Federal Flood Mapping
Guidelines Series

Federal Geomatics Guidelines for Flood Mapping

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NOTICE

Disclaimer of Liability

Additional Information

For more information about this document, please contact the Canada Centre for Mapping and Earth Observation of Natural Resources Canada: NRCan.Geoinfo.RNCan@Canada.ca.

CONTEXT

A community achieves an elevated level of resilience when its risks are proactively managed, it is adequately prepared for known and potential disaster events and it demonstrates an ability to recover after such events have taken place. In order to become resilient, a community's mitigation planners must first understand risks and ensure their capacity to manage those risks.

Floods are commonly occurring natural hazards in Canada and account for the largest portion of disaster recovery costs on an annual basis. Mitigating flood risks is therefore key to increasing the resilience of affected communities. By proactively investing in flood mitigation activities, a community secures its future growth and prosperity, reducing the risk of significant disaster recovery costs, productivity losses, economic losses, destruction of non-monetary cultural assets, environmental damage, injuries and deaths.

Flooding is the temporary inundation by water of normally dry land, and it can occur in coastal and lake areas, along rivers, from stream blockages including ice jams, from failure of engineering works including dams, from extreme rainfall, rapid snow/ice melt or poor drainage characteristics, and other sources. Flood mapping that accurately delineates flood hazards, including those impacted by future conditions due to anticipated development or projected changes in climate, serves as the precondition for such mitigation activities and is therefore the first step to increasing community resilience with regard to flooding. Establishing a national approach to flood mapping will facilitate a common national best practice and increase the sharing and use of flood hazard information, thereby improving the foundation from which further mitigation efforts can be initiated.

FLOOD MAPPING FRAMEWORK

The Flood Mapping Framework consists of all the components of the flood mitigation process, from flood hazard identification to the implementation of flood mitigation efforts. Figure 1 illustrates the relationship between these different components and links each of them to the relevant *Federal Flood Mapping Guidelines Series* document.

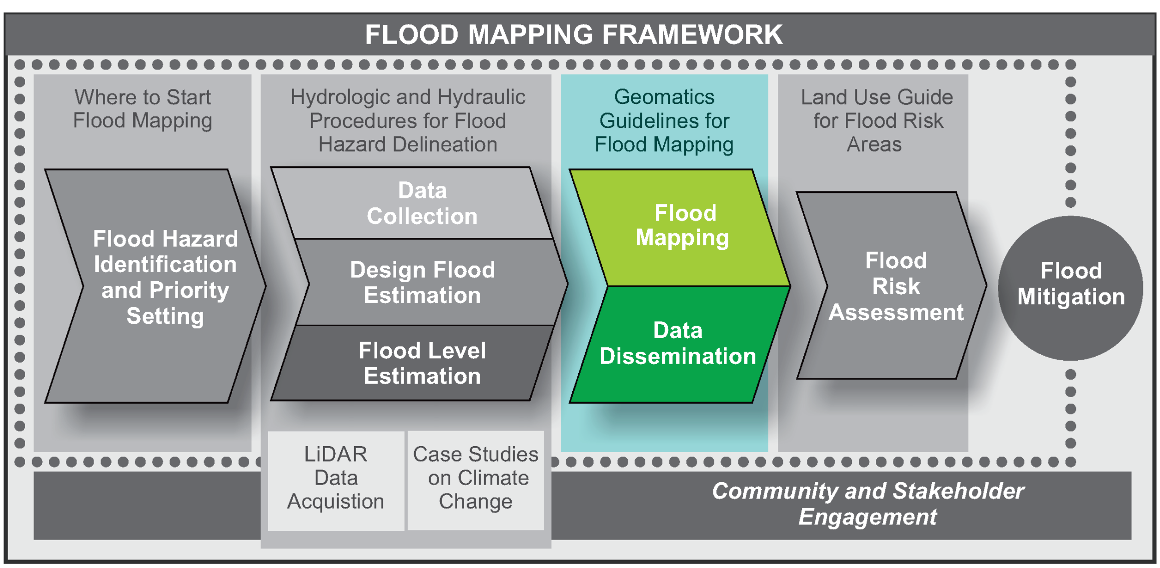

Figure 1: Flood Mapping Framework

FEDERAL FLOOD MAPPING GUIDELINES SERIES

The following documents are intended to inform any individual or organization involved with flood management in Canada:

1. Federal Flood Mapping Framework
2. Flood Hazard Identification and Priority Setting
3. Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation
4. Federal Airborne LiDAR Data Acquisition Guideline
5. Case Studies on Climate Change in Floodplain Mapping
6. **Federal Geomatics Guidelines for Flood Mapping**
7. Flood Risk Assessment
8. Federal Land Use Guide for Flood Risk Areas
9. Bibliography of Best Practices and References for Flood Mitigation

GUIDELINE SUMARIES

1. Federal Flood Mapping Framework

This document provides background and context on flood mapping in Canada, describes a vision and principles for flood guidance, and introduces the *Federal Flood Mapping Guidelines Series*. It provides a summary of each of the documents in the Series and explains how each document fits into the overall framework, including its place in the flood mapping cycle.

2. Flood Hazard Identification and Priority Setting

This document outlines methods for determining where to conduct flood mapping and how to prioritize flood mapping projects.

3. Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation

This document provides technical guidance on hydraulic and hydrologic procedures for preparing flood hazard maps in a Canadian jurisdiction, including standard of care, different types of flooding, guidelines for hydraulic and hydrologic analyses, and incorporation of non-stationary processes including climate change.

4. Federal Airborne LiDAR Data Acquisition Guideline

This document is a resource for the acquisition of base elevation data from airborne LiDAR data undertaken across Canada. This guideline provides technical specifications to federal, provincial and territorial departments, as well as individuals and organizations in Canada requiring information to understand and plan for airborne LiDAR data acquisition.

5. Case Studies on Climate Change in Floodplain Mapping

This collection of documents describes projects from across Canada where climate change was incorporated into the floodplain mapping process. It provides examples for practitioners to draw upon and learn from others' experiences and complements the climate change-related information and resources included in the "Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation" document.

6. Federal Geomatics Guidelines for Flood Mapping

This document covers the Flood Mapping and Dissemination components of the Flood Mapping Framework. It contains information on the different types of flood maps and outlines technical specifications to consider when acquiring, managing and disseminating these maps and their associated geospatial data.

7. Federal Flood Risk Assessment

This document provides technical guidance on conducting flood risk assessments in Canada.

8. Risk-based Land-use Guide: Safe use of land based on hazard risk assessment

This document provides guidance to communities in using risk-based methodologies for the purpose of land-use planning.

9. Bibliography of Best Practices and References for Flood Mitigation

This document contains lists of Canadian and international references and case studies pertaining to hydrology and hydraulics, climate change, risk assessment and flood mapping. The purpose of this document is to provide a consolidated list of reference materials intended as further resources for practitioners involved in flood mapping.

LIST OF ABBREVIATIONS AND ACRONYMS

AEP: Annual Exceedance Probability

CSRS: Canadian Spatial Reference System

CGDI: Canadian Geospatial Data Infrastructure

CGG2013: Canadian Geoid 2013

CGVD: Canadian Geodetic Vertical Datum

DEM: Digital Elevation Model

DFAA: Disaster Financial Assistance Arrangement

DTM: Digital Terrain Model

ECCC: Environment and Climate Change Canada

EMFC: Emergency Management Framework for Canada

FDRP: Flood Disaster Reduction Program (1975 – 1997)

GIS: Geographic Information Systems

HNAP: Harmonized North American Profile

LAS: LiDAR Data Exchange File

LAZ: Compressed Data Exchange File

MTM: Modified Transverse Mercator

NAD83: North American Datum of 1983

NDMP: National Disaster Mitigation Program

NRCan: Natural Resources Canada

OGC: Open Geospatial Consortium

PMF: Probable Maximum Flood

PS: Public Safety Canada

SAR: Synthetic Aperture Radar

TIN: Triangular irregular networks

UAV: Unmanned Aerial Vehicle

UTM: Universal Transverse Mercator

WMS: Web Map Service

1.0 PURPOSE

This document is part of the *Federal Flood Mapping Guidelines Series*, developed to support individuals and organizations involved in flood mapping activities. These guidelines aim to provide advice to support the management of flood risks and their consequences to communities. They are intended as a basis for further specification as defined by provinces and territories, whose technical standards, policies and regulations take precedence over the suggestions contained herein.

The document serves as a resource for geomatics professionals and flood mapping practitioners, as well as municipal planners involved in flood protection and mitigation activities. Region-specific requirements may be developed by including more detailed procedures at the territorial or provincial level. This document contains the requirements for various types of flood maps as well as guidelines for the associated digital geospatial data. Water depth levels - determined from hydro technical process described within the *"Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation"* document, are applied as input to the flood mapping process, it is recommended that both documents be consulted jointly.

2.0 NOTE ON TERMINOLOGY

All *Federal Flood Mapping Guidelines Series* documents will apply the following definitions, derived from both the Emergency Management Framework for Canada (EMFC 2017)[1] and National Disaster Mitigation Program (NDMP 2018) literature[2]:

Flooding: The temporary inundation by water of normally dry land.

Flood Mapping: The delineation of flood extents and elevations on a base map. This typically consists of delineations on a map indicating the area that will be covered by water, or the elevation that water would reach during a specified flood event. Additional details may be displayed on the map, including: flow velocities, depth, other risk parameters, and vulnerabilities.

Hazard: A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.

Risk: The combination of the likelihood and the consequence of a specified hazard being realized; refers to the vulnerability, proximity or exposure to hazards, which affects the probability of adverse impact.

[1] https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/2017-mrgnc-mngmnt-frmwrk/index-en.aspx
[2] https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/index-en.aspx

It is recognized that provinces and territories may define these terms differently, and these definitions are not intended to be prescriptive outside the context of the *Federal Flood Mapping Guidelines Series* documents.

It is important to note that during the Flood Damage Reduction Program (FDRP), areas subject to designation were referred to as 'flood risk zones'. According to the terminology provided above, they would now be referred to as 'flood hazard zones'.

This guideline contains numerous references to industry specific terms that may vary in other application areas or differ from other guidelines or specifications. For example, in the LiDAR community, bare earth DEM is commonly used to represent ground surface terrain. In this guideline, DTM is used in alignment with the High Resolution Digital Elevation Model (HRDEM) – CanElevation Series - Product Specification Edition 1. DTM is considered equivalent to bare earth DEM.

3.0 BACKGROUND

Flood maps serve as important decision-making tools in disaster mitigation planning, emergency management, land use planning, and general public awareness. These maps typically provide detailed information at large scales (1:1,000 to 1:25,000) about areas at risk of flooding. The displayed information may contain additional details such as topography, land cover and infrastructure.

Flood hazard maps produced under the FDRP, which was administered from 1975 to 1997, serve to identify flood hazard areas that became designated under federal-provincial agreements. Designated flood hazard areas were subject to specified provincial/territorial flood mitigation measures and policies, all of which were aimed at informing decisions pertaining to developments in flood prone areas.

The *Federal Flood Mapping Guidelines Series* aims to improve Canada's ability to effectively mitigate, prepare for, respond to, and recover from, flood-related events by building a body of knowledge on flood management in Canada. Such up-to-date and accessible knowledge and flood mapping will help governments, communities and individuals to understand flood hazards and employ effective mitigation strategies to reduce the impacts of flooding.

Since the end of the FDRP, significant advancements have been made in hydraulic modelling, the ability to process large amounts of data, and accuracy of remote sensing data such as high resolution aerial imagery and airborne Light and Detection and Ranging (LiDAR) surveys. Therefore, the practice of flood mapping has evolved to incorporate these advancements and to produce maps with higher resolution and accuracy.

4.0 GENERAL CONCEPTS AND DEFINITIONS

The following chart displays the general steps in preparing flood maps for many studies:

Background Information and Data Collection: Collection of all available and relevant data including but not limited to past studies, topographic maps, infrastructure data, land cover, land use information, and topographic and river survey data. This task may include aerial imagery collection and LiDAR surveys.

Hydrology Assessment: Estimation of flood discharges for a study area including large tributaries. This may include peak instantaneous flow estimates for various return periods or design flood hydrographs for various return periods in cases where unsteady flow simulations are considered necessary.

River Survey: Collection of river survey data including the channel bed, channel banks, hydraulic structures (i.e. bridges, culverts, weirs and dams), and flood control structures (i.e. flood walls, berms and dikes) to support hydraulic modelling. This may include a topographic survey of the floodplain areas where high resolution digital elevation models are not available or unsuitable.

Hydraulic Modelling: Development of a suitable hydraulic model to estimate the flood peak water levels along a study reach for various return periods. The design flood peak water levels may occur under open water conditions or due to ice jam flooding.

Inundation Mapping: Preparation of maps that show the floodwater extent of real flood events, or that show potential floodwater coverage for flood events of different magnitudes. They aid in the management of emergency preparedness plans for communities situated within floodplains and flood prone areas.

Flood Hazard Mapping: Delineation of a flood at a given location, based on the flood's anticipated magnitude (e.g. its depth, horizontal extent, and flow velocity) and its annual exceedance probability. It shows the extent of the regulatory flood hazard, often including two zones: floodway and flood fringe areas. This type of map is used for regulatory planning purposes.

Digital File Compilation: Compilation of a complete, detailed and well-organized archive that contains all relevant digital files generated during the flood mapping process.

Additional steps may include, a channel stability assessment, stakeholder engagement, flood risk assessment and mapping that accounts for the economic value of land use and the statistical cost of flood damages (see Federal Flood Risk Assessment Guideline), and other forms of map products such as floodway criteria maps or flood awareness maps.

5.0 GEOSPATIAL DATA REQUIREMENTS FOR FLOOD MODELLING

Data collection requirements

Applying an appropriate spatial reference system and ensuring data accuracy are critical to the integrity of any project involving geospatial data integration, including flood mapping.

Flood mapping projects should use the most current datum and geoid model defined by Natural Resources Canada for data acquisition, or the datum and geoid model applied by the relevant provincial or territorial authority.

Projection and datum requirements for geospatial data collection are summarized in Table 1.

Requirements	Value
Horizontal Datum	NAD83 CSRS epoch 2010 *
Vertical Datum	CGVD2013
Geoid Model	CGG2013
Map Projection	Universal Transverse Mercator **

Table 1. Projection and datum requirements summary

* or the Epoch recommended by the relevant provincial or territorial authority. (https://www.nrcan.gc.ca/earth-sciences/geomatics/geodetic-reference-systems/17908))

** or any standard regional projection recommended by the relevant provincial or territorial authority

5.1 Digital Terrain Models

For the purpose of this guideline a Digital Terrain Model (DTM) is defined as a digital three-dimensional (3D) representation of the terrain's surface free of above-ground features, such as vegetation and built-up structures (e.g., buildings and bridges).

DTMs are a key input to hydrologic models and flood mapping. DTMs should be accurate, precise, current and of an appropriate scale to fulfill the modelling and mapping requirements.

5.1.1 DTM Data Sources

High resolution DTMs used for flood mapping are typically generated from any of the following types of data:

- Light Detection and Ranging (LiDAR) data,
- Stereo images (if above ground features are removed),
- Interpolated ground survey data, or
- Combination of these data sources.

DTMs from LiDAR Data

Airborne LiDAR data is created using a laser scanning system that measures the distance between the sensor and objects in its path which reflect light pulses back to the sensor. The resulting three-dimensional point cloud is processed to classify ground, vegetation, buildings and other objects. By filtering out the non-ground points, the elevation of the ground surface can be interpolated into a raster (image) format with a consistent ground sample distance.

Bare earth (i.e. ground surface) LiDAR is preferred over other elevation sources because it provides a high level of accuracy and detail. It is worth noting that the point density of a bare earth surface is not constant and may be much lower in densely vegetated areas, as well as areas where points have been removed, such as under bridge decks and inside building footprints. Please refer to the *Federal Airborne LiDAR Data Acquisition Guideline* document for more information.

DTMs from Stereo Images

DTMs can be extracted from stereo images using photogrammetric pixel autocorrelation techniques. Image stereopairs employed to produce DTMs are typically acquired by satellite (optical and radar), aircraft, or unmanned aerial vehicles (UAV). The quality of DTMs extracted from stereo imagery may be adversely affected by poor pixel autocorrelation (i.e. failed pixel matching in visually homogenous areas) and uncertainty introduced by approximating the ground surface elevation in vegetated and built-up areas.

