Technical Bulletin - Flooding Hazards: Data Survey and Mapping Specifications

Version 1.0 - December, 2023

Ontario

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List of Acronyms

ADCP: Acoustic Doppler Current Profiler

CGVD: Canadian Geodetic Vertial Datum

CSRS: Canadian Spatial Reference System

DEM: Digital Elevation Model

DSM: Digital Surface Model

DTM: Digital Terrain Model

FEMA: Federal Emergency Management Agency

FGD: Foundation Geospatial Data

GIS: Geographic Information System

GNSS: Global Navigation Satellite Systems

GO-ITS: Government of Ontario Information and Technology Standards

GPS: Global Positioning System

H&H: Hydrology and Hydraulics

LAS: LASer

LiDAR: Light Detection and Ranging

MMAH: Ontario Ministry of Municipal Affairs and Housing

MNRF: Ontario Ministry of Natural Resources and Forestry

NAD83: North American Datum of 1983

NRCan: Natural Resources Canada

OIH: Ontario Integrated Hydrology

OLS: Ontario Land Surveyor

OSG: Office of the Surveyor General

PPP: Precise Point Positioning

PPS: Provincial Policy Statement

QL: Quality Level

RTK: Real-time Kinetic positioning

SONAR: Sound Navigation and Ranging

TIN: Triangular Irregular Network

UAV: Unmanned Aerial Vehicle

USGS: United States Geological Survey

UTM: Universal Transverse Mercator

1. Introduction

This Technical Bulletin is part of a guidance series which supports flood hazard identification and management activities in Ontario. One method to support flood hazard identification is through flood hazard mapping. This chapter provides a brief background on natural hazards and policy in Ontario, the purpose and scope of this document, and the main components of flood hazard mapping.

In the process of identifying flooding hazards, there may be a need to review additional guidance to support further technical work, prior to mapping the hazard. This additional information can be found in other available MNRF Natural Hazard Technical Bulletins (e.g., MNRF, 2002).

This document is reflective of the recommended best practices in flood hazard mapping in Ontario (data acquisition, processing, and mapping) at the time of the document release. MNRF intends to update this document periodically as technology and practices change.

1.1 Background

Ontario's approach to managing risks associated with flooding is based on the five pillars of emergency management: prevention, mitigation, preparedness, response, and recovery. The objectives of this approach are to reduce the risks to public health and safety, reduce public costs, build community resilience and maintain long-term prosperity, reduce the social disruption associated with emergencies; and help assure the continuance of critical infrastructure. The province uses a combination of legislation, regulations, policies, and guidance to achieve these objectives.

The main tools used to implement these policies are the Provincial Policy Statement (PPS) issued under the *Planning Act*, and natural hazard Regulations issued under the *Conservation Authorities Act*. MNRF's series of Natural Hazard Technical Bulletins supports the implementation of these tools.

As an overall principle for flood management, MNRF emphasizes the *prevention* pillar and prioritizes the use of non-structural approaches and land use planning measures to mitigate flood risks. This enables the province to direct development away from flooding hazards (and other hazardous lands) and prevent the creation of new or the aggravation of existing flood hazards. Understanding where hazards exist, by defining and identifying *hazardous lands* including *flooding hazards,* is a critical first step to supporting this direction. Mapping flooding hazards is often the most prudent way to identify these areas.

Flood hazard maps can be used to support the basic components of flood plain management, and the objectives outlined above. When flood hazard mapping is being created or updated, the procedures, methods, technologies, and accuracy levels recommended herein, should be applied.

1.2 Document Purpose and Scope

This document describes and presents the recommended survey and mapping procedures and standard methods needed to spatially characterise and map the flooding hazard. It is not intended to be a list of mandatory instructions or methodologies to be rigidly applied in all circumstances, but commonly accepted and recommended best practices. It serves to assist technical staff experienced in geomatics and water resources in the selection of the most appropriate and flexible implementation measures, provided the decisions made are consistent with the latest PPS, and current MNRF flooding hazard technical guidance (e.g., MNRF, 2002).

Although the Technical Bulletin presents commonly accepted and recommended best practices, it remains the users' responsibility to recommend and justify procedures, methods and parameters that best represent the conditions for the area of study. The Technical Bulletin cannot replace good geomatic, engineering and environmental judgement in adopting the most appropriate procedures required to achieve the amount of detail and effort involved, and in determining the practical degree of accuracy achievable when undertaking a flood hazard mapping initiative.

This Technical Bulletin is intended for use by municipalities, and for conservation authorities (CAs) in fulfilling their respective legislated mandates, as well as by consultants or other service providers undertaking flood hazard data acquisition, surveying, and mapping services for municipalities or CAs.

This Technical Bulletin aligns with provincial natural hazard policies outlined in Section 3.1 of the *Provincial Policy Statement* (MMAH, 2020) and should be used when mapping the *flooding hazard* and be considered as the definitive source for flood hazard data, survey, and mapping guidance in Ontario.

