mapping: GIS	Lakes and ponds- water height and elevation at shoreline points of interest from storm surge, wave setup and runup data where infrastructure and property may be affected	1:20	1:100	ArcGIS, AutoCAD
Flood Hazard Mapping: GIS	River cross-section layer showing 1:20-year and 1:100-year flood elevations	1:20	1:100	ArcGIS, AutoCAD, cross-sections (1D), points (2D)
Flood Hazard Mapping: GIS	Hydraulic structures, riverine flood protection, coastal flood protection location layers			ArcGIS, AutoCAD
Flood Hazard Mapping: GIS	Limit of mapping layer			ArcGIS, AutoCAD
Flood Hazard Mapping: GIS	Delineation of the shoreline			ArcGIS, AutoCAD
Flood Hazard Mapping: GIS	Current Climate and Current Development Condition (CC-CD) Wave Flood Zone	1:20	1:100	ArcGIS, AutoCAD
Flood Hazard Mapping: GIS	Current Climate and Fully Developed Condition (CC-FD) Wave Flood Zone	1:20	1:100	ArcGIS, AutoCAD

Flood Hazard Mapping: GIS	Climate Change and Current Development Condition (CLC-CD) Wave Flood Zone	1:20	1:100	ArcGIS, AutoCAD
Flood Hazard Mapping: GIS	Climate Change and Fully Developed Condition (CLC-FD) Wave Flood Zone	1:20	1:100	ArcGIS, AutoCAD
Flood Hazard Mapping: GIS	Coastal transects layers showing 1:20, 1:100 flood elevations, wave heights	1:20	1:100	ArcGIS, AutoCAD, transects (1D), points (2/3D)
Flood Hazard Mapping: GIS	Primary wave effect zone layer			ArcGIS, AutoCAD
Flood Risk Mapping: GIS Rasters	Current Climate and Current Development Condition (CC-CD) Flood Inundation Depth a. For inland communities: riverine b. For coastal communities: riverine + tides + storm surge	1:20	1:100	ESRI_Grid, GeoTIFF
Flood Risk Mapping: GIS Rasters	Current Climate and Current Development Condition (CC-CD) Velocity a. For inland communities: riverine b. For coastal communities: riverine + tides + storm surge	1:20	1:100	ESRI_Grid, GeoTIFF
Flood Risk Mapping: GIS Rasters	Current Climate and Current Development Conditions (CC-CD) Flood Risk a. For inland communities: riverine b. For coastal communities: riverine + tides + storm surge	1:20	1:100	ESRI_Grid, GeoTIFF
Flood Risk Mapping: GIS Rasters	Current Climate and Current Development (CC-CD) Wave Risk	1:20	1:100	ESRI_Grid, GeoTIFF
Flood Risk Mapping: GIS Rasters	Climate Change and Current Development Condition (CLC-CD) Inundation Depth a. For inland communities: riverine b. For coastal communities: riverine + tides + sea level rise + storm surge	1:20	1:100	ESRI_Grid, GeoTIFF
Flood Risk Mapping: GIS Rasters	Climate Change and Current Development (CLC-CD) Velocity a. For inland communities: riverine b. For coastal communities: riverine + tides + sea level rise + storm surge	1:20	1:100	ESRI_Grid, GeoTIFF

Flood Risk Mapping: GIS Rasters	Climate Change and Current Development Condition (CLC-CD) Flood Risk a. For inland communities: riverine b. For coastal communities: riverine + tides + sea level rise + storm surge	1:20	1:100		ESRI_Grid, GeoTIFF
Flood Risk Mapping: GIS Rasters	Climate Change and Current Development (CLC-CD) Wave Risk	1:20	1:100		ESRI_Grid, GeoTIFF
Flood Risk Mapping: GIS Rasters	2D raster maps of maximum storm surge water level over the hindcast period for local model domains				ESRI_Grid, GeoTIFF
Flood Risk Mapping: GIS Rasters	2D raster maps of extreme wave events over the hindcast period for the local model domains				ESRI_Grid, GeoTIFF
Flood Risk Mapping: GIS Rasters	Bathymetry-coastal, lakes and ponds, rivers- 2D raster map of bathymetry integrating all sources of data				ESRI_Grid, GeoTIFF
Consequence Assessment	Estimates for the 1:20 and 1:100 CC and CLC scenarios of consequences of flooding: land area, number buildings, people affected, economic losses				Tables
Presentations	Field Program Presentation				PowerPoint
Presentations	Completion of hydrologic, hydraulic, hydrodynamic modelling presentation				PowerPoint
Presentations	Completion of flood mapping presentation				PowerPoint
Presentations	Final presentation				PowerPoint
Reporting	Monthly Reports				PDF
Reporting	Final Report- signed and stamped				Printed hardcopy, PDF, MS Word, signed and stamped by P.Eng.
Special Objectives	Recommendations for the location of new hydrometric stations				Part of final report

Special Objectives	Recent aerial photography or satellite imagery for base mapping that reflects current conditions (on a site-by-site basis)	GeoTIFF
Special Objectives	CC 1:20 and 1:100 precipitation (mm) for 12- and 24-hour periods for each study area for use in the Hurricane Season Flood Alert system (HSFAS)	Tables
Special Objectives	Evaluation on how coastal flood defenses should be treated in coastal flood modelling and mapping	Part of final report
Special Objectives	Evaluation of an enhanced scenario for future sea level rise- Antarctic, AMOC collapse	Tables, PDF and printed maps

CC- Current Climate

CLC- Climate Change

CD- Current Development

FD- Fully Developed

FZ- Flood Zone

WL- Water level