When using image stereo pairs to produce DTMs, it is advisable to utilize imagery with at least three times the resolution of the resulting elevation surface. For instance, a 25 cm resolution stereopair may yield a reliable elevation surface with a resolution of approximately 1 metre after post-processing. Ground survey data should be used to assess the accuracy of the DTM prior to undertaking modelling activities, or it may be combined with an existing DTM to augment detail in the elevation surface.

DTMs from Ground Survey Data

DTMs can be interpolated from ground survey points. Due to the accuracy requirements of flood mapping, equipment such as Real Time Kinematic (RTK) differential GPS receivers or total stations are required for these surveys.

Because of the density of data required for flood mapping DTMs, ground surveys are practical only for small areas. Typically, ground survey data are applied to update larger DTMs created from LiDAR surveys or stereo imagery. Where recent changes to the terrain are limited to small areas, it is often effective to conduct ground surveys and update an existing, older DTM. Examples of such limited changes include small areas of bank erosion or newly constructed flood control structures (e.g. dikes).

Elevation data from multiple sources may be combined, but it is imperative that the different datasets are of comparable accuracy and scale, and reference the same horizontal and vertical datum.

5.1.2 DTM Types and Formats

DTMs created from the various data sources can be delivered in a variety of formats, including proprietary formats. The following commonly used formats are recommended:

- **3D Point cloud** created from LiDAR or image stereo pairs extraction: LAS, LAZ or ASCII format (.xyz, .csv, .txt)
- Elevation surface as a **georeferenced raster**: geoTIFF, .img, (see Figure 2).
- Elevation surface as a **triangulated irregular** network: ESRI TIN, ESRI Terrain, AutoCAD Surface, LandXML (see Figure 3).

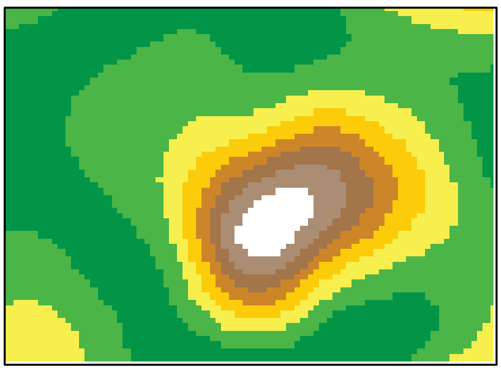

Figure 2: Raster Surface (Source ESRI)

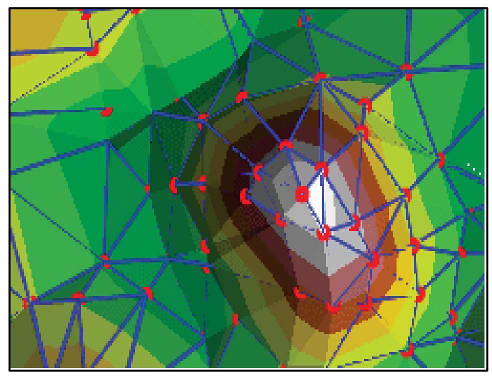

Figure 3: Triangulated Irregular Network (source ESRI)

5.1.3 Accuracy

When selecting the most appropriate elevation data, it is important to consider the X,Y,Z accuracy of each product, in addition to the scale, age and cost of the data. Similar elevation products produced by different data providers may vary in accuracy and precision, because this depends on the data collection and processing specifications.

Accuracies are often stated as absolute (e.g. ± 15 cm), relative, or as a measure of the deviation between the predicted and actual location, such as root mean square error (RMSE) values. Additionally, measure of probability has important considerations, for instance, an accuracy of “90 percent confidence level” means that 90 percent of data point locations will be situated at a distance to the actual location equal to or smaller than the reported accuracy value (e.g. ± 15 cm).

Each flood hazard mapping project must define the level of accuracy of the digital elevation data appropriate for its unique project requirements. . The accuracy of the digital elevation data should be based on data requirements related to the project’s Terms of Reference. In this guideline, a 1 metre resolution DTM is the minimum recommended requirement for a flood mapping project. Natural Resources Canada, aims to provide a 1 metre DTM across the country.

Please refer to Appendix 2 of the *Federal Airborne LiDAR Data Acquisition Guideline* document for acquisition and accuracy specifications when using LiDAR data as an input for DTM for flood mapping.

If using other types of data to create DTMs, please refer to the *ASPRS Positional Accuracy Standards for Digital Geospatial Data* guide for accuracy requirement.

5.1.4 Recommendations

The following are general recommendations for using DTMs for flood mapping:

- Quality checks should be performed on DTMs created from remote sensing data (LiDAR and stereo images) to confirm elevation accuracy. Checkpoints must be different from control points and evenly distributed across the check area.
- Raster DTMs should have a minimum horizontal resolution of 1 m.
- The accuracy of the digital elevation data should be based on data needs related to the project Terms of Reference.
- DTMs should include all relevant breaks in topography and especially the top of flood control structures such as dikes, berms and flood walls. If the resolution of a raster DTM is not sufficient to include these details, manual adjustments to individual cells along the top of the structures are recommended.

Best Practice Examples

Example 1: Raster DTM

A raster DTM with a horizontal resolution of 1 m was created from a LiDAR survey with at least 4 points per square metre. The vertical accuracy was confirmed by a ground survey with survey points on flat surfaces at least every kilometre along the river reach of interest. Additional small features such as flood walls were manually integrated. The DTM was delivered as a GeoTIFF in the appropriate local coordinate system with one band, 32 bit floating point accuracy and in a lossless compression such as LZW.

Example 2: ESRI Terrain

An ESRI Terrain was created from a bare earth LiDAR LAS point cloud. The point density (file size) was reduced while maintaining a minimal vertical accuracy of 15 cm. The DTM was delivered in the appropriate local coordinate system as a feature class in an ESRI Geodatabase.

5.2 Aerial Photography and Satellite Imagery

When performing flood mapping studies, aerial photography is useful for obtaining information about the current river system and its historical fluvial processes. Photography captured by aircraft, UAV or satellite can be obtained at varying scales and resolutions over varying timeframes, which can be selected to best meet the modelling and flood mapping criteria. Various types of imagery that support flood mapping are provided in this section.

5.2.1 Historical Aerial Photography

Aerial photography may provide a historical record of past flood events and in some regions may date back to the 1920s. Older aerial photographs shot on film should be scanned using a high resolution photogrammetric scanner whenever possible, to retain image detail and clarity when digitized. A scanning resolution of 1200 dpi or greater is recommended. Contact prints and negatives may become damaged or distorted with age, which may reduce the accuracy of derived products. This can be avoided with careful air photo selection, and assessed with an accuracy assessment once the images are georeferenced and orthorectified.

Older aerial photos are expected to have lower spatial accuracy due to the possibility of missing fiducial markings, missing or sparsely detailed camera calibration reports, a lack of accurate inflight navigation data, and challenges with finding modern, real-world control points. The latter of which may cause irregularities in flight line spacing that could be detrimental if lateral overlap (sidelap) is less than 30%.

5.2.2 Modern Imagery Sources

Modern aerial imagery is almost exclusively digital and reaps the benefit of advanced camera sensors combined with high accuracy Global Navigation Satellite System (GNSS) and Inertial Measurement Unit (IMU) systems. These camera systems have improved radiometric consistency and yield spatially accurate imagery after post-processing with the inflight GNSS/IMU data and a DTM. The spatial accuracy of orthorectified aerial photography is expected to vary according to image scale, resolution and age. Therefore, it is recommended that the horizontal accuracy should typically be within ±3 times the ground sample distance (GSD) at least 90% of the time (CE90), and up to ±5 times the GSD CE90 for older imagery.

The historical air photography used for flood mapping is typically of a 1:40,000 scale or larger, although in some cases coarser scales may be necessary to capture expansive areas. This roughly corresponds to sub-metre resolution images, which are most commonly within 15 cm to 70 cm resolution. Modern imagery flown specifically for use in flood mapping studies is usually captured at a resolution between 15 cm and 30 cm.

In addition to aerial photography, high resolution satellite imagery provides a modern archive going back to 2000, where available. These satellite images are greyscale or colour pan-sharpened images with a resolution less than or equal to one metre, with a few exceptions (e.g. RapidEye, SPOT5 and SPOT 6/7). Orthorectified satellite images are useful for many flood mapping-related activities including the identification of flood-prone watercourses in normal conditions, the extraction of cultural and natural features (e.g. building footprints, land use, roads and hydrologic features), flood extent delineation during a flood event, and as a base or drape layer to improve the visualization of flood maps (see Appendix 3).

Both aerial photos and satellite images are important tools to monitor and assess the extent of floods during an ongoing event. Some high resolution satellites can be tasked to acquire imagery on short notice and can offer frequent revisits (one to three days). This is especially useful in the case of large lake flooding, where water levels can remain high for longer periods, or in remote areas where the rapid mobilization of an aerial survey may be impossible. It should be noted that the optical sensors, whether mounted on satellites or aircraft, cannot image the earth's surface through cloud cover.

By contrast, aerial photographs are more effective at capturing on-demand images of the extents of a flood event as it is occurring, as they may be able to fly lower than the cloud ceiling. While the revisit frequency with which a satellite passes over any given place on Earth is generally too infrequent to serve as a reliable source of near real-time information, satellite imagery is still a valuable and cost effective data source, which are useful to capture flood extents and damages.

5.2.3 Imagery Formats

Aerial photography and satellite imagery are available in a variety of formats, including proprietary formats. The following formats are recommended to facilitate sharing and interoperability:

- Scanned historical aerial photographs: GeoTIFF, or ESRI Grid formats
- Digital aerial photography: GeoTIFF, or .ECW.
- Satellite imagery: GeoTIFF, .hdf, (other proprietary vendor formats not recommended)

5.2.4 Recommendations

The following are general recommendations for resolution and accuracy of digital modern imagery:

- Modern imagery (either aerial or from satellite) should have a minimal resolution of 30 cm.
- Positional accuracy of any imagery should be at least within three times the ground sample distance (e.g. +/- 90 cm for 30 cm resolution data).
- Satellite imagery should be orthorectified using a quality DTM and ground control points so that an accuracy of ±5 times the GSD CE90 or better, can be achieved. Satellite images orthorectified using low to medium resolution DTMs are typically accurate within ±10 times the GSD CE90

5.3 Thematic Geospatial Datasets

Other geospatial datasets (typically vector data) are important in floodplain mapping to represent cross sections, base data such as river centre lines, bank lines, survey points, hydraulic structures, and other relevant structures or boundaries. Socio-economic data can also be very useful when doing a flood risk map.

5.3.1 River Cross Sections

Cross sections are initially created for one-dimensional hydraulic analysis (see *Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation - Version 1.0* (NRCan, 2019)). Cross sections can also be used to create water level surfaces (see Section 6.1on flood maps).

To allow for the creation of water level surfaces, cross sections must be wide enough to cover the entire floodplain for the largest return period considered. If the cross sections used in the hydraulic analysis are too short, the features must be extended. Often a straight extension perpendicular to the estimated flow directions will be sufficient. However, practitioners will need to use judgement to prevent features from intersecting each other and to ensure that cross sections remain perpendicular to estimated flow directions on the floodplain.

The cross section dataset should contain the water levels of all flood return periods in its attribute table to allow for the efficient generation of water level surfaces. In addition, the attribute table should include the fields shown in Table 2 at a minimum. All fields should be included in the metadata records.

Name	Unit	Type	Examples	Note
Number	-	Integer, float or text, depending on numbering scheme.	"1", "1.2", "1a"	The cross section numbers should coincide with the numbers in the hydraulic analysis.
Station	Metres	Float	"5765.3"	The cross section station should reflect the station applied in the hydraulic analysis.
River	-	Text	"Clearwater River"	-
Reach	-	Text	"Elk Island to End"	To be used if the hydraulic analysis is divided into separate reaches.
WL_2-Year, WL_50-Year, WL_100-Year, etc.	Metres	Float, typically two decimals will be required.	"690.12"	Add fields for each return period considered in the floodplain mapping.

Table 2. Attribute table requirements

5.3.2 Hydraulic and Flood Protection Structures

Practitioners may decide to depict all or some of the hydraulic and flood protection structures utilized in the hydraulic analysis on the floodplain maps. Even if they are not included on the maps, it is good practice to create comprehensive datasets containing all bridges, dams, weirs, culverts and other hydraulic structures as well as flood protection structures such as dikes and flood walls used in the hydraulic analysis.

Bridges, dams, weirs, culverts and similar structures should generally be represented as point features. Linear flood protection structures, (e.g. dikes), are generally best represented as polyline features.

For hydraulic structures, the attribute table should include the fields shown in Table 3 at a minimum.

Name	Unit	Type	Examples	Note
Name	-	Text	“Elk Island Weir”	-
Station	Metres	Float	“5765.2”	The station should coincide with those used the hydraulic analysis.
River	-	Text	“Clearwater River”	-
Reach	-	Text	“Elk Island to End”	Applied if the hydraulic analysis is divided into separate reaches.

Table 3. Recommended fields for hydraulic structure datasets

Datasets representing hydraulic structures may include further information as used in the hydraulic analysis (e.g., bridge deck and low chord elevation, culvert diameter, etc.) or may make reference to the hydraulic analysis reporting in their metadata. All attribute fields should be included in the metadata records.

Flood protection structures, represented as point features, should include the fields shown in Table 4 at a minimum.

Name	Unit	Type	Examples	Note
Name	-	Text	"Elk Island Weir"	-
Station_From	Metres	Float	"5765.2"	The station should coincide with the stations used in the hydraulic analysis.
Station_To	Metres	Float	"5300.7"	The station should reflect the stations from the hydraulic analysis.
River	-	Text	"Clearwater River"	-
Reach	-	Text	"Elk Island to End"	To be used if the hydraulic analysis is divided into separate reaches.

Table 4. Recommended fields for flood protection structure datasets

Hydraulic structure datasets may include further information such as structure type, building material and average height above ground or may make reference to the hydraulic analysis reporting in their metadata. All attribute fields should be included in the metadata records.

In addition to datasets relevant to the hydraulic analysis, flood maps typically show base data features. Although the backdrop for flood maps may consist of aerial imagery, base data serves to highlight important features and allows for labelling. Base data may include land use, zoning or other relevant boundaries if required.

5.3.3 Base Data

Base data depicted on flood maps should include roads, railroads, and administrative boundaries at a minimum. These datasets can be obtained from various sources at the municipal, provincial or territorial or federal level. Where available, municipal datasets often provide the most complete and up-to-date information. When obtaining base data, the sources should be checked for completeness, accuracy (as appropriate for the scale of the flood maps) and sufficient coverage. Attribute fields should allow for labelling at a minimum.

A Canada-wide source for base data

Where no appropriate municipal or provincial or territorial datasets are available, base data can be obtained from CanVec+. CanVec+ is a digital cartographical reference product produced by Natural Resources Canada. The CanVec+ product contains more than 90 topographical entities thematically organized into 11 distribution themes: Administrative Boundaries, Buildings and Structures, Energy, Hydrography, Industrial and Commercial Areas, Places of Interest, etc. CanVec+ is scheduled to be published every two months. The CanVec+ product is free and is distributed via the GeoGratis portal in output file formats GML (Geography Markup Language), SHAPE (ESRI and File Geodatabase (ESRI), or as a Web Map Service (WMS) that can be used as a map background without the need to download data.

5.3.4 Summary

Table 5 illustrates the different datasets useful in flood mapping studies.

Depicted	Type	Source	Note
Cross Sections	Polyline	From Hydraulic Modelling	
Cross Sections clipped to the extent of the design flood	Polyline	To be created	To be created after flood inundation extent polygons have been created.
Hydraulic Structures	Point	From Hydraulic Modelling	Including bridges, dams, weirs, culverts, etc.
Bridges	Polyline	From Hydraulic Modelling	Showing the alignment of the bridges for mapping purposes.
Flood Control Structures	Polyline	From Hydraulic Modelling	Including dikes, flood walls, etc.
Roads	Polyline	Various possible sources	
Railroads	Polyline	Various possible sources	
Administrative Boundaries	Polygon	Various possible sources	
Contour Lines	Polyline	To be derived from a DTM	Optional, if contours are to be depicted on the inundation maps.

Table 5. Datasets typically used in flood mapping studies

Datasets should be named and centrally stored according to the applicable geospatial data management framework.