While the PPS also defines the *flooding hazard* to include areas along the shorelines of the Great Lakes – St. Lawrence River System and large inland lakes, the mapping of *flooding hazards* in these areas, is not necessarily the focus of this

Technical Bulletin, nor is the mapping of erosion, dynamic beach hazards or hazardous sites. While this does not preclude the use of this Technical Bulletin as a resource to guide natural hazard mapping in those areas, and for those specific hazards, direction for identifying and delineating the flooding hazard in these other areas is provided in separate MNRF Technical Bulletins.

Ontario's flood standards, as well as the hydrologic and hydraulic methods used to conduct flood hazard analyses and define the flooding hazard limit for riverine and small inland lake systems are outlined in the *Technical Guide – River & Stream Systems: Flooding Hazard Limit* (MNRF, 2002). The policies and performance standards and special flood hazard conditions and technical policies that inform this mapping, are also identified therein.

This document applies to both the development of new flood hazard mapping and the updating of existing flood hazard mapping.

1.2.1 Flood Hazard Mapping Project Components

A flood hazard mapping study includes a range of distinct components that define separate, but related processes. At a fundamental level this includes the following components:

- Selecting the flood standard;
- Reviewing data requirements for methods of hydrologic and hydraulic calculations as well as mapping requirements;
- Selecting hydrologic modelling parameters, including soil and land use data (mapping) to inform modelling;
- Selecting methods of computing flood flows (e.g., hydrologic model);
- Selecting method of computing water surface elevations (e.g., hydraulic model);
- Delineating/mapping the Flooding Hazard Limit (i.e. flood line);
- Preparing the Technical Report.

Not all components are necessarily conducted during the same study, and a particular study may choose to update or reuse components from a previous study where it is justified and defensible.

It should be noted that this Technical Bulletin does not reference or include information on all processes, components and/or data for the above highlighted flood study components that must be collected to complete a flood hazard mapping study. For instance, required monitoring data, channel roughness, stream gauge, rainfall, and other information to support flood modelling, are beyond the scope of this Technical Bulletin. A diagram outlining data and modelling components commonly used in flood hazard mapping and those specifically addressed in this Technical Bulletin, is included in Figure 1-1. More detailed examples of flood hazard mapping schematic workflow diagrams are included in Appendix 1, to assist in understanding various data inputs as well as model development and parameterization components included in the flood hazard mapping process.

1.3 Note on Terminology

This Technical Bulletin contains numerous references to Ontario and industry specific terms that may vary in other application areas or differ from other guidelines or specifications.

In Ontario, flood hazard mapping is defined as the extent of inundation from a defined *flooding hazard* as specified in the Provincial Policy Statement (PPS). *Flooding hazard* is defined as the "*inundation under conditions specified* [in the PPS] *of areas adjacent to a shoreline or a river or stream system and not ordinarily covered by water*" and defined by specific flood criteria.

In the LiDAR community, bare earth DEM is commonly used to represent ground surface terrain. In this Technical Bulletin, DTM is considered equivalent to bare earth DEM.

A glossary of terms is provided in Chapter 6.

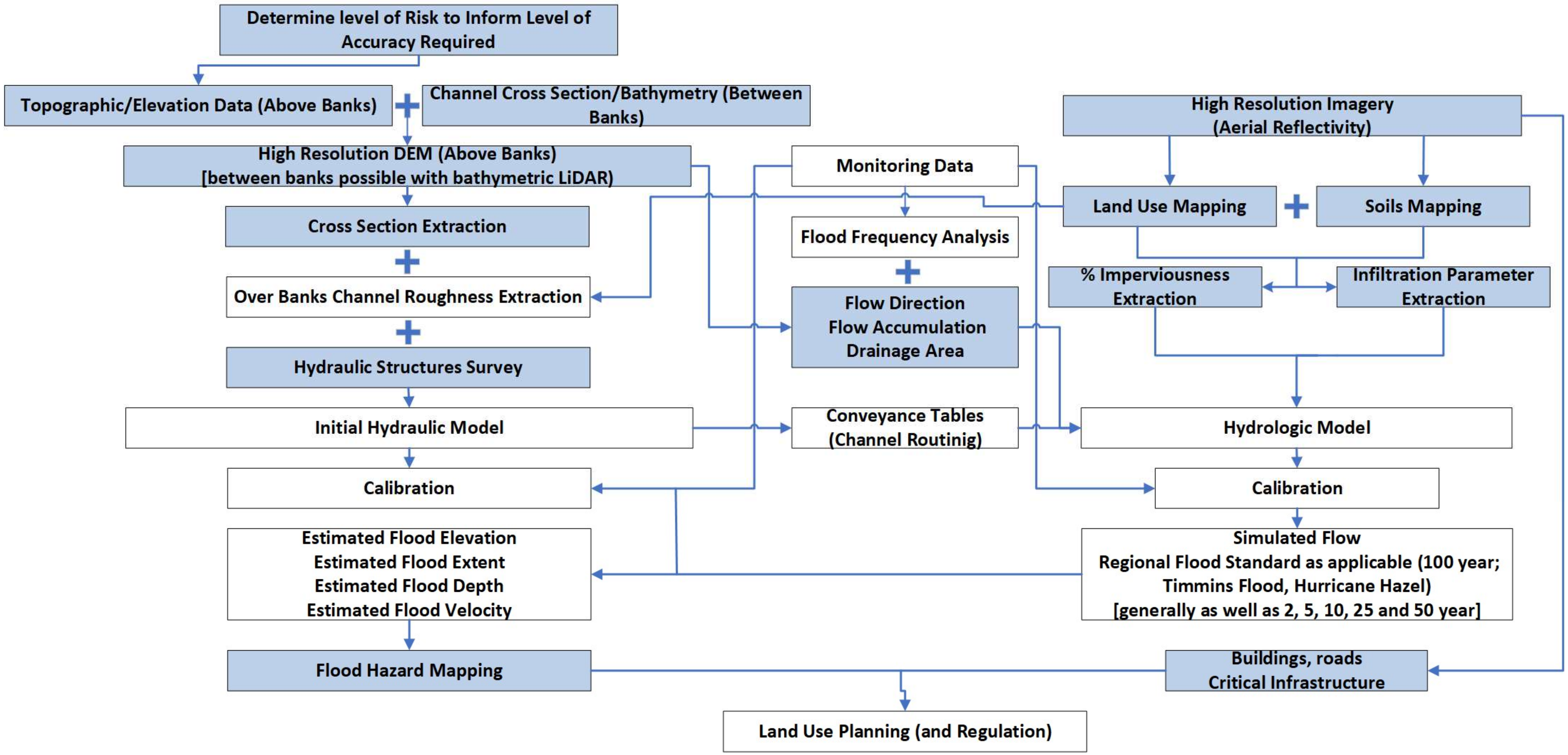

Figure 1-1: Recommended geospatial data components and workflows for flood hazard mapping. Components addressed in this Technical Bulletin, denoted by blue-grey coloured boxes.

2. Flood Hazard Mapping Framework

Flood hazard mapping is developed from a variety of survey data sources, including traditional, new, and emerging methods. Many forms of processed data from the survey may be used to complete flood modelling and base mapping. The recommendations in this document are intended to be technology-neutral, but the variety of survey and data processing methods and resulting end products will require some directed references.

As many different data sources and processing steps may be used to produce flood hazard modelling and mapping, this Technical Bulletin applies a framework to aid in this discussion, particularly regarding recommendations for specifications that would apply to relevant stages of the process, regardless of the exact methods being used. The framework shown in Figure 2-1 groups possible data sources and data processing steps to produce flood hazard mapping in defined steps and incorporating relevant decision points and checking standards for each stage of the flood hazard mapping process outlined. This framework allows the discussion of survey and mapping for flood hazards to be clearly generalized, and to define terms for categorized elements of the process without specifically defining standards for each possible survey technology or data source, which maintains the technology-neutral aspect of the recommended standards and specifications. Where relevant, however, recommended standards and specifications have been included for specific technologies.

The proposed framework is divided into five steps: Data Collection (Step 1), Data Processing (Step 2), Project Data and Deliverables (Step 3), Modelling (Step 4), and Mapping (Step 5) (Figure 2-1). This Technical Bulletin focuses on steps (1) to (3) and provides recommended specifications for step (5). Quality assurance checking processes necessary at each step are shown at the top of Figure 2-1: -1 (Described further in Section 3.6). Recommended data quality and accuracy specifications for data collection (Step 1) are described in Section 3.3 of this Technical Bulletin. Recommended specifications for data processing (Step 2) are described in Section 3.5 of this Technical Bulletin. Standards and specifications for project data deliverables (Step 3) are described in Section 3.8 of this Technical Bulletin. Recommended specifications for mapping (Step 5) are described in Chapter 5 of this Technical Bulletin.