5.3.5 Data Formats

The described datasets can be obtained and managed in a variety of formats. Generally, the data formats should be compatible with the Canadian Geospatial Data Infrastructure operational policies. The following commonly used formats are recommended for vector data sets:

Data Formats	File Extension
GML (Geographic Markup Language	.gml
ESRI Shapefile	.shp
AutoCAD Drawing file or Drawing Interchange file	.dwg .dxf
ESRI File Geodatabase	.gdb

Table 6. Data formats

6.0 FLOOD DATA DISSEMINATION AND SHARING

6.1 Flood Maps

Types of Flood Maps

Flood mapping provides a mechanism to convey a wide range of flood hazard and flood risk information, from flood extents of observed historical events to simulated flood extents for specified return periods. Historically, hard copy flood maps have served as the primary source of flood information for land use planning and flood management. However, advances in data acquisition and geospatial and web technology have facilitated the production and dissemination of flood maps in a digital environment. In whatever form they are generated and distributed, flood maps play an important role in communicating information regarding areas subject to flooding.

Although there is a high degree of flexibility in flood mapping practices, the Federal Flood Mapping Guidelines Series identifies four main types of maps that cover a wide spectrum of mapping activities. As illustrated in Figures 4 to 7, these are:

Inundation Maps: Maps that show the floodwater extent of real flood events, or that show potential floodwater coverage (e.g. annual exceedance probabilities). They are intended to aid in the management of emergency preparedness plans for communities situated within floodplains and flood hazard zones. *(Image source: Toronto and Region Conservation Authority)*

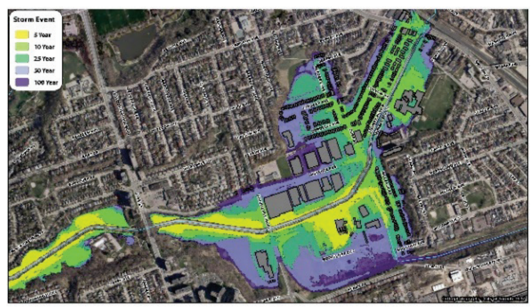

Figure 4: Example Flood Inundation Map

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 purposes related to land use planning and flood mitigation. *(Image source: Rideau Valley Conservation Authority)*

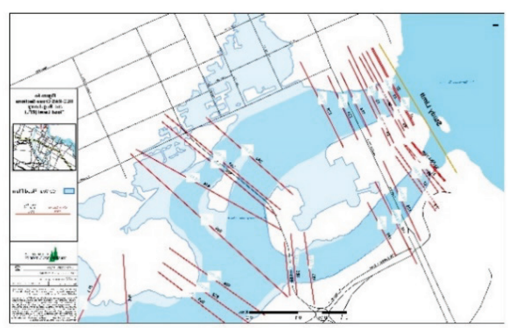

Figure 5: Example Flood Hazard Map

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. *(Image source: Toronto and Region Conservation Authority)*

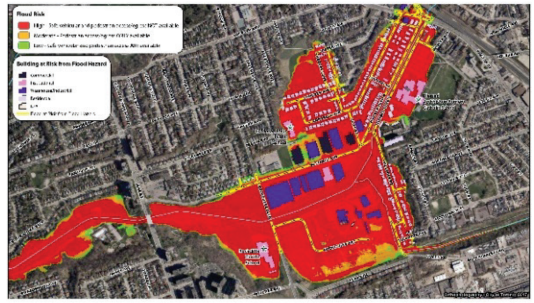

Figure 6: Example Flood Risk Map

Flood Awareness Maps: Communication maps that serve to inform members of the public regarding the history of flooding in their communities, as well as the potential for future flooding and the risks that such flooding would pose to residential properties, businesses, cultural assets, infrastructure and human life. These interactive web maps or printed poster-style maps include a range of additional content types, such as photographs, descriptive text and graphics. *(Image source: Grand River Conservation Authority)*

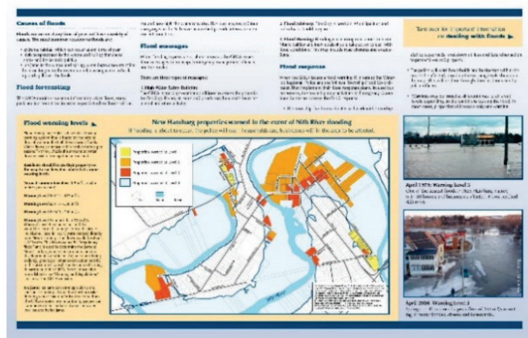

Figure 7: Example of Flood Awareness Map

The following sections provide descriptions of the purpose, production, suggested content and format, and dissemination of the different map types.

6.1.1 Flood Inundation Maps

Purpose

The purpose of flood inundation maps is to show the extent of inundated (flooded) areas for various flood event probabilities (e.g. 2-, 5-, 10-, 20-, 25-, 50-, 100-, 200-, 350-, 500- and 1,000-year flood events). These maps are typically created to inform affected communities and can be used as a tool for flood emergency management planning and response for communities and municipalities.

Map Creation

The flood inundation maps are created based on the results of hydraulic modelling (see [Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation]()) and additional judgement and analysis where appropriate. The procedures for delineating the flood inundation extents varies depending on the type of the hydraulic model (e.g., one-dimensional, two-dimensional or a connected one- and two-dimensional model) used in the study.

Mapping Based on One-Dimensional Hydraulic Models

One-dimensional hydraulic models are based on river cross sections that should span over the full floodplains on both sides of the main channel. These cross sections should be georeferenced in the appropriate study coordinate system and may include several vertices. It is recommended to add the simulated water levels for multiple flood events as attributes to each cross section polyline feature.

The following procedure describes the general steps required to calculate the inundation extent from the simulated water levels at the cross sections:

1) Interpolate a continuous water level surface TIN between the cross sections. Cross section lines may need to be extended outside of the hydraulically active flow area to cover wider floodplain areas or floodplains around outside bends between cross sections.
2) Subtract the water level surface from the DTM to obtain the water depth. In many cases the DTM will be a raster model. In these cases the water level surface TIN will be first converted into a raster water level surface with exactly the same resolution and cell alignment as the DTM raster. If the DTM is a triangulated surface the water surface TIN can be subtracted directly using a cut-and-fill method.
3) Convert the wet areas with water depth larger than 0 m into inundation polygon features.
4) Review all produced inundation extents (and water depth rasters) in detail, and edit them if necessary, including assessment of special areas as described below.

Areas requiring special attention:

Due to the limitations of one-dimensional hydraulic modelling, some “special areas” may need special attention and manual editing as follows:

1) Backwater Areas:

Single Overtopping Point: At locations where inundated areas are connected to the main channel at a single overtopping point (spill point), the inundation extent is re-evaluated using a constant water level which is equal to that at the spill point.

Multiple Overtopping Points: If there are multiple overtopping points related to a single overflow area, the inundation extent is based on the hydraulic gradient in the main channel between the overtopping points. The inundation extent upstream of the most upstream overtopping point and downstream of the most downstream overtopping point are evaluated using the estimated water level at these bounding spill points.

Single Overtopping Point Causing Overtopping Downstream: If a single overtopping point exists, the inundation extent is re-evaluated using a constant water level which is equal to that at the spill point (see above). However, if this constant water level causes another overtopping point downstream, the inundation extent is re-evaluated using a linear interpolation between the water level at the upstream spill point and the ground elevation at the downstream re-entry point.

2) **Potential Flood Inundation due to Flood Control Structure Failure:** In areas where identified flood control structures (e.g., flood berms or dikes) separate protected areas from the main channel, some jurisdictions may map these areas as flooded assuming that the flood control structure had failed. The area behind the flood control structure could be shown as inundated to the river water level calculated at the flood control structure under non-failure conditions. However, these inundation area should be marked with an identifier attribute and mapped in a different colour or hatching.

3) **Isolated Areas:** Some jurisdictions may wish to show potentially inundated areas that have no direct hydraulic or overland flow connection to the main channel, but are mapped using main channel water levels. These are typically areas of low ground, and may potentially be inundated due to groundwater seepage or storm sewer backup.

Mapping Based on Two-Dimensional Hydraulic Models

Most two-dimensional hydraulic models can be used to directly generate the inundation extent within the model application. However, the level of detail of the inundation extent depends on the model resolution if it does not use a subgrid approach where the topography is based on a high resolution DTM.

Therefore, it is recommended to carefully review the detail of the computed inundation extent. Two-dimensional hydraulic models can generally be used to correctly estimate inundation extents in most special inundation areas. However, special attention is recommended for potential flooding behind flood control structures, because these areas may need to be manually defined based on the computed water levels along the flood control structures and professional judgement.

Content and Format

The following minimum content is recommended for flood inundation maps:

- Cross sections including labels (if based on one-dimensional hydraulic model),
- Inundation extent as polygons,
- Direction of flow (arrow),
- Hydraulic structures such as bridges, weirs, or dams,
- Roads and railways, and
- High resolution background imagery.

Additional discretionary cartographic layers to be shown in flood inundation maps may include the following:

- Elevation contour lines,
- Other critical infrastructure (e.g. pump stations, pipelines, generating stations, dams),
- Flood control structures (e.g. dikes, berms, flood walls, mobile flood protection),
- Water depth,
- Flow velocity,
- Municipal boundaries, and
- Evacuation routes.

Sample cartographic symbols for the various map layers are provided in Appendix 2.

The flood inundation polygon datasets resulting from the subtraction of the water level surface from the DTM or created for special areas should be attributed with their inundation type. These inundation types are for example “directly inundated”, “flood control structure failure”, or “isolated” areas.

Inundation mapping produces one or multiple inundation extent polygon datasets. Where mapping is prepared for multiple flood events, one dataset should be created for each return period. The attribute table should include the fields shown in Table 7 at a minimum.

Name	Unit	Type	Examples
Inundation Type	-	Text	“directly inundated”, “isolated”, “flood control structure failure”
Return Period	-	Integer	5-Year, 100-Year

Table 7: Recommended Fields for Flood Inundation Polygon Datasets

Datasets should be named and centrally stored according to the applicable geospatial data management framework. In addition to digital data files, static maps should be produced in device-independent pdf format in a standard paper size such as ANSI B (11” x 17”), ANSI C (17” x 22”) or ANSI D (22” x 34”). All static maps must include standard technical drawing information such as scale, north arrow, coordinate system, references, date, author and publishing entity. See Appendix 4 for map template.

Example

Figure 8 shows an example of a flood inundation map.

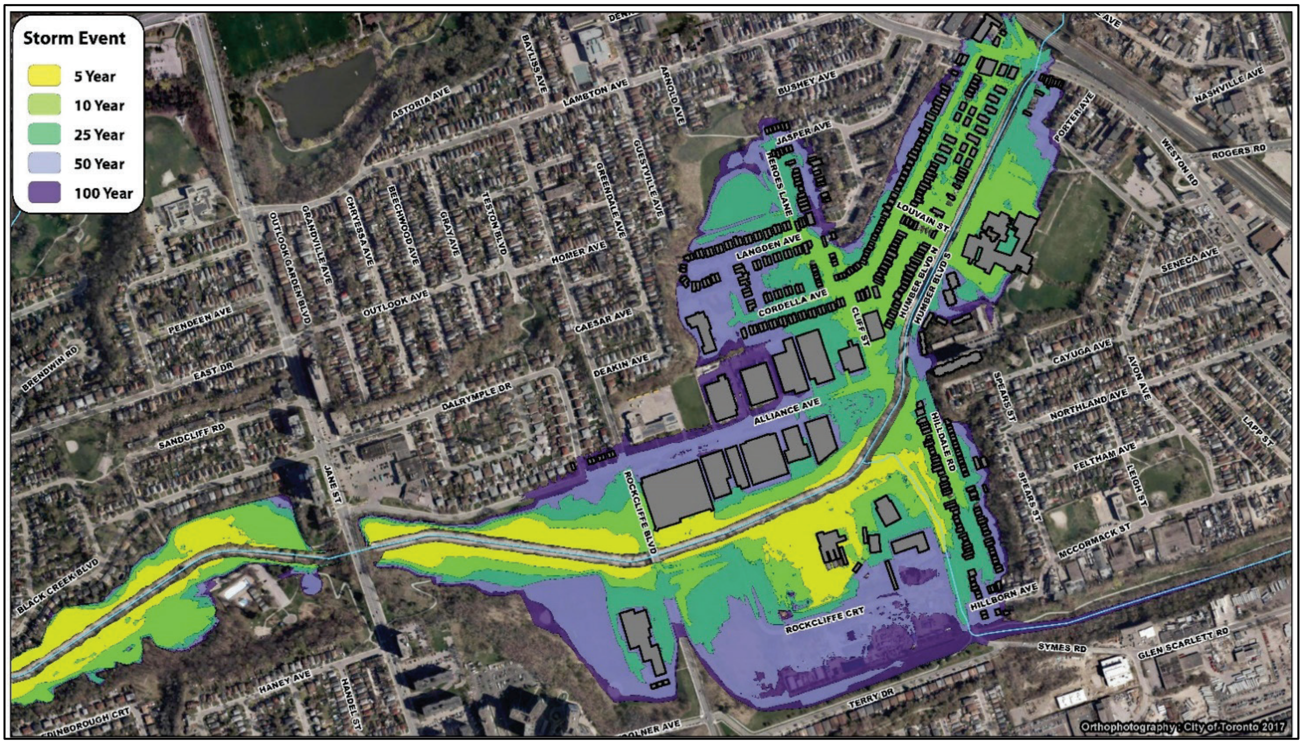

Figure 8: Flood Inundation Map

6.1.2 Flood Hazard Maps

Purpose

Flood hazard maps show the extent of the regulatory design flood (flood hazard area) as mandated by the provincial or territorial governments and the designated floodway and flood fringe areas. Flood hazard maps are available to the general public.

Map Creation

The flood hazard area is the area of land that will be flooded during the design flood event. The design flood event varies across Canada, depending on provincial and territorial requirements and legislation. The 100-year flood event is recommended as the minimum design flood event. The flood hazard area is typically divided into two zones (i.e. **floodway** and **flood fringe**) as illustrated in Figure 9 and Figure 10.

In general, the **floodway** conveys the majority of the flow and it is the area where flows are deepest, fastest and most destructive; the **flood fringe** is generally shallower and has slower velocities than in the floodway. In many jurisdictions, the technical criteria to define the floodway includes the following:

- Areas where water depths are greater than 1 m during the design flood event,
- Areas where the local flow velocity is greater than 1 m/s, and
- Areas in which, if the river were encroached upon (as identified by conducting an encroachment analysis), the water level rise would be 0.3 m or more.

It is recommended that the edge of the floodway between cross sections is delineated as a continuous, hydraulically smooth line. There should be no islands within the floodway if there is no safe emergency access or egress during a flood event.

The **flood fringe** includes all other areas within the flood hazard area that are not considered floodway, that would have relatively shallow water depth (less than 1 m) and relatively low flow velocities (less than 1 m/s). If encroachment analysis is conducted, the flood fringe could be completely blocked (encroached) without causing a water level increase of more than 0.3 m.

Instead of the above mentioned criteria, the **floodway** may also be defined as the area inundated during a lower return flood event (e.g. 20-year flood) and the **flood fringe** the additional area inundated during a higher return period flood (e.g. 100-year flood).

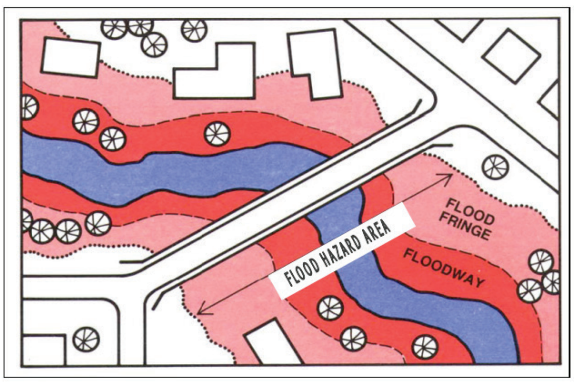

Figure 9: Plan view of a typical flood hazard area

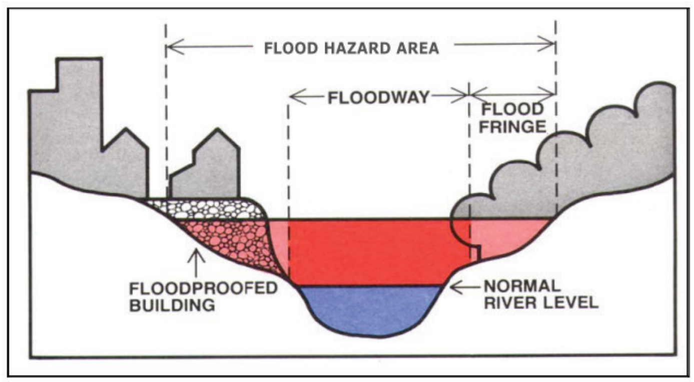

Figure 10: Cross section of a typical flood hazard area

(Image source: https://www.alberta.ca/flood-hazard-mapping.aspx)

The following procedure describes typical steps to define the flood hazard area and delineate the floodway for the design flood event:

1) Create the 1 m water depth contour line from the hydraulic model by subtracting the simulated water level surface from the DTM.