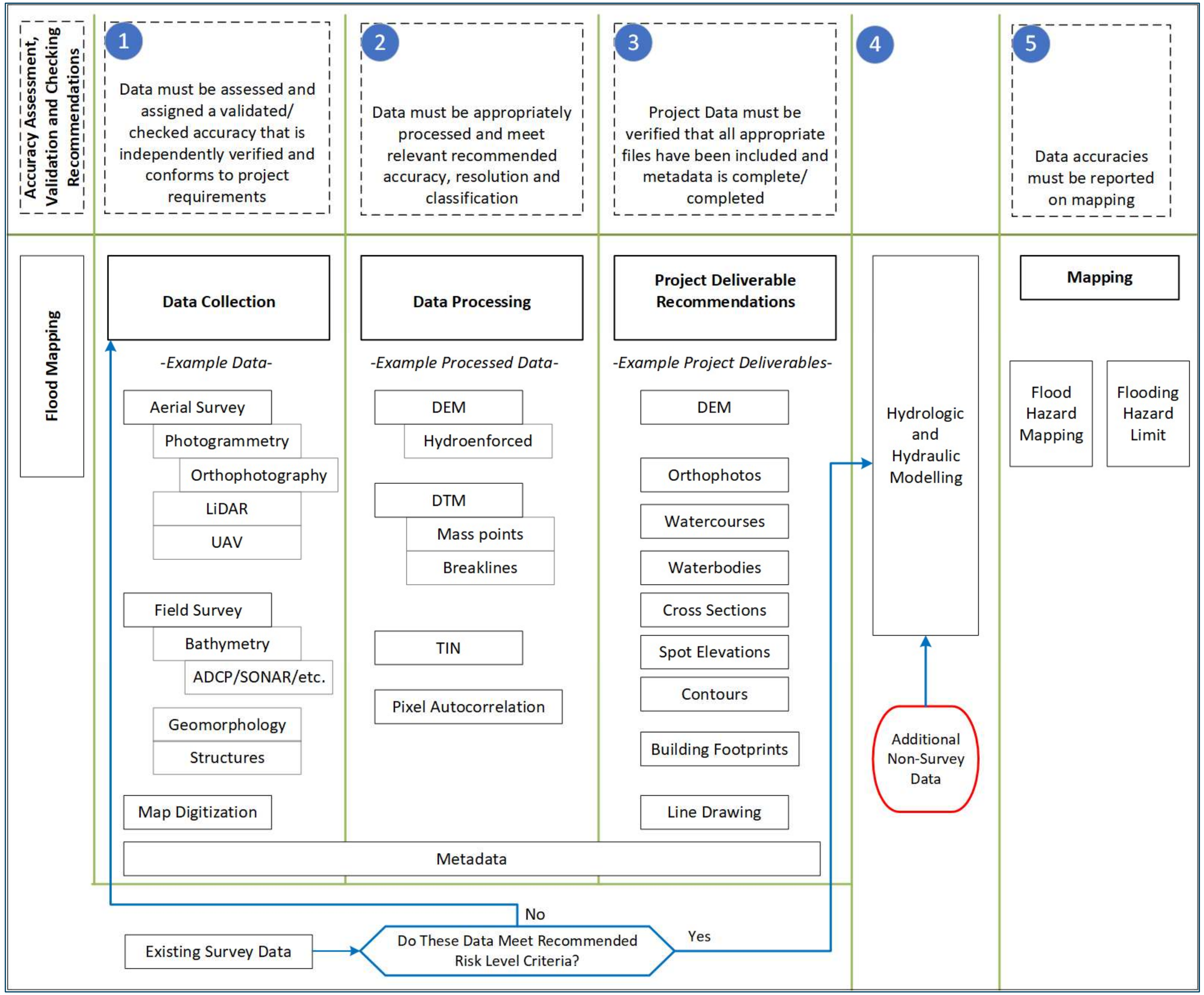

Figure 2-1: Key steps of the flood hazard mapping framework. Steps in bold are covered in this Technical Bulletin

3. Data Acquisition, Processing, Deliverables and Associated Recommendations

3.1 Scope

This chapter describes foundational procedures and protocols for acquiring data for flood hazard mapping as well as outlining risk classification categories that are used to define recommended accuracy levels for mapping in a manner commensurate with risk to people and property. Additional information on field and remote sensing methods as well as recommended project deliverables when conducting or procuring these data is also addressed.

3.2 Georeferencing and Metadata

Geospatial data for flood hazard mapping should be collected using consistent provincial georeferencing standards that allow for broad scale referencing, analysis, and integration. This section details recommendations for georeferencing and metadata that should be used and reported as part of a mapping project. The Province is working towards updating the Government of Ontario Information and Technology Standards (GO-ITS) to support height modernization including development of guidelines for horizontal and vertical datum transformations. This Technical Bulletin will be updated in the future to align with and reference pending GO-ITS standards.

3.2.1 Horizontal Datum

The current version of the horizontal datum NAD83 Canadian Spatial Referencing System (CSRS) realization, used in Ontario, is the Canadian Base Network (CBN) Version 6 - Epoch 2010.0 (available through COSINE, the provincial geodetic database). However, as of November 2021, the Geodetic Services program of the Office of the Surveyor General (OSG) is reviewing and analyzing the appropriateness of a new version of NAD83-CSRS (Version 7 – Epoch 2010.0) that has been defined and made available by the Canadian Geodetic Survey in February of 2019. This new version is developed from a newer realization of the International Terrestrial Reference Frame (ITRF 2014.0) versus ITRF 2008.0 associated with NAD83-CSRS-V6Epoch 2010.0. The Canadian Geodetic Survey considers NAD83-CSRS-V6 – Epoch 2010.0 and NAD83-CSRS-V7 – Epoch 2010.0 to be essentially compatible because the differences in coordinates are generally considered to be a few millimetres. This will be confirmed from an Ontario perspective by the work of the Geodetic Services program of the Office of the Surveyor General.