2) Determine locations along the cross sections with more than 1 m/s flow velocity (based on one-dimensional modelling) or create the 1 m/s flow velocity contour line (based on two-dimensional modelling).

3) Determine initial hydraulically smooth floodway boundary based on 1 m depth and 1 m/s flow velocity. For those jurisdictions that do not include encroachment analysis as a technical criteria, stop here.

4) For those jurisdictions that include encroachment analysis as a technical criteria, set locations of encroachment and run the hydraulic model again with these initial encroachments.

5) If necessary, adjust encroachments until the 0.3 m water level increase criterion is not violated at all cross sections.

6) Repeat steps 1 to 4 until all floodway criteria are met.

Important Note:

Floodway delineation requires careful attention as it may have direct impact on property owners in terms of insurability, development restrictions and property values.

Content and Format

The following minimum content is recommended for flood hazard maps:

- Cross sections including labels (if based on one-dimensional hydraulic model),
- Direction of flow (arrow),
- Flood hazard area divided into floodway and flood fringe for the design flood event as polygons,
- Hydraulic structures such as bridges, weirs, or dams,
- Critical infrastructure such as roads and railways, and
- High resolution background imagery.

Additional discretionary cartographic layers shown in flood hazard maps may include the following:

- Elevation contour lines,
- Other critical infrastructure (e.g. pump stations, pipelines, generating stations, dams),
- Flood control structures (e.g. dikes, berms, flood walls, mobile flood protection), and
- Evacuation routes.

The resulting flood hazard polygon dataset should be attributed with the hazard type (“floodway” or “flood fringe”) as shown in Table 8.

Name	Unit	Type	Examples
Flood Hazard Type	-	Text	“floodway” or “flood fringe”

Table 8: Recommended Fields for Flood Hazard Polygon Datasets

Datasets should be named and centrally stored according to the applicable geospatial data management framework. In addition to digital data files, static maps should be produced in device-independent pdf format in a standard paper size such as ANSI B (11” x 17”), ANSI C (17” x 22”) or ANSI D (22” x 34”). All static maps must include standard technical drawing information such as scale, north arrow, coordinate system, references, date, author and publishing entity. See Appendix 4 for map template.

Example

Figure 11 shows an example of a flood hazard map.

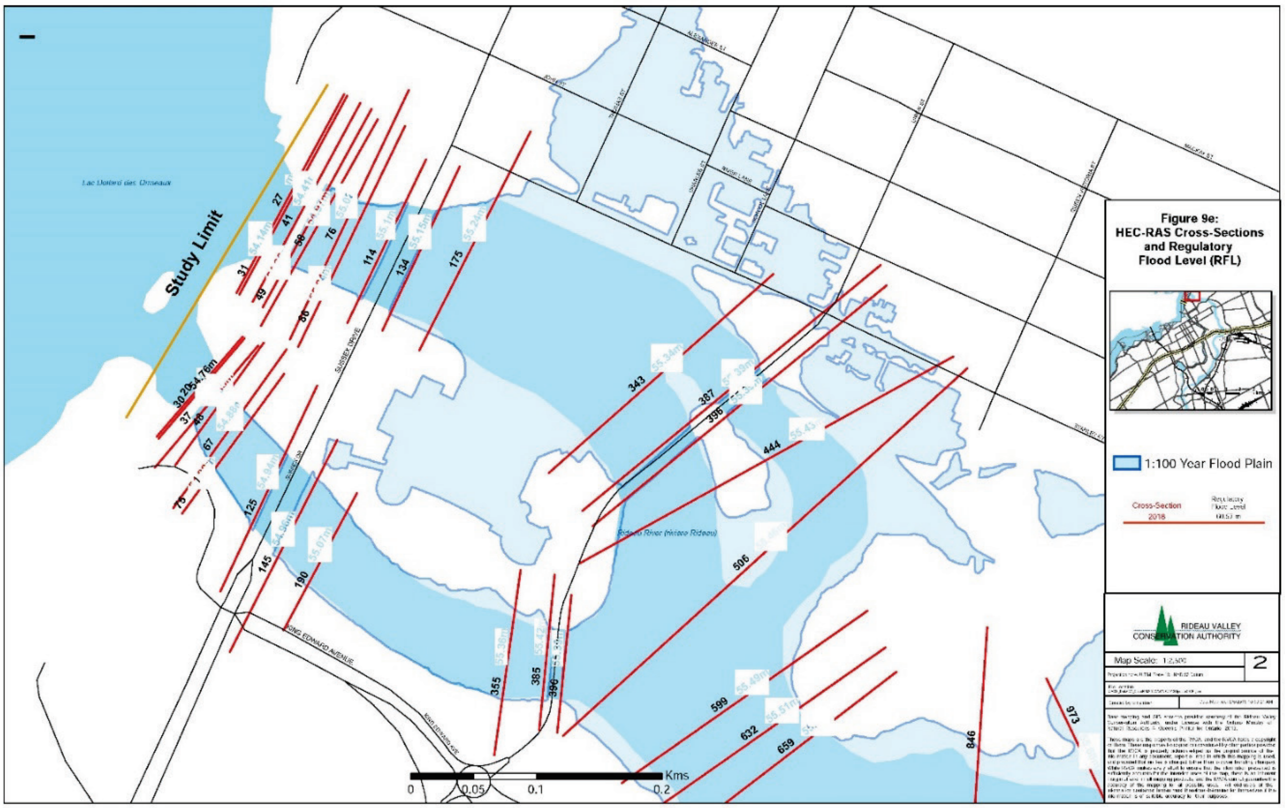

Figure 11: Flood Hazard Map

6.1.3 Flood Risk Maps

Purpose

Flood risk maps convey information regarding the vulnerability of communities to flooding, particularly the potential impacts to people, property, infrastructure and the environment. Generally, flood risk is shown by colour-coded areas classified by the level of risk. Flood risk maps serve to inform policy makers and private sector industries (e.g. real estate and insurance), improve public flood awareness, guide land use decisions, prioritize flood mitigation efforts, and identify key infrastructure for use in emergency management.

Map Creation

Flood risk is defined as the combination of vulnerability and exposure (probability of consequence). Typically, this is determined using a spatial overlay of the flood hazard with social, economic and environmental vulnerability components. These data may include the number of inhabitants, type and value of properties at risk, type of economic activities potentially affected and potential environmental damage.

Risk levels may be calculated in terms of potential economic cost and potential loss of human life. Typically, specific flood damages are calculated for individual flood events based on flood damage curves for various land use and building types. The average annual damage is then obtained by integrating the area under the damage-probability curve which depicts total damage versus probability of occurrence. The flood risk will then be classified from low risk to high risk.

Further details regarding flood risks are provided in the Federal Guideline for Flood Risk Assessment (under development).

Content and Format

Flood risk maps typically show areas of probable damage using risk classes ranked from high risk to low risk.

The data used to create flood risk maps may vary according to intended purpose, data availability, and mapping scale. The following content is often included on flood risk maps:

- Areas of flood risk classified by colour-coding (high risk to low risk),
- Inundation extent for the design flood event,
- Critical infrastructure, and
- High resolution background imagery.

Additional discretionary cartographic layers shown in flood risk maps may include the following:

- Population information by municipality, postal code or per building,
- Location of vulnerable populations, such as schools, hospitals, homes for the elderly, and public areas where people tend to congregate,
- Locations of essential infrastructure, utilities and services,
- Land use information to determine the local Industry types, their susceptibility to damage and the potential economic loss,
- Locations of potential sources of pollution (e.g. chemical plants, stockpiles, fuel stations, waste water treatment facilities and known contaminated sites), and
- Locations of environmental assets (e.g. protected areas and parks).

The resulting flood risk polygon datasets should be attributed with the risk class (e.g. "1 – Low Risk", 2 – Medium Risk" and "3 – High Risk", or any other form of appropriate classification) as shown in Table 10.

Name	Unit	Type	Examples
Flood Risk Class	-	Integer	1, 2, 3, …
Flood Risk Description	-	Text	"Low Risk", "Medium Risk", High Risk"

Table10. Recommended fields for flood hazard polygon datasets

Datasets should be named and centrally stored according to the applicable geospatial data management framework. In addition to digital data files, static maps should be produced in device-independent pdf format in a standard paper size such as ANSI B (11" x 17"), ANSI C (17" x 22") or ANSI D (22" x 34"). All static maps must include standard technical drawing information such as scale, north arrow, coordinate system, references, date, author and publishing entity. See Appendix 4 for map template.

Example

Figure 12 shows an example of a flood risk map.

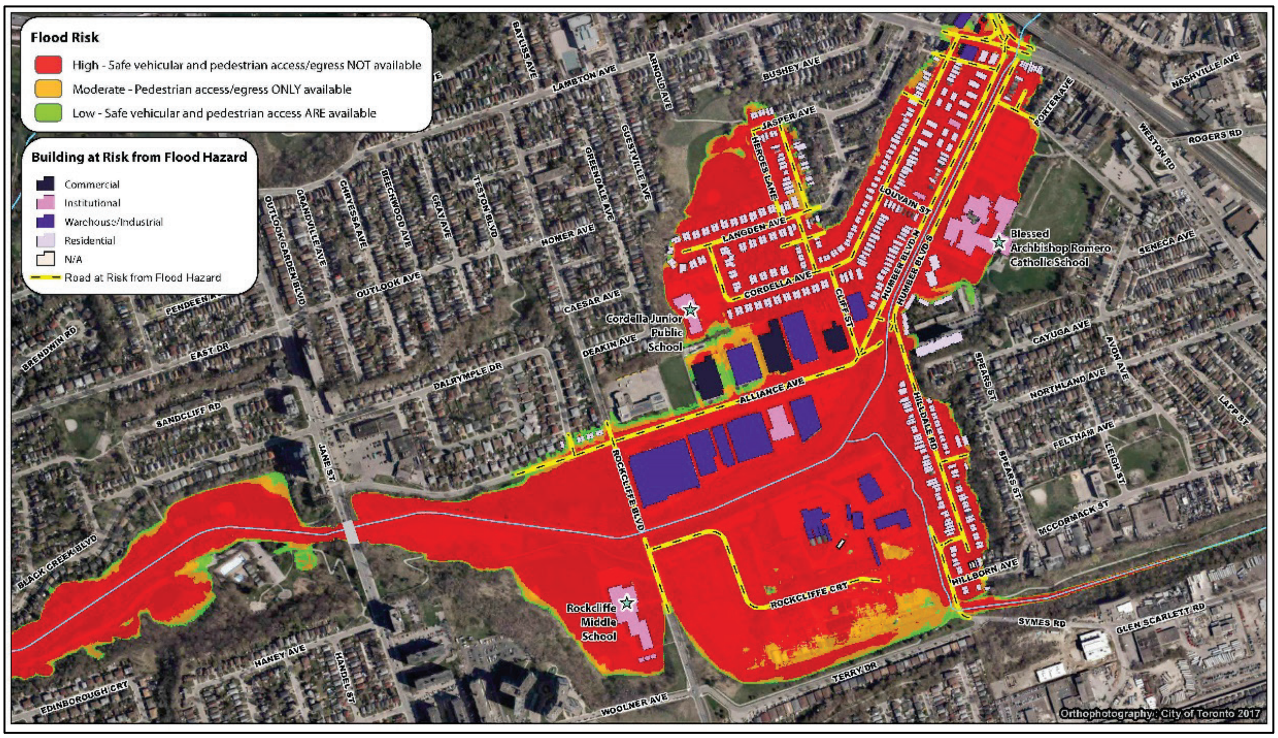

Figure 12: Flood Risk Map

6.1.4 Flood Awareness Maps

Traditional flood awareness poster maps are useful to communicate to members of the public the history of flooding in their communities. They are also practical tools to inform and educate on the risks associated with flooding to residential properties, businesses, cultural assets, infrastructure and human life. These poster maps generally include additional content such as photographs, descriptive text and graphics.

Example

Figure 13 shows an example of a flood awareness poster map.

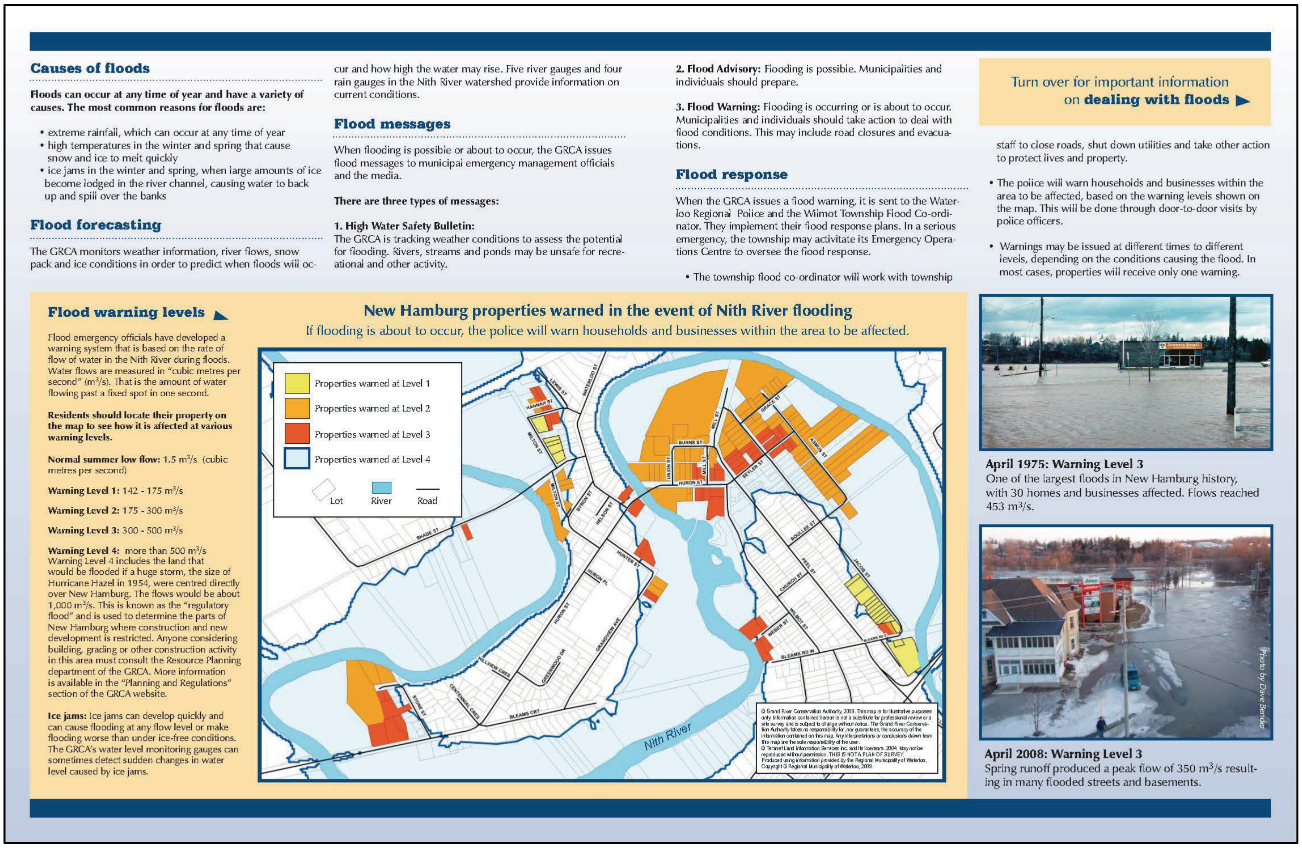

Figure 13: Flood Awareness map

As technology evolves, online interactive tools have become a popular way to disseminate flood awareness information. An interactive web map contains a number of tools and data allowing users to retrieve up-to-date flood information. The following links provide examples of interactive flood awareness tools:

Brisbane Flood Awareness Map

Geoinondations

San Antonio Risk Web Map Application

Consult your policy, legal, and communications department to ensure you respect the rules surrounding your organization's information sharing policies.

6.2 Coordinate Systems

Geospatial data for flood mapping must include specification of the coordinate system. A variety of coordinate systems are used in Canadian provinces and territories. The following sections provide recommendations regarding the selection of the datum, geoid and projection of geospatial data.