3.2.2 Vertical Datum

The vertical datum should be the Canadian Geodetic Vertical Datum CGVD2013 whenever benchmarks related to that system are available in the area of the project. The Geoid associated with the CGVD2013 vertical datum is the Canadian Gravimetric Geoid CGG 2013a. The current Geoid model associated with CGVD28-78 Version is the Canadian Gravimetric Geoid 2000 (CGG2000) in conjunction with height transformation software HT v 2.0. It is being replaced by the CGVD2013 vertical datum, and Ontario will eventually move to that as the first official Government of Ontario Information and Technology Standards (GO-ITS) for a vertical datum. At that time, datasets related to CGVD28-78 Version should be converted to the new official standard vertical datum, that is CGVD2013. However, with any conversion or transformation process, there is some loss in accuracy regarding the data that has been gathered and subsequently converted to the new datum. The only precise technique to convert heights between one vertical datum to another (e.g., CGVD28-78 to CGVD2013, NAVD88 to CGVD2013 etc.) is by conducting a geodetic-standard GNSS survey directly on benchmarks having published heights (NRCan, 2022a).

Therefore, it is recommended that when reference points (vertical benchmarks) are available that have CGVD2013 height values associated with them, that any new data associated with flood hazard mapping should be collected in relation to the new anticipated vertical datum standard, that is, CGVD2013. It is recommended that all new projects use the new CGVD2013 vertical datum whenever vertical benchmarks related to that system are available. If compatibility with CGVD28-78 is required, use of benchmarks that are related to both vertical datums (CGVD28-78 and CGVD2013) is recommended. Only when a project/levelling network is integrated with benchmarks available with respect to both datums can the values be rigourously computed with respect to both datums. Any time a transformation is used to convert data from one datum to another, there is an inherent loss of accuracy, because the transformation has its own accuracy in making the datum conversion. The more data that is available in relation to the new vertical datum, the less data must be converted and slightly degraded through a transformation process. Less data conversion means less costs for transformation in the future. That is why it is being recommended that new projects be completed in, or at least linked directly to benchmarks in the CGVD2013 vertical datum.

3.2.3 Coordinate Reference System

Six-degree Universal Transverse Mercator (UTM) mapping plane coordinates (projected from NAD83 CSRS, V7 Epoch 2010.0) should be used as the project reference systems and horizontal coordinates should be specified as eastings and northings, with the associated scale factor errors. Data must be collected in one UTM zone only. Detailed coordinate system metadata must be included with coordinate values including UTM zone (e.g., Zone 17 north).

3.2.4 Units

All data should be collected in metric units.

3.2.5 Data Extents

Data extents will depend on the project area and the survey technology. For field survey collection, the data extents must include any notable features that may influence water flow in the project extent. For LiDAR or other remote sensing data collection, a minimum buffer area of 100 m wide must be collected around the project area. For further considerations on data extents, refer to Natural Resources Canada (NRCan) *Guidelines for RTK/RTN GNSS Surveying in Canada* (Donahue et.al., 2015).

3.2.6 Metadata Standard

Metadata is the responsibility of the project custodian. All data associated with the flood hazard mapping process should include metadata conforming to the CGDI North American Profile (NAP) of the ISO 19115 Metadata standard. Additional metadata requirements are described in Section 3.8.2.

3.3 Data Quality and Accuracy Recommendations

The level of data collection effort should generally reflect the requirements of the intended flood mapping application, which typically depend on the level of flood risk and the regulatory framework in place. In Ontario, municipalities have a responsibility to identify areas subject to natural hazards and to develop management plans to limit exposure to public health and safety risks. It is up to the individual municipality to determine how best to achieve this requirement. Conservation authorities also map flooding hazards to identify areas where development is regulated under Section 28 of the Conservation Authorities Act, and to support providing programs and services related to the risk of natural hazards as prescribed by O.Reg. 686/21: Mandatory Programs and Services. Add to this, the considerations of population density, areas prone to flooding, and the availability of geospatial data and data acquisition technologies, it soon becomes apparent that one solution may not fit all applications.

The Flood Risk Categories defined by the federal guidelines assume LiDAR is available or can be acquired for the project of interest. While the elevation strategy and vision of the federal High-Resolution Digital Elevation Model (HRDEM) (NRCan 2022c) is to acquire LiDAR south of the productive forest line across the country, this does not preclude acquiring LiDAR for northern communities and other populated areas. There are many areas in northern Ontario including the Far North that do not have LiDAR or areas where field surveys to establish sufficient geodetic control networks and checkpoints may not be logistically practical and need to rely on more traditional geospatial data such as aerial photography (autocorrelated stereographic images or photogrammetry) and satellite imagery for their elevation derivatives. Many of these traditional technologies may not meet the more stringent accuracy criteria for LiDAR acquisition set out in the federal guidance. The guidance provided herein addresses this issue and should be considered the definitive source of flood hazard mapping guidance for use in the Province of Ontario.

Maintaining accuracy for flood hazard mapping is important for understanding the extents of areas and property susceptible to flooding. Good mapping relies on accurate source data in both horizontal (flood extent) and vertical (flood depth) dimensions.

Obtaining quality and timely elevation data and elevation derived features (see “Elevation and Breakline & Spot Height” themes in APPENDIX 3 for details) becomes critical as the accuracy is reflected and error is propagated through all data outputs of the project including the final flood hazard delineation.

All these features including published flood elevations should be captured using a horizontal and vertical datum that are consistent with the foundational elevation information acquired for a flood hazard mapping project. Relative accuracy becomes very important for accurate feature representation within the flooding hazard while absolute accuracy in many cases will be coarser than engineering level requirements. The model accuracy should be defined by the ability of the model to correctly reproduce the variables of interest, for instance, an observed flood event (Dottori et al., 2013). This involves a combination of factors including the accuracy of the input elevation data, the resolutions used for modeling and other characteristics that affect the behaviour of flooding like land cover and permeability.

When considering a new project, the practitioner should follow a few logical steps to determine whether new data or mapping is required and what level of accuracy is required for the project area (Figure 3-1). This assumes the agency responsible for flood hazard mapping has already gone through a flood hazard prioritization process to define where new or updated mapping is required to better support the protection of people and property. Also refer to Chapter 2 of this Technical Bulletin for different phases of a project where accuracy should be assessed or validated and Chapter 4 for other triggers for updating.

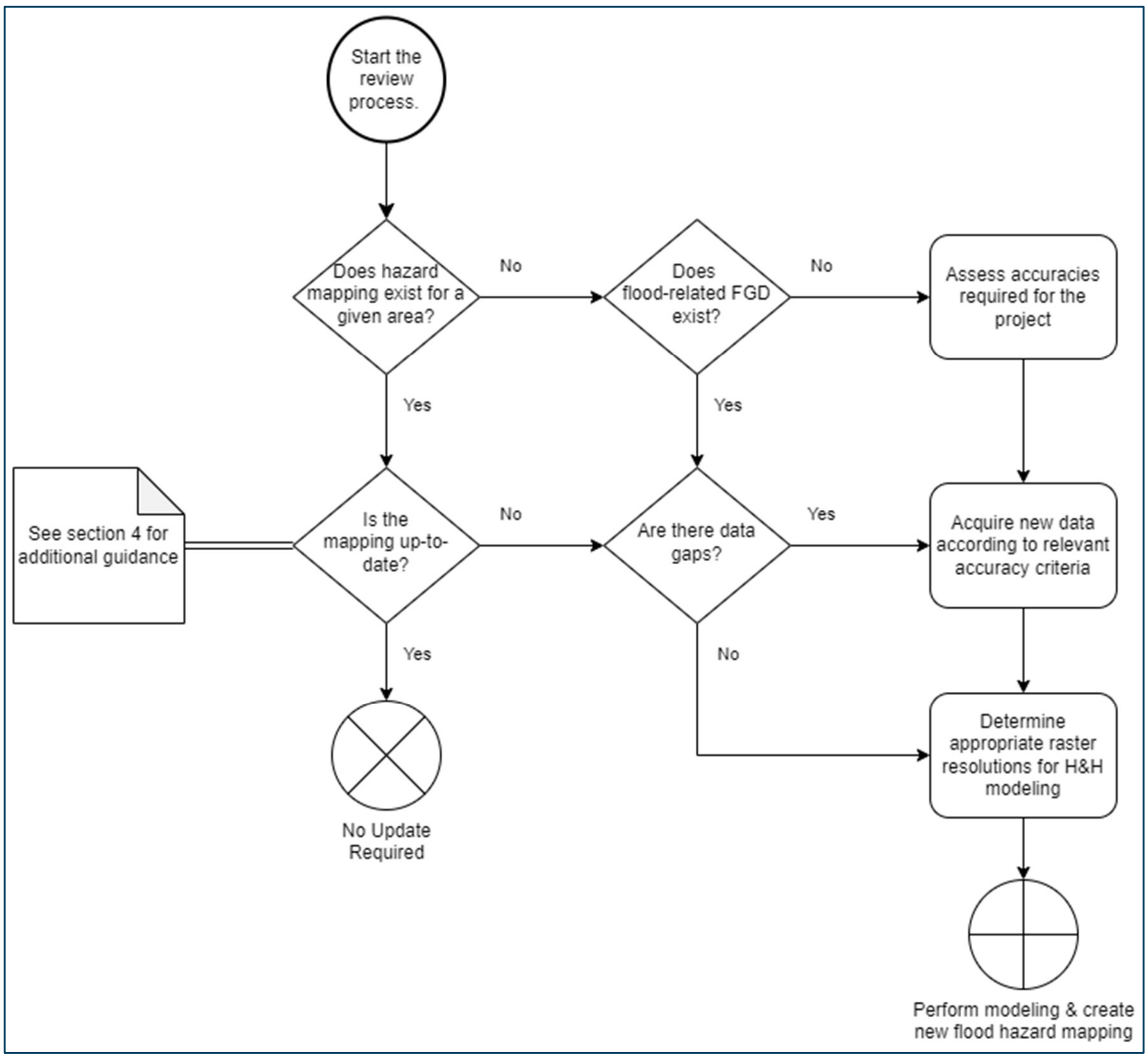

Figure 3-1: Example decision process diagram for assessing hazard mapping accuracy and modelling requirements.