6.2.1 Datums and Geoids

Datums are reference systems that define locations and distances on a map. The North American Datum of 1983 (NAD83) of the Canadian Spatial Reference System (CSRS) is the official three-dimensional geometric reference frame for Canada.

The vertical component of NAD83 (CSRS) is based on the Canadian Geodetic Vertical Datum of 2013 (CGVD2013), where orthometric heights are calculated from the GRS80 ellipsoidal heights using the Canadian Gravimetric Geoid model of 2013 (CGG2013). CGVD2013 replaced the Canadian Geodetic Vertical Datum of 1928 (CGVD28) in November, 2013. Therefore, care should be taken with older geospatial data and flood maps that may reference elevations to CGVD28. For CGVD28, applying the HTv2.0 hybrid geoid model enables the transition between ellipsoidal and orthometric heights.

In the case of flood-prone watercourses or lakes that span the Canada-USA border, it is recommended that the area at the border be extensively surveyed to perform vertical correction of water levels in either the Canadian system, CGVD2013, or the North American Vertical Datum of 1988 (NAVD88). Using the same datum is critical to accommodate projection change without concern about datum shifts.

6.2.2 Projections

Projections transform the three-dimensional surface of the earth into two-dimensional map space. Projected coordinate systems allows practitioners to define the horizontal position of features on a map in common units such as meters. Various projections are widely used throughout Canada, including Transverse Mercator (TM), Lambert Conformal Conic (LCC) and Albers Projection.

For flood mapping, practitioners are encouraged to use common projected coordinate systems that preserve shape and direction, such as Universal Transverse Mercator (UTM), Modified Transverse Mercator (MTM) in Eastern Canada or three-degree Transverse Mercator (3TM) in Alberta. MTM and 3TM reduce the distortions introduced by the Transverse Mercator Projection by reducing the zone width from six-degrees to three-degrees. MTM and 3TM may also be used where the boundary of two UTM zones falls on urban centres or highly populated areas. MTM and 3TM are generally preferable for large scale mapping (such as 1:10,000). However, UTM is an alternative for mapping where no other municipal or provincial or territorial standards exist.

6.3 Interoperability

By employing standards in geospatial data management, flood mapping projects will benefit from the resulting interoperability of their data and maps. The Canadian Geospatial Data

Infrastructure (CGDI) is an important Canadian Government initiative advocating best practices in standardized geospatial data management and sharing methods.

6.3.1 Canadian Geospatial Data Infrastructure (CGDI)

In Canada, the GeoConnections initiative has coordinated a national effort to build the CGDI. Geospatial operational policies are essential to eliminating barriers and enabling users to exchange location-based information effectively and efficiently. The CGDI provides operational policies and standards for interoperability that range from legal considerations to technical specifications (NRCan, 2015).

6.3.2 Importance of Geospatial Standards

Applying standard specifications to geospatial data greatly facilitates its development, sharing and use. Increasing the standardization, structure and content of geospatial information improves its accessibility, promotes its exchange and enhances its usability by both humans and machines. Such specifications are necessary to facilitate robust, open transfer of spatial data packages between platforms, without the constraints of proprietary systems. This in turn provides other key benefits, such as contributing to innovation, improving efficiency, reducing transaction costs and increasing transparency.

Practitioners of flood mapping are encouraged to adhere to the core values, minimum geospatial standards and operational policies of the CGDI.

The Canadian Geospatial Data Infrastructure (CGDI)

More information on the geospatial standards and operational policies of the CGDI can be found here: http://www.nrcan.gc.ca/earth-sciences/geomatics/canadas-spatial-data-infrastructure/8902

6.4 Web Mapping

In addition to creating static maps and geospatial data, it is recommended that web map service be published to display or distribute flood map information.

The key advantage of web services is that they are inherently interoperable. They allow applications built using different technologies to communicate with each other.

Geographic web services allow the discovery, sharing, visualization, transaction and processing of geospatial data.

A guide is currently being developed to provide information and advanced best practices and instructions in and effort to provide sufficient guidance in web mapping services. The link to this guide will be available in the next version of the present document.

6.5 Metadata

A metadata record captures the basic characteristics of geospatial data resources and includes information on content, quality, condition, location, ownership and other details of the data. Metadata allows producers and users of geospatial data to discover data and to determine its suitability. All geospatial data used for flood mapping projects in Canada should contain appropriate metadata that is maintained.

It is recognized that many jurisdictions use metadata standards suitable for their specific data management needs. NRCan recommends the use of the Harmonized North American Profile of the ISO 19115: Geographic Information – Metadata standard (Government of Canada, 2016) through the Canadian Geospatial Data Infrastructure (CGDI) (CGDI, 2017). This metadata standard is expected to replace the FGDC Content Standard for Digital Geospatial Metadata (CSDGM) in the near future.

To ensure interoperability and minimum standards, metadata should conform to the Harmonized North American Profile (HNAP) of the ISO 19115: Geographic Information – Metadata specifications. HNAP specifies the required minimum elements to be included in the metadata, such as data identification, keywords, legal constraints, temporal and geographic extent, contact information and others. As per HNAP, metadata should be provided in both official languages where applicable.

Metadata for geospatial data representing the inputs (e.g. cross sections) and results of flood mapping (e.g., inundation extents, floodway, flood fringe, etc.) should meet the standards of HNAP and the standards of the jurisdiction it is created for. Additionally, special attention should be paid to recording key information on the underlying hydrology and hydraulic analyses and the flood mapping such as:

- Hydrology model or method applied;
- Latest year the hydrology model was run in or the latest year in the data set for a flood frequency type analysis;
- Hydraulic model or method to derive water levels;
- River survey data (including the date) used in the hydraulic model;
- Data (e.g. high water marks) and process used to calibrate (where applicable) the hydraulic model;
- Quality assessment of the model calibration and input data to the hydraulic model; and
- Date, specifications (e.g. resolution) and quality assessment of the DTM used to create flood extent polygons.

A metadata template is provided in Appendix 1

Complete metadata adhering to minimum standards promotes the ease of sharing data, which is a key principle of the Federal Flood Mapping Framework. Geospatial data is most efficiently shared by publishing its subsidiary information (metadata) in a specified form, allowing for data discovery through data catalogues and search engines.

7.0 DATA OWNERSHIP AND COPYRIGHT

It is recommended that the vendor deliver all the data with unrestricted copyright, and the ability for the contract authority to place the data within the public domain or distribute as the contracting authority sees fit. The specific arrangement is to be determined by the contracting authority and the vendor.

8.0 GLOSSARY OF TERMINOLOGY

Annual Exceedance Probability (AEP): The probability, expressed as a percentage, of a given flood magnitude being exceeded in any given year. Flood events are usually expressed in terms of a return period or an Annual Exceedance Probability (AEP). For example, a flooding event with an AEP of 0.01 (1%), and a flood event with a return period of 100 years, are equivalent. However, the concept of return periods can be misleading to a non-technical audience who may erroneously infer that two “100 year floods” (100 year return period or 0.01 AEP floods) cannot occur, for example, 25 years apart.

Coastal Flooding: Coastal flooding can be defined as flooding associated with a defined shoreline along an ocean. This can be due to a combination of high tides, storm surges, waves, rising sea levels and riverine flooding.

Design Flood: A specific flood magnitude that is used for a design purpose, including delineating Flood Hazard Areas. In Canada, the 0.01 AEP flood is used as the minimum Design Flood for delineating Flood Hazard Areas, and many jurisdictions use higher magnitude floods (e.g. 0.005 AEP flood) or Design Storms. The Design Flood is usually expressed as flow in metres per second, and hydraulic analysis is then used to calculate the corresponding floodwater elevation and extent.

Designated Flood Risk Area: Areas that were delineated under the Flood Damage Reduction Program (FDRP) as being inundated by a regulatory flood event and formally recognized by federal and provincial governments.

Digital Terrain Model (DTM): A land surface represented in digital form by an elevation grid or lists of three-dimensional coordinates.

Flood Awareness Map: Communication maps that serve to inform members of the public regarding the history of flooding in their communities, as well as the potential for future flooding and the risks that such flooding would pose to residential properties, businesses, cultural assets, infrastructure and human life. These interactive web maps or printed poster-style maps include a range of additional content types, such as photographs, descriptive text and graphics.

Flood Fringe Areas: The area between the Floodway and the delineated extent of flooding for a Design Flood. In Canada, the Flood Fringe Area is often defined as having a flood depth below 1 metre and a flood velocity less than 1 metre per second.

Flood Hazard Map: A flood delineation at a given location, based on the flood’s anticipated magnitude (e.g. its depth, horizontal extent, and flow velocity) and its annual exceedance probability. It shows the extent of the regulatory flood hazard, often including two zones: floodway and flood fringe areas. This type of map is used for regulatory planning purposes.

Flood Hazard Area: The delineated extent of flooding for a Design Flood (e.g. 0.01 AEP flood), which includes the 'Floodway' and the 'Flood Fringe Area'.

Flood Inundation Map: Maps that show the floodwater extent of real flood events, or that show potential floodwater coverage for flood events of different magnitudes (e.g. annual exceedance probabilities). They are intended to aid in the management of emergency preparedness plans for communities situated within floodplains and flood hazard zones.

Flood Mitigation: A sustained action taken to reduce or eliminate long-term risk to people and property from flood hazards and their effects. Mitigation distinguishes actions that have a long-term impact from those that are more closely associated with preparedness for, immediate response to, and short-term recovery from specific events.

Flood Risk Map: 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.

Flood Risk: Flood risk is a combination of the likelihood of a flood event occurring (**Flood Hazard**) and the social or economic consequences of that event when it occurs (the exposure to the flood hazard).

Floodway: The channel and adjacent area where flood depths and velocities are greatest and most destructive. In Canada, the Floodway is often defined as having a flood depth above 1 metre and flood velocity greater than 1 metre per second.

Flow: The rate of flow of water measured in volume per unit time – for example, cubic metres per second (m^3/s). Flow is different from the speed or velocity of flow, which is a measure of how fast the water is moving – for example, metres per second (m/s).

Light Detection and Ranging (LiDAR): A remote sensing technology which uses lasers to collect accurate continuous elevation data.

Peak Flow: The maximum flow occurring during a flood event measured at a given point in the river system (see **Flow).**

Pluvial Flooding: The temporary inundation by water of normally dry land, usually caused by extreme rainfall events and not necessarily near to water bodies. Pluvial flooding is common in urban areas where water temporarily accumulates due to more rainfall entering an area than can be removed by infiltration into the ground and discharge through infrastructure (e.g. storm sewers).

River Cross-section: A survey string of channel and floodplain elevations that is taken perpendicular to the main flow direction in a river.

Riverine Flooding: The temporary inundation by water of normally dry land adjacent to a river and caused by rainfall, snowmelt, stream blockages including ice jams, failure of engineering works including dams, or other factors.

Velocity of Floodwater: The speed at which waters are moving, typically measured in metres per second (m/s).

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APPENDIX 1 – METADATA

Metadata for Flood Mapping Polygons

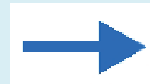
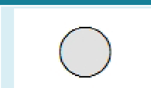
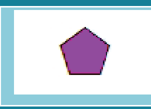
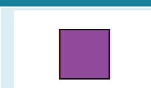
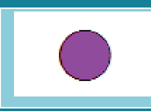
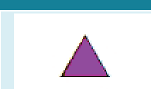
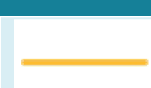
NAP ISO19115 Location	NAP ISO19115 Item Name	Description	Key Information to Include	Example
MD _DataIdentification	Citation	Name by which the cited resource is known.	Name of the dataset	Calgary_2-Year_Inundation_Extent
MD _DataIdentification	Abstract	Brief narrative summary of the dataset's contents.	Summary of the dataset, including spatial and temporal extent and purpose.	Modelled inundation extent for the 2-Year return period for the City of Calgary as of 2013.
MD _DataIdentification	TopicCategory	The main theme(s) of the dataset.	To be set to "Inland Waters".	Inland Waters
MD _DataIdentification CI_Citation	Date	Reference date for the cited resource.	Creation date for the dataset.	Creation Date: 2017-04-13
MD _DataIdentification CI_Contact	Contact	Information which assists one to contact an individual or organization.	Entity and/or person responsible for the creation and/or maintenance of the dataset.	Name: Sample Person Organization: Natural Resources Canada Position: GIS Analyst Role: Custodian
EX_Extent EX_TemporalExtent	TemporalElement	The time period related to the dataset content.	Time period the dataset is relevant for.	Description: Temporal period the modelling is relevant for. Begin Date: 2013-01-01 End Date: 2013-12-31
MD_DataIdentification resourceConstraints MD_Constraints	UseLimitation	Statement on the fitness for use or limitations on the use of the resource or metadata.	A reference to potential limits of quality and accuracy of the input data (i.e. hydrology and hydraulic modelling, DTM, etc.) and where to find them. Any other limitations that would affect the use of the dataset.	An accuracy and quality assessment of the hydrology and hydraulic model as well as the DTM is included in the project report (*include reference*). This dataset should be used in awareness of the accuracy limitations imposed by the source data and source modelling.
MD_DataIdentification resourceConstraints MD_LegalConstraints	UseConstraints	The legal restrictions or prerequisites to using the resource or accessing the metadata.	Any legal restrictions that would affect the use of the dataset.	Privacy, Confidential, Unrestricted License, etc.
MD_DataIdentification resourceConstraints MD_LegalConstraints	AccessConstraints	Limitations on access to the resource or metadata to protect privacy, intellectual property, or any special limitations.	Any legal restrictions that would affect the access of the dataset.	Privacy, Confidential, Unrestricted License, etc.
MD_DataIdentification resourceConstraints MD_LegalConstraints	OtherConstraints	Other restrictions or legal prerequisites for accessing the resource or metadata.	Any other restrictions that would affect the access or use of the dataset.	No constraints exist.
MD_ReferenceSystem	ReferenceSystemInformation	Identification of the spatial and temporal reference systems used.	Horizontal and vertical reference system and projection, ESPG code(s) identifying the reference systems	Dimension: horizontal Code: 3780 Code Space: EPSG Version: 6.16

				Dimension: vertical Code: 3780 Code Space: EPSG Version: 6.16
LI_LINEAGE LI_Source	Source	Information about the source data used in creating the data.	Relevant source data used in the modelling and delineation of the inundation polygons, such as: • Hydrology model used • Year of the hydrology model • Hydraulic model used to derive water levels • Data and processes used to calibrate the hydraulic model • Quality assessment of the model calibration and input data to the hydraulic model • Date, specifications (e.g., resolution) and quality assessment of the DTM used to create flood extent polygons.	Source Description: 2012 1m resolution bare earth aerial LiDAR DEM. Source Citation: 2012 LiDAR Creation Date: 2012-02-01
LI_LINEAGE LI_ProcessStep	ProcessStep	The events in the development of the dataset.	Description of process used to derive the inundation polygons (e.g. one- or two-dimensional hydraulic model)	Water level surface subtracted from the DTM. Areas with depths larger than 0 m converted into inundation polygons.

Metadata should also meet the standards of the jurisdiction it is created for. A metadata template (.xml) for an ESRI shapefile (.shp) is provided with this report.