3.3.1 Risk Criteria Levels Applied to Mapping Areas: Rationale

This section describes the recommended risk criteria levels for vertical and horizontal accuracy to produce suitable flood hazard mapping based on population density, critical infrastructure, and land use within the flooding hazard. Levels are based on advice of geomatics and engineering practitioners involved in flood hazard mapping in Ontario, and therefore may differ from federal guidelines.

The accuracy rigour required for elevation related data may not apply equally to other geospatial data inputs used in hydrology and hydraulic modelling. For example, land use and soils can influence infiltration and run-off rate parameters in hydrologic modeling. These parameters can be adjusted to produce more conservative water levels where the input data quality is coarse, sparse, or unknown.

The criteria levels defined below are suitable for most flood mapping applications. Data quality is often governed by how densely populated a certain area is or how the land use changes over time. A finer level of detail may be required to capture very subtle changes in the landscape. In some special cases, vertical accuracies of less than 7.5 cm as indicated in federal guidance (NRCan, 2022b) may be required, for example, for engineering or survey grade applications. Finer levels of accuracy should be weighed against the computational limitations of the modeling software and hardware used. Going too fine in resolution can also introduce undesirable noise artifacts when interpolating the flooding hazard limit.

Ontario's risk criteria levels are defined as follows:

Level 1: Densely populated urban areas, including urban and rural areas behind flood structures and/or where critical infrastructure is within or expected to be within the flooding hazard limit.

- These areas should be mapped using the 10 cm Vertical Accuracy Class or better.

Level 2: Densely or moderately populated urban areas that are expected to fall near or within the flooding hazard limit, that are expected to experience potentially high impacts of flooding, including property damage.

- These areas should be mapped using the 20 cm Vertical Accuracy Class or better.

Level 3: Moderately to sparsely populated areas near or within areas potentially prone to flooding, primarily surrounded by agricultural and/or forested lands with low to very low potential flooding impacts or other land-based risk.

- These areas should be mapped using the 50 cm Vertical Accuracy Class or better. This may depend on the best available data for the area of interest. Some areas in northern Ontario may be limited to coarser satellite or imagery-based elevation products and are often smaller rural communities which would be suitably captured in this category.

3.3.2 Recommended Accuracy Classes and Cell Sizes

The values in Table 3-1 define the accuracies recommended for flood hazard mapping in Ontario using the risk criteria levels set out in the previous section. These levels attempt to consider the differences in data quality and the different elevation technologies that may be available for a particular project study area. Note the same accuracy values applied to the input data may not always apply to the derived flooding hazard limit delineation because a compounding error can occur in the modeling process as surveyed data, land cover, impervious surfaces and other parameters are factored in. Therefore, it is important to report the accuracy of the derived DEM outputs and the flood hazard line separately from the input data.

The recommended raster cell size category in Table 3-2 are intended for interim raster products and derivatives created for flood modeling purposes. Care must be taken in selecting the appropriate resolutions for the project especially in the flood plain where the flooding hazard line (i.e., the flood line) is being determined. For example, in extremely flat areas, a subtle change in elevation can result in a significant change in the horizontal position of the flood hazard line. If the originating elevation data is very accurate with a dense point spacing, then selecting a smaller raster cell size would more appropriately capture the subtle changes in flat terrain. Where the terrain is hilly or the flood plain slopes are well defined, a coarser resolution might not impact the resulting flood line as much as it would in flat terrain. Choosing a fine resolution would need to be weighed against the processing capability of the model and hardware that are available. In some cases, multiple resolutions may be required in different areas of the flood hazard study area based on the characteristics outlined in Table 3-2.

Table 3-1: Recommended Minimum Accuracies by Risk Criteria Level for Flood Hazard Mapping.

Risk Levels for Ontario	Vertical Accuracy Class (VAC) (X_v = $RMSE_z$)	Non-vegetated Vertical Accuracy (NVA) - 95% Confidence Level (≤ 1.96 * X_v)	Vegetated Vertical Accuracy (VVA) - 95th Percentile (≤ 3* X_v)	Horizontal Accuracy Class (HAC) (X_h=$RMSE_r$)	Horizontal Accuracy 95% Confidence Level (≤ 1.7308 * X_h)
Level 1	≤ 10 cm [[1]]	≤ 19.6 cm	≤ 30 cm	≤ 15 cm [[2]]	≤ 25.96
Level 2	≤ 20 cm [[3]]	≤ 39.2 cm	≤ 60 cm	≤ 35.1 cm [[2]]	≤ 60.75 cm
Level 3	≤ 50 cm	≤ 98 cm [[4]]	≤ 1.5 m	≤ 60 cm [[5]]	≤ 1 m

Characteristics of the model being used, and the data required to support its application are also important to consider. For instance, use of the finer resolution raster cell size category, "A" (see Table 3-2), which is equal to USGS QL2 (or better) is recommended for 2D hydraulic modelling to improve confidence in flow routing and hydraulics outputs (e.g., FEMA, 2021), regardless of the complexity of the terrain identified in Table 3-2. Most 2D modelling studies would rely on Risk Level 1 data accuracies.