APPENDIX 2- MAP SYMBOLOGY

Flood Maps Base Data

Direction of flow			
Line	Solid, 1.5pt	0,112,255 (blue)	
Arrowhead	Triangle, size 7pt	0,112,255 (blue)	
Label	Arial, 7 pt.,1pt halo (white), Italic, parallel, below	0,77,168 (dark blue)	
Bridge			
Point	Circle, size 10pt, outline 0.2pt (black)	225,225,225 (light gray)	
Label	Arial, 7 pt.,1pt halo (white), bold	0,0,0 (black)	
Culvert			
Point	Pentagon, size 10pt, outline 0.2pt (black)	197,0,225 (dark purple)	
Label	Arial, 7 pt.,1pt halo (white), bold	0,0,0 (black)	
Weir			
Point	Rectangle, size 10pt, outline 0.2pt (black)	197,0,225 (dark purple)	
Label	Arial, 7 pt.,1pt halo (white), bold	0,0,0 (black)	
Dam			
Point	Circle, size 10pt, outline 0.2pt (black)	197,0,225 (dark purple)	
Label	Arial, 7 pt.,1pt halo (white), bold	0,0,0 (black)	
Other Hydraulic Structure			
Point	Triangle, size 10pt, outline 0.2pt (black)	197,0,225 (dark purple)	
Label	Arial, 7 pt.,1pt halo (white), bold	0,0,0 (black)	
Major Contour (e.g. 5 m Interval)			
Line	Solid, 1pt	128,110, 82 (dark brown)	
Label	Arial, 7 pt.,1pt halo (white)	128,110, 82 (dark brown)	
Minor Contour (e.g. 1 m Interval)			
Line	Solid, 2pt	215,194, 158 (light brown)	
Label	NA		
Roads			
Major Road			
Line	Solid, 2pt	230,152,0 (orange)	
Label	Arial, 7 pt.,1pt halo (white), capitalized, parallel	0,0,0 (black)	
Local Road			
Line	Solid, 1pt	255,170,0 (orange)	
Label	Arial, 7 pt.,1pt halo (white), capitalized, parallel	0,0,0 (black)	
Pathway			
Line	Solid, 0.5pt	255,211,127 (yellow)	
Label	NA		

Railways			
Line (top)	solid, 0.5pt	0,0,0 (black)	
Line (hash)	solid 0.4 pt., length - 4.0 pt. long, angle - 90°, spacing – 7.0pt.	0,0,0 (black)	
Label	NA		

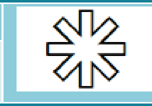
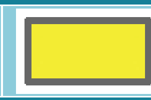
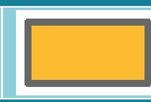
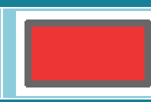
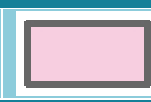
Inundation Maps

	Style	Colour (RGB)	Example
Cross Sections			
Line (top)	solid, 1.5pt	0,0,0 (black)	
Line (bottom)	Solid, 2pt.	255, 255, 255 (white)	
Label Cross Section Number	Arial, 7 pt., 1pt halo (white), orientation – perpendicular, position – above	0,0,0 (black)	
Label Cross Section Station	Arial, 6 pt., 1pt halo (white), orientation – parallel, position – above	0,0,0 (black)	
Inundation Extent Polygons			
Inundated			
Line	solid, 2pt	0,77,168 (dark blue)	
Fill	solid, 70% transparency	0,77,168 (dark blue)	
Isolated			
Line	solid, 2pt	115,178,255 (light blue)	
Fill	solid, 70% transparency	115,178,255 (light blue)	

Flood Hazard Maps

	Style	Colour (RGB)	Example
Cross Sections			
Line (top)	solid, 1.5pt	0,0,0 (black)	
Line (bottom)	Solid, 2pt.	255, 255, 255 (white)	
Label Cross Section Number	Arial, 7 pt., 1pt halo (white), orientation – perpendicular, position – above	0,0,0 (black)	
Label Cross Section Station	Arial, 6 pt., 1pt halo (white), orientation – parallel, position – above	0,0,0 (black)	
Inundation Extent Polygons			
Flood Fringe Limit			
Line	solid, 2pt	230,0,0 (red)	
Fill	solid, 70% transparency	255,190,190 (pink)	
Floodway Limit			
Line	solid, 2pt	230,0,0 (red)	
Fill	solid, 70% transparency	230,0,0 (red)	

Flood Risk Maps

	Style	Colour (RGB)	Example
Affected Population			
Point	Asterisk, size 20pt, outline 0.2pt (black)	255, 255, 255 (white)	
Label	Arial, 10 pt., bold, 1pt halo (white), position – offset horizontally around point	0,0,0 (black)	
Flood Risk Polygons			
Low Risk, Developed Land			
Raster	25% transparency	255, 255,0 (yellow)	
Medium Risk, Developed Land			
Raster	25% transparency	255, 170,0 (orange)	
High Risk, Developed Land			
Raster	25% transparency	255, 0,0 (red)	
Low Risk, Undeveloped Land			
Raster	25% transparency	255, 190,232 (light purple)	
Medium Risk, Undeveloped Land			
Raster	25% transparency	198, 166,255 (medium purple)	

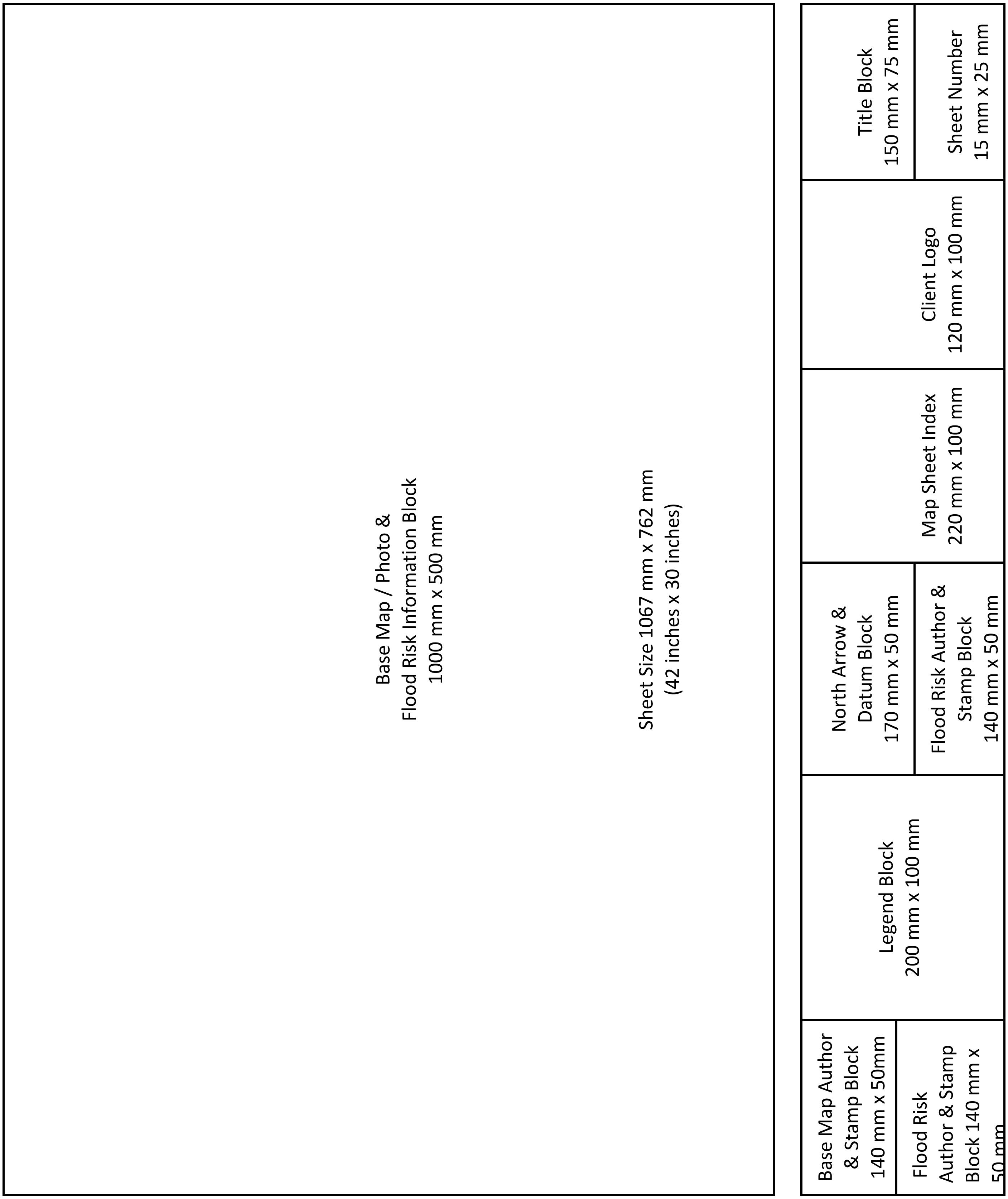
APPENDIX 3 - HIGH RESOLUTION SATELLITE IMAGERY

The table below provides a list of satellites producing commercially available high-resolution satellite imagery[3]:

Satellite Name	Supplier	Resolution	Image Capture Capacity	Swath Width
RapidEye	- BlackBridge AG	- 5 m	- 4 million km^2/day	- 77 km
WorldView-2	- DigitalGlobe	- 46 cm panchromatic - 1.85 m multispectral	- 785,000 km^2/day	- 16.4 km
WorldView-3	- DigitalGlobe	- 31 cm panchromatic - 1.24 m multispectral - 3.7 m shortwave infrared - 30 m CAVIS imagery	- 680,000 km^2/day	- 13.1 km
WorldView-4 (Formerly GeoEye-2)	- DigitalGlobe	- 34 cm panchromatic - 1.36 m 4-band multispectral	- 600,000 km^2/day	- 14.5 km
QuickBird II	- DigitalGlobe	- 61 cm panchromatic - 2.4 m multispectral	- 544 km^2/day centered on the satellite ground track (to 30° off nadir)	- 18 km
Pléiades	- Airbus Defense and Space	- 50 cm panchromatic - 2 m 4-band multispectral - Pléiades 1A and 1B are 70-cm panchromatic and 2.8-m multispectral	- Optimized daily acquisition capacity: 300,000 km^2/day/ satellite	- 20 km
GeoEye-1	- DigitalGlobe	- 46 cm panchromatic - 1.84 m 4-band multispectral (i.e. blue, green, red and NIR)	- 700,000 km^2/day of pan area (about the size of Texas) - 350,000 km^2/day of pan-sharpened multispectral area	- 15.2 km

[3] https://apollomapping.com/imagery/high-resolution-imagery/geoeye-1

APPENDIX 4 – MAP LAYOUT



ANNEX A – FLOOD SIMULATION MODELS

Background

Prediction and analysis of flood hazards provide valuable information necessary for the implementation of emergency response plans, favouring the prevention and mitigation of damage due to this type of natural disaster. Flood modelling generally involves complex processes that involve numerous variables and parameters. Because this information is often unavailable for many Canadian watersheds, it can be difficult to generate flood maps on the fly in an emergency [1].

However, simplified conceptual models that are based only on topography can be used to assess flood risks for well defined floodplains. The concept of height above nearest drainage (HAND) is among these simplified conceptual models. With this approach, the topography is normalized using the height above the nearest drainage [2]. Flood simulations are then carried out by selecting the cells with a value that is less or equal to the projected water level for the water course. The HAND model is a simple, quick approach to flood simulations in a fluvial context [1].

Creation of HAND flood simulation models

Two inputs are needed to create flood simulation models using the HAND approach: a digital terrain model (DTM) and the water linear flows of the drainage network for the area of interest.

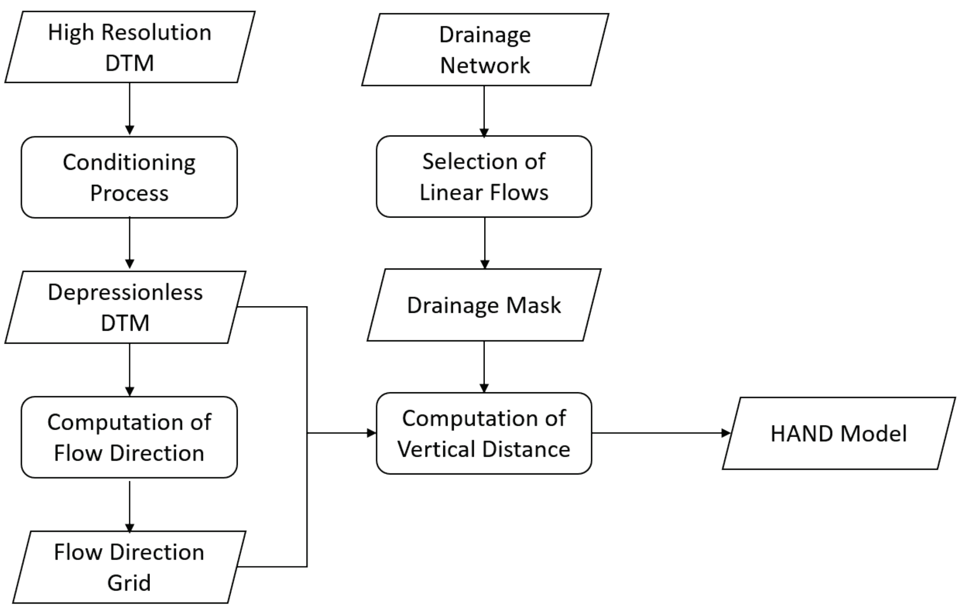


Figure 1: Data processing flows for generating HAND models

The geometry of the drainage network is identified using the water linear flows. Only the main river and its principal tributaries are used by keeping only the linear flows corresponding to a certain stream order. This approach produces the most realistic results while reducing the processing time required to compute the model [3]. Vector segments corresponding to the selected order of the drainage system are turned into a drainage mask with the same resolution as the DTM. This drainage mask is then aligned with the DTM being used.

DTMs require a series of pre-processing steps to generate HAND models. The first step is to produce a depressionless, or conditioned, DTM. This step modifies the elevation values of certain cells in the original DTM so that all cells spill into an adjacent cell. Figure 1 illustrates an example of alterations to the DTM for the area of Fredericton, New Brunswick, to fill the depressions in the original model and then guarantee the flow.

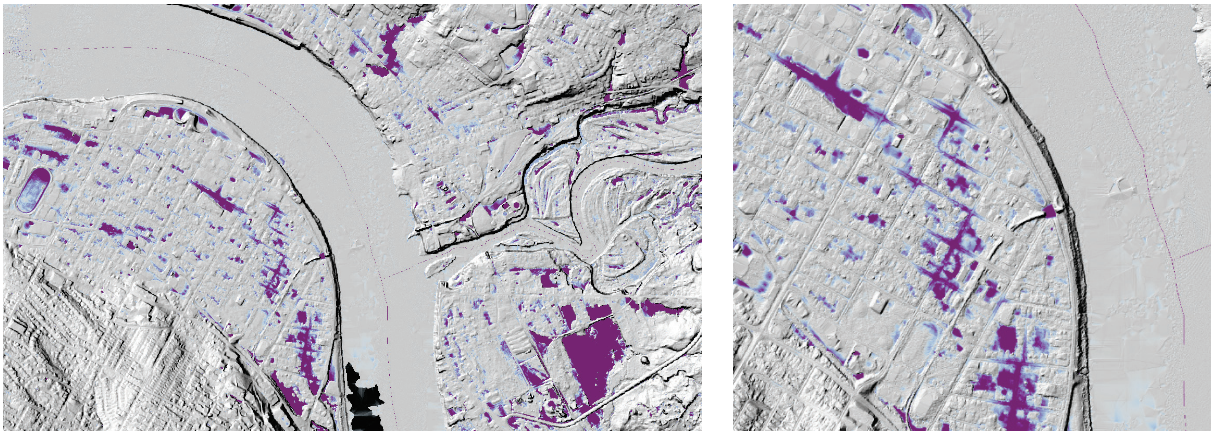


Figure 2: Scope of alterations to the DTM to guarantee flow

The modified DTM is used to create flow direction grid. Two types of flow direction can be calculated. The first is the 8-value deterministic (D8) model [4]. When this type of flow direction is established, every cell is assigned an integer value that determines into which of the adjacent cells it will drain as a function of the steepest slope. Figure 1 illustrates examples of the encoding that can be used for D8 direction flows. The second type of flow, referred to as D infinite (D∞), consists of determining the angle of the main slope and assigning this value to every cell on the grid [5]. This alternative can be used to calculate the proportion of the flow spilling into each of the adjacent cells.

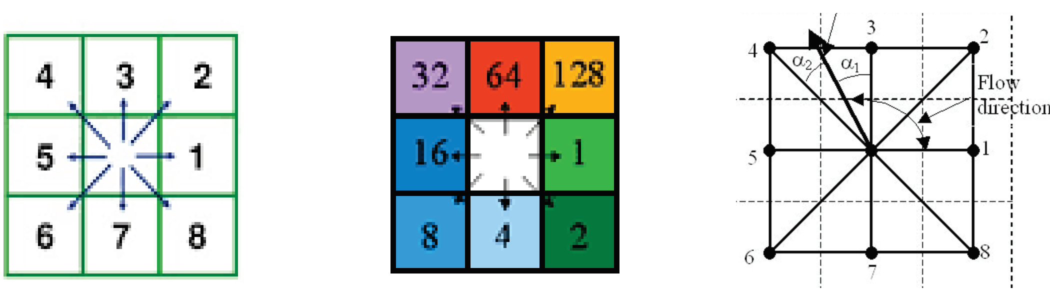


Figure 3: Examples of flow direction encoding. a) D8 encoding with 8 integer values, b) D8 2-base encoding, which can be used to combine multiple flow directions, and c) infinite encoding that corresponds to the angle of the main slope

The HAND model is created using flow directions, the drainage network mask, and DTMs. Processing consists of calculating the vertical distance of each cell from the nearest drainage point based on the flow direction grid. The flow direction grid is used to connect every cell to the drainage point that is horizontally nearest, then calculate the difference in elevation values between these two cells. Two variants of the HAND models are generated, the first using the depressionless DTM and the second using the original DTM. The first model, the HAND-*conditioned*, is used to determine the extent of the flooded areas, while the second, the HAND-*unmodified*, is used to calculate flood depths.

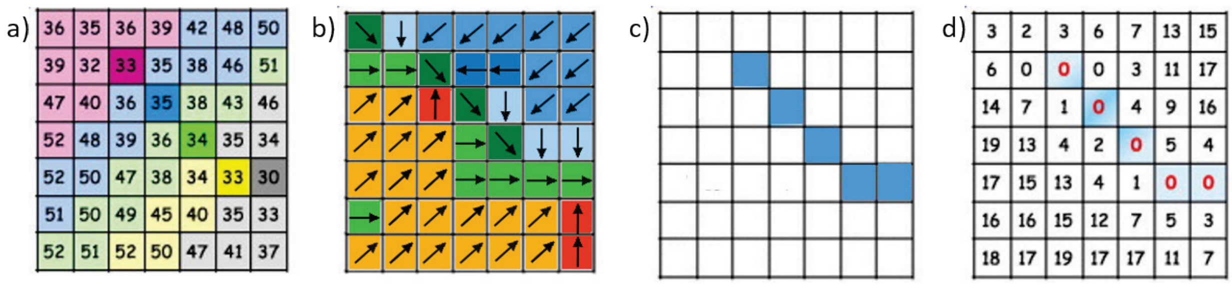


Figure 4: Process for creating HAND models using a) a digital terrain model (DTM), b) a flow direction grid, and c) a drainage system mask, to produce d) a HAND model

Use of HAND models

Flood simulations are carried out by selecting the cells of the HAND models with a value that is less than or equal to the projected water level. The extent of the simulated floods corresponds to all of the selected cells (Figure 4).

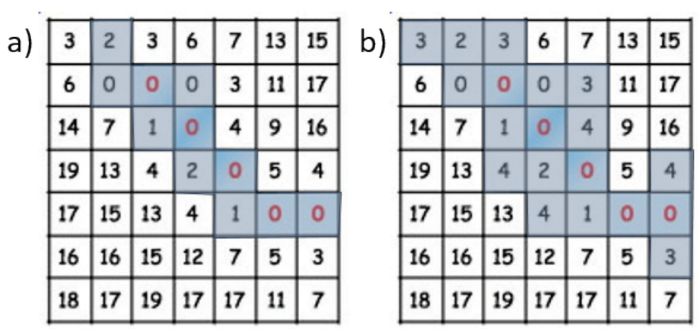


Figure 5: Simulated floods using HAND models for projected water levels of a) 2 m and b) 4 m

The HAND-*unmodified* model derived from the original DTM can be used to identify all of the cells located under the projected water level, while the HAND-*conditioned* model can be used to identify only the cells that are located below the projected water level and that are directly connected to the drainage system. A combination of the two models allows to distinguish between the areas directly impacted by the watercourse overflows from potentially flooded areas if underground or non-apparent connection would exist. In the second case, the areas that are lower than the projected water level can be protected by nearby tracts of land higher up, especially a watertight structure such as a dike.

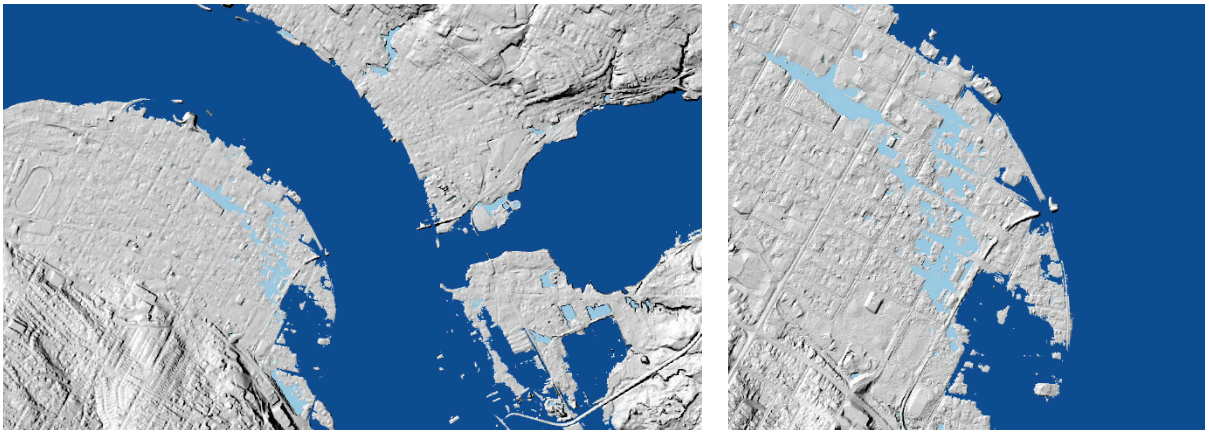


Figure 6: Simulations distinguishing flooded cells from potentially flooded cells for the Fredericton, New Brunswick, area

The HAND-*unmodified* model is used to directly calculate flood depths. The flood depth of every cell is calculated by subtracting the HAND value of the cell from the projected water level (Equation 1).

$$\text{Water depth} = \text{Water level} - \text{Cell value} \qquad \text{(Eq. 1)}$$

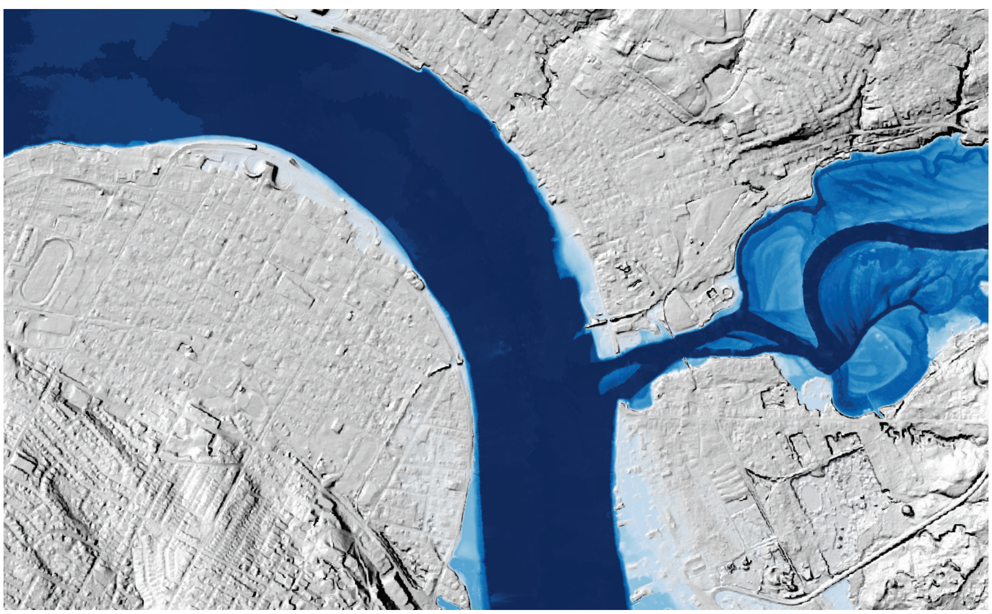


Figure 7: Overview of flood depths calculated using the HAND-unmodified model for the Fredericton area, distinguishing the highly flooded areas (dark blue) from the areas with little flooding (pale blue)

The information from HAND models can be transferred to vector features using zonal analysis tools. These tools calculate statistics based on the geometry of geospatial features such as building footprints, road segments or point addresses. Calculating the minimum value of the HAND model and assigning it to each feature makes it possible to determine the elements affected by the increased water level through direct attributive queries [6].

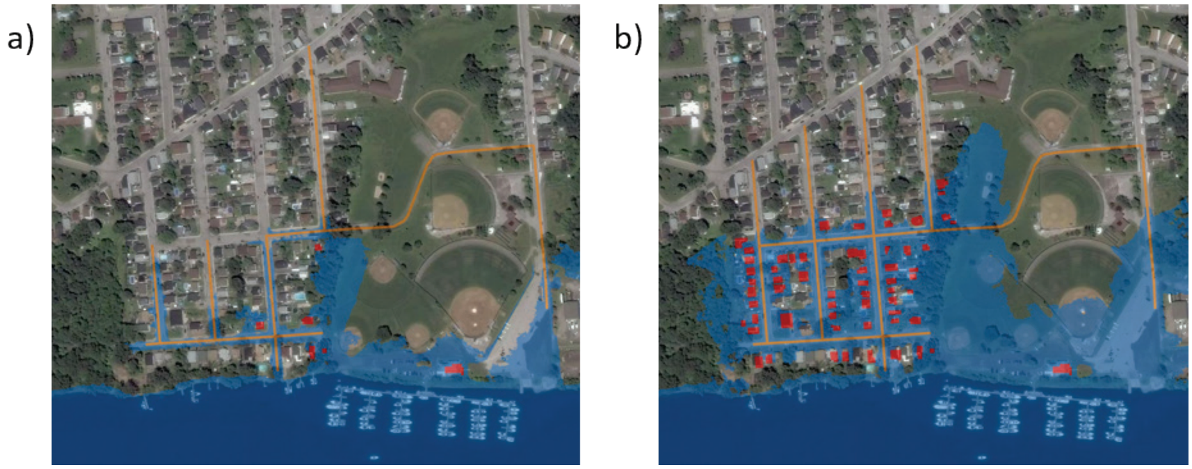


Figure 8: Overview of potentially affected buildings and road segments in one sector of Gatineau, Quebec, for Ottawa River water levels a) 44.0 m and b) 44.5 m

Limitations

HAND models cannot be used to model and predict the speed and rise of rivers, and represent only the potential maximum extent. They do not necessarily calculate the change over time for a flood [1]. It is therefore best to evaluate these model on various terrains and various types of rivers, as well as in areas where the floodplain is not well-defined. Also, the effect of flow or water level control structures within this type of model has not been studied.

Future work

The proposed methodology does not include the processing that would allow to take into consideration certain structures such as bridges and culverts that can be mistaken for ground in the input DTM. Applying a hydro enforcement process at the locations where such structures exist would reduce the scope of alterations caused during the creation of a depressionless DTM. It would also reduce the number and size of areas that appear to be protected by neighbouring tracts of land higher up, but which are in fact connected to the drainage system.

The elevation values currently expressed in the HAND models represent an elevation above the water level at the point in time when the source data used to create the DTM were collected. It is difficult to relate this arbitrary and limited reference to other sources of information. Converting the model values to a common system of reference would enable integration with other types of observations.

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ANNEX B – NEAR-REAL-TIME MAPPING OF OPEN WATERS USING SAR SENSORS

Introduction

Natural Resources Canada (NRCan) has been providing geomatics support during emergency response actions since 2006. NRCan holds expertise in the supply of geospatial products and services for numerous types of major, natural and anthropogenic emergencies. It provides the following services:

1. Access to geospatial data via web mapping services or direct download;
2. Planning for data acquisition and reception and for production of value-added products for RADARSAT-2 and other commercial satellites (if funding is available);
3. Data reception and the creation of value-added products for free satellite programs, such as Landsat and Sentinel;
4. Access to the archives of the National Photo Library;
5. Retrieval of geospatial data from satellite data sources; and
6. Creation of specialized geospatial products using all available geospatial data sources.

Geomatics products and services derived from Earth observation (EO) data can provide essential situational information in the event of a natural disaster. Because floods are a major risk in Canada, NRCan has developed a strong operational capacity for flooding and river ice surveillance using EO. The ability to access maps of flooded areas in near-real time and data detailing flood extent, gravity and progression contributes significantly to knowledge of the situation on the ground and facilitates decision-making during disaster response.

Although there are several ways to gather data on flood extent, near-real-time flood extent maps that use satellite imaging (RADARSAT-2, Sentinel-1) are the emergency geomatics products requested most often by NRCan clients. Radarsat missions allow for regular, systematic, synoptic and repetitive image production.

Theoretical framework

Synthetic aperture radar (SAR) satellites, like the Canadian RADARSAT-2 satellite, are particularly well suited to flood mapping because they generate daytime and nighttime images, whatever the weather conditions. That said, SAR satellites move in definite orbits, which limits the time and frequency of image acquisition. Conventional earth observation methods and SAR satellites should therefore be considered supplemental data sources, rather than concurrent ones.

The success of SAR satellites in flood mapping has been well documented (Brisco 2008, 2009). It is usually easy to detect the contrast between water (specular reflection) and earth (diffuse reflection) in SAR images. The differences in diffusion mechanisms allow for easy interpretation of flood extent and quick generation of flood maps for disaster response.

To detect flooded areas, NRCan uses a thresholding method to extract the low values from SAR images. These dark values correspond to environments where specular reflection is dominant (Figure 1); the lack of waves makes this method particularly effective in low-wind conditions (Figure 2). Specular reflection is caused by a smooth surface with a strong dielectric constant that serves as a mirror for the radar's incident pulse. Most of the incident radar energy is reflected forward with very little backscatter, which means the satellite receives only a very weak signal, hence the colour black for low values (Figure 3).

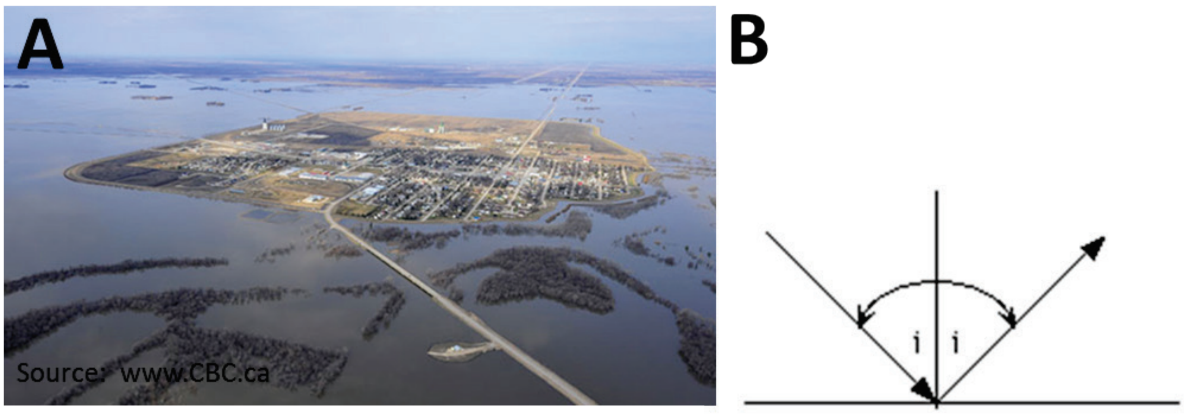

Figure 1. a) Example of the Red River flood in Manitoba. The water is calm and therefore leads to specular reflection.

Diffuse reflection is caused by a rough surface with a strong dielectric constant that reflects the radar's incident pulse in all directions. In this situation, part of the radar energy is scattered toward the radar sensor. The amount of backscattered energy depends on the properties of the target on the ground.

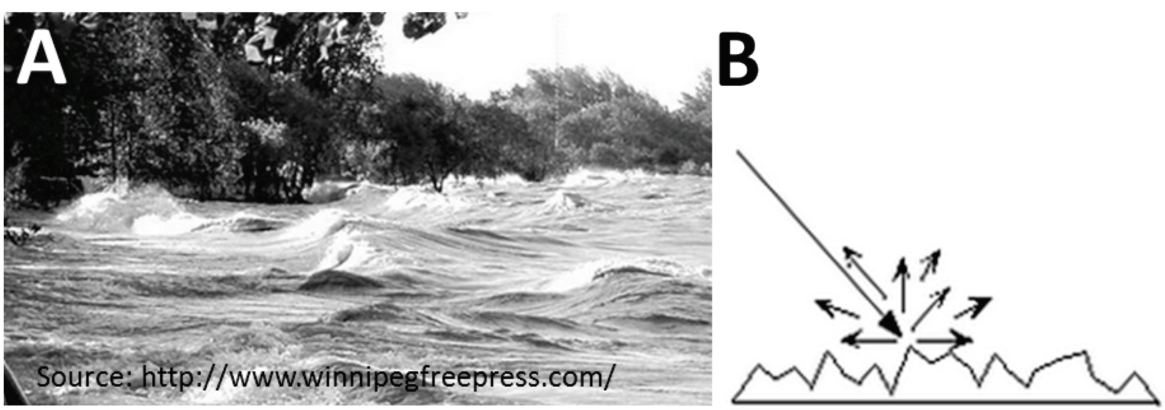

Figure 2. a) Example of waves on Lake Winnipeg in Manitoba. The water is rough and therefore produces diffuse reflection.

In Figure 3, a RADARSAT-2 image shows a body of open water caused by flooding; the black area represents the calm body of water that generates the specular reflection and is used to create the flood extent polygon, the contour of which is in blue.

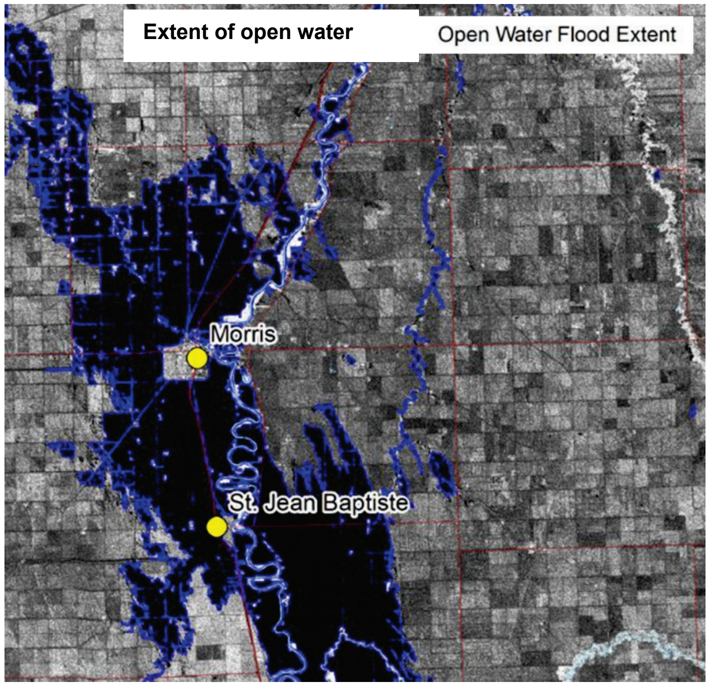

Figure 3. Extent of Red River (Canada) flood – based on a RADARSAT-2 image dated April 28, 2011. The extent of open water at the time of flooding is represented by the dark blue polygons.

For more about the basic principles of radar remote sensing, visit the website of the Canada Centre for Remote Sensing[4] (Natural Resources Canada).

Method

Mapping of open water flooding by SAR imaging at NRCan involves several steps, ranging from prior preparation of auxiliary data and semi-automatic processing of SAR images to distribution of the final products via web services. Every step requires validation by a SAR photo-interpreter.

Data preparation and tools

Several specialized software programs and data sets are needed to perform these tasks. The Open Source Geospatial Foundation (OSGEO), European Space Agency (ESA), United States Geological Survey (USGS) and Natural Resources Canada make a range of open-data tools and portals available to the public for the creation of such an integrated data processing chain.

The planning of mapping operations begins with the planning of satellite acquisitions. The ESA Copernicus program and the USGS Earth Resources Observation and Science Center are two of the foremost sources of Earth observation data and are publically available. The past and future acquisition plans are available on the websites for these programs. The data of the various sensors (e.g. Sentinel-1 and Sentinel-2) are available through the Scihub[5] portal, while the USGS[6] portal provides access to digital elevation models and medium-resolution optic

[4] https://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9309
[5] https://scihub.copernicus.eu/;
[6] https://earthexplorer.usgs.gov;

imaging (Landsat-8). For provincial public safety organizations, during emergency actions, a request can be sent to the federal Government Operations Centre (GOC) for access to near-real time data from the RADARSAT sensor.

The resolution required to map a flood event depends on the size of the area observed. Tobler's work (1987) provides guidelines to assist with decision-making when selecting the relevant Earth observation data. Tobler (1987) writes: "The rule is: divide the denominator of the map scale by 1,000 to get the detectable size in meters. The resolution is one half of this amount." This gives us Table 1, a modified version of Tobler's table (1987) in Nagi (2010).

Table 1: Guidelines for selecting the appropriate resolution (Nagi 2010)

Map Scale	Detection Threshold (metres)	Raster Resolution (metres)
1:1,000	1	0.5
1:5,000	5	2.5
1:10,000	10	5
1:50,000	50	25
1:100,000	100	50
1:250,000	250	125
1:500,000	500	250
1:1,000,000	1000	500

Thus, according to Tobler (1987), to detect a river 60 m in width, the pixels would have to be no more than 30 m in size to produce a map scale of 1:60,000. Using high-resolution data allows for precise mapping of the flood boundaries to the detriment of spatial coverage; as such, the final choice of the optimal resolution is up to the user and depends on the organization's strategic needs.

In Canada, NRCan maintains and disseminates the base data that can be used to create the final maps that show flood extent. All the basic data at a scale of 1:50,000 are available through the Government of Canada's Open Maps[7] portal. Moderate (CDSM) and high-resolution digital elevation models (HRDEMs) for certain areas of Canada are also available on the Open Maps portal.

Below are some of the basic data useful for quality control and as aids to decision-making:

- Runways
- Hydrography
- Railways
- Roadways
- Indigenous lands
- Elevation
- Strategic infrastructure
- Agglomeration boundaries

[7] https://open.canada.ca/en/open-maps

Geomatics data can be processed, managed and shared using freeware[8] (e.g. QGIS, MapServer, PostGIS) or licensed software (e.g. ArcGIS) depending on your organization's requirements and constraints.

Processing of SAR images

In preparation for receiving satellite imaging, a work environment must be created in a geographic information system. The basic data for an area of interest are extracted beforehand and the available historic imaging is gathered. A digital elevation model that is at least as large as the satellite image must be created.

When the image is received, it must be orthorectified. Specialty software such as PCI Geomatica, SNAP,[9] Map Ready or Orfeo ToolBox can be used to that end.

Orthoimages are assembled into mosaics and inspected. Based on the available data, the image with the clearest contrast between water bodies and land will be selected.

In the methodology adopted by the EGS, the depth of the initial image is sampled on the basis of the maximum and minimum values observed for the scene to obtain an 8-bit image with 256 grey levels. A 3x3 median filter is then applied to reduce the noise inherent to any SAR image.

After this sampling, a thresholding procedure is used to extract the dark areas and reject higher values. The dark areas correspond to environments where backscatter is low. Often, several thresholds must be tested before satisfactory results are obtained: the photo-interpreter's work is to select the appropriate threshold. When the optimal threshold has been identified, the mask is vectorized to achieve a raw product for the potentially flooded areas. The product must then be cleaned up and the false positives removed, particularly large asphalt surfaces, such as airport runways.

When the photo-interpreter is satisfied with the final product, quality control should be carried out by another interpreter.

The final step of the process is to publish the data in your organization's catalogue. First, the metadata must be generated, preferably in the Harmonized North American Profile (HNAP) format. Then, the data distribution web services (WMS, REST) must be updated. These services must be prepared ahead of time. Where necessary, map templates should also be prepared in advance to allow for the quick creation hard copy or electronic maps for use in your organization's situation reports.

Figure 4 illustrates the operational process for mapping open water flood extent, in this case using the ArcGIS suite and PCI Geomatica.

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[8] https://www.osgeo.org/
[9] http://step.esa.int/main/

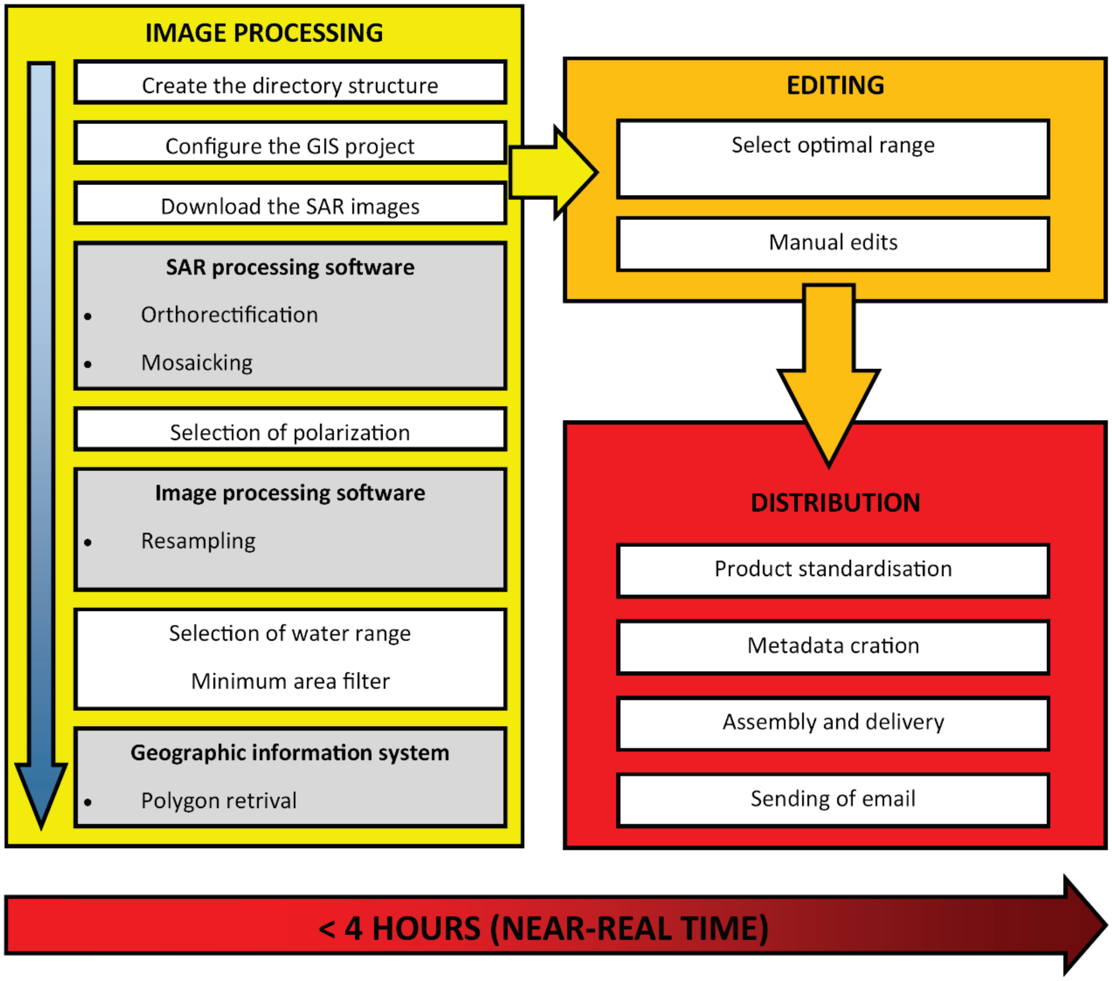

Figure 4: Concept diagram of the SAR image processing steps for mapping flood extent in operational mode.

Description of the derived open water extent

Figure 5 shows an example of a final product of extracting open water flood areas, that is, in an environment without impediments to radar waves, such as trees or buildings. This example of open water flood extent was produced using images acquired by Canada's RADARSAT-2 synthetic aperture radar (SAR) radar.

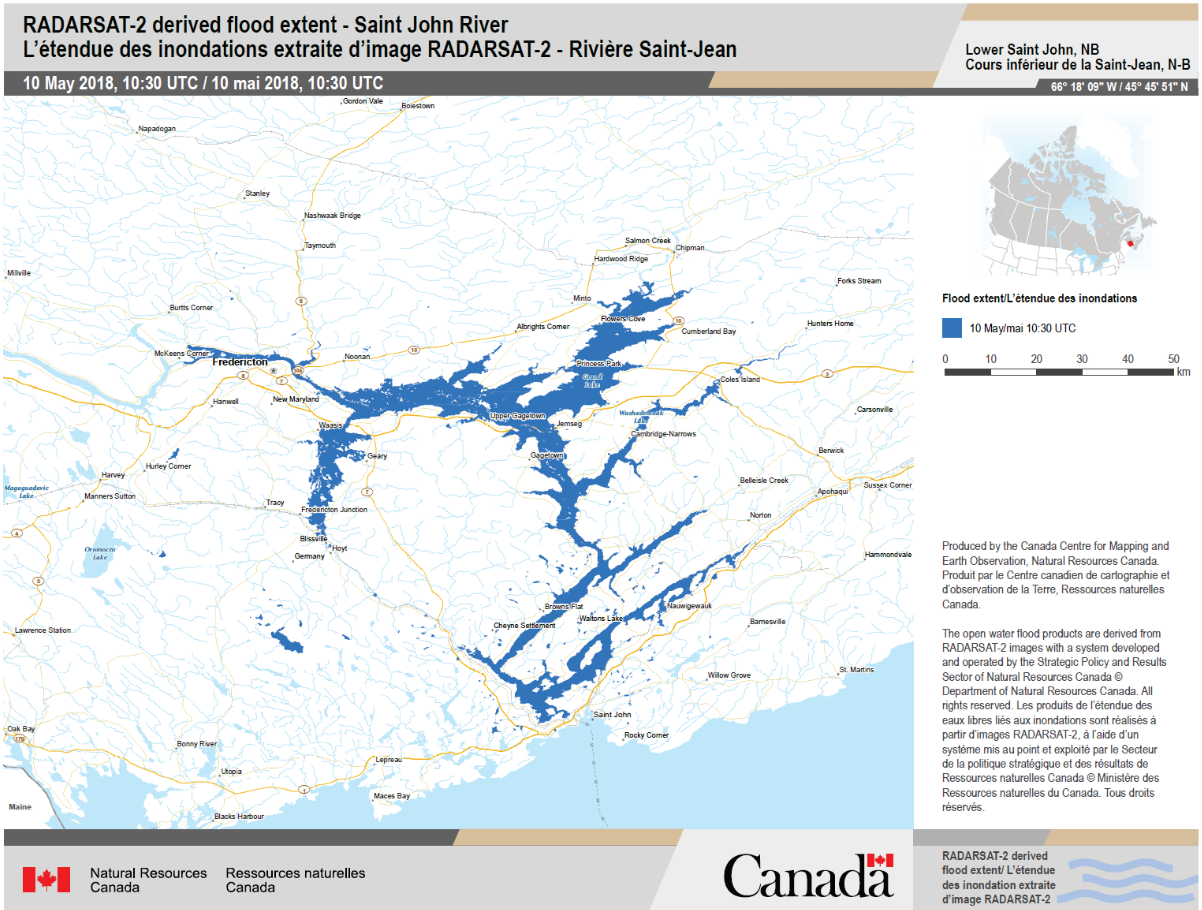

Figure 5: Example of final map produced by the EGS for the 2018 flood events of the Saint John River in New Brunswick.

Because emergency response authorities are the primary users of open water flood extent maps, these are generated quickly, leaving little time for editing and validation. Although every step is taken to guarantee their quality, near-real-time products may contain errors. In addition, the rise in water level may be very dynamic during spring thaw, and the products reflect the conditions at the date and time of satellite image acquisition (information available in the metadata for distributed products). The gravity of flooding is best interpreted by analyzing a time series of several products and/or in conjunction with validation in the field.

Considerations regarding final product quality

The data products sourced from SAR images entail limits imposed by the sensor parameters and the environmental conditions at the time the images are acquired. For example:

SAR images are sensitive to rough surfaces. Strong winds that generate waves, currents, rapids or the presence of ice are all factors that increase the roughness of surface water and make it harder to extract open waters.

SAR images are sensitive to soil moisture. Large quantities of wet snow or very wet fields have been known to be mistakenly categorized as water.

Other natural or anthropogenic targets that generate specular reflection may be mistakenly interpreted as water (e.g. smooth, wet ice; paved roads and parking lots; desert sand; airport runways).

SAR images acquired in mountainous areas can significantly distort the topography (foreshortening, layover, radar shadow) because of the lateral viewing geometry. Thus, a very steep topography can make it hard to extract flood extent data.

In dense urban environments, the presence of numerous buildings and many roads complicate flood mapping. Assuming that the SAR image resolution can be used to resolve the various targets, the shadow of buildings and the low radar response of roads will be confused with flooded areas, thereby generating many false positives in a highly vulnerable area.

Other elements to consider:

To reduce editing, a fixed spatial extent processing mask is used to delimit the extraction of polygons representing open waters in the areas of interest.

Minimum polygon size is established in hectares and varies by region, end-user requirements and field conditions.

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