Hydrologic or watershed modeling outside the flooding hazard limit may not require as fine a resolution to get an accurate prediction of flows upstream of a project area. For example, FEMA suggests raster cell sizes upwards of 30 metres for larger tertiary level watersheds may be adequate for hydrologic computations (FEMA, 2016a). In Ontario, the Provincial DEM or the Ontario Integrated Hydrology

[1] VAC value is in line with Quality Level (QL)2 FEMA/USGS lidar (FEMA, 2016b) and minimum federal recommendations (NRCan, 2022b).
[2] HAC value is in line with federal recommendations (NRCan, 2022b).
[3] VAC value is in line with QL3 USGS minimum lidar recommendation (USGS, 2021).
[4] NVA value is in line with FEMA medium specification level vertical accuracy requirements (FEMA, 2016b; FEMA, 2023).
[5] HAC value is in line with federal recommendations (NRCan, 2018).

(OIH) dataset could be suitable for this scale and purpose especially where large scale computation of entire watersheds is an issue.

Table 3-2: Recommended Hydraulic and Hydrologic Raster Cell Sizes

Cell Size Category	**Hydraulic Terrain or Study Area Characteristics**	**Recommended Raster Cell Size (Hydraulic Modelling)**	**Hydrologic Terrain or Study Area Characteristics**	**Recommended Raster Cell Size (Hydrologic Modelling)**
A	Subtly defined spillways or depressions with no distinct change in slope / Short Channel Length / Dense cross sections – High Complexity or Sinuosity	≤ 1 m x 1 m [6]	Flat Terrain / Small Watershed or Catchment	≤ 2 m x 2 m
B	Medium Channel Length / Medium Complexity	≤ 2 m x 2 m [7]	Rolling Terrain / Medium Watershed (Quaternary level)	≤ 10 m x 10 m [8]
C	Well-defined floodplain with distinct slopes / Long Channel Length / Low Complexity or Sinuosity	≤ 5 m x 5 m	Hilly Terrain / Large Watershed (Tertiary level)	≤ 30 m x 30 m [9]

6 Raster cell size is in line with QL2 USGS recommendation (USGS, 2021).
7 In line with QL3 USGS recommendation (USGS, 2021).
8 In line with FEMA Automated Engineering Guidance for hydrologic computations at the Hydrologic Unit Code 10 (HUC-10) or smaller watershed level (FEMA, 2016a).
9 In line with FEMA Automated Engineering Guidance for hydrologic computations at the HUC-8 watershed level (FEMA, 2016a).

3.3.3 Accuracy Class Specifications

The Ontario Elevation Accuracy Guidelines (MNRF, 2020) includes the formulas for calculating these accuracies. The tested accuracies should be reported in a project report in accordance with these guidelines with the following phrasing to indicate that they have been tested against independent check points, as outlined in section 3.4 of those Guidelines (MNRF, 2020). The accuracy level details should be filled in and should replace the blank spaces surrounded by square brackets.

For horizontal accuracy:

"This data set was tested to meet accuracy standards for Ontario Digital Geospatial Data for a [ ] cm Horizontal Accuracy Class. Actual positional accuracy was found to be $RMSE_r$ = [ ] cm which equates to +/- [ ] at a 95% confidence level."

For vertical accuracy:

"This data set was tested to meet accuracy standards for Ontario Digital Geospatial Data for a [ ] cm Vertical Accuracy Class. Actual non-vegetated vertical accuracy was found to be $RMSE_z$ = [ ] cm, equating to +/- [ ] cm at a 95% confidence level. Actual vegetated vertical accuracy was found to be +/- [ ] cm at the 95% percentile."

3.4 Data Acquisition and Collection Recommendations

All survey data must be collected using established procedures and be documented to make the work reproducible. The specific data required for each project must depend on the project area focus, extents, budget, and assessed risk criteria level as defined in Section 3.3. Projects may include areas that need to meet different criteria levels. The specific model application employed (hydrology, vs. hydraulic, 1D vs 2D hydraulic) can affect the type and accuracy of the data necessary to support a successful analysis.

This section defines data collection requirements that apply to all flood hazard mapping projects, and specific additional requirements based on survey technology. See APPENDIX 3 for a list of recommended data for flood hazard mapping. For clarity on elevation related terminology used in this guidance see the Glossary of Terms. In this guideline DEM is a generic term referring to a digital topographic and/or bathymetric data that is comprised as x/y coordinates and z-values to represent an elevation surface. A DTM refers to the bare earth surface (lowest surface, last reflective surface, or LIDAR last return) representing the surface of the "bare-earth" terrain, after removal of vegetation and constructed features. It can be structured either as a vector dataset (comprised of mass points and optionally 3D breaklines) to model bare-earth elevations or a raster dataset that is interpolated from the vector elevation data to model bare-earth terrain elevations.

Underground utility location should be performed prior to the field survey if there are any utilities identified or suspected in the channel. Utility location should be performed to the more stringent of the ASCE 38.02 or CSA S250-11 standards for accuracy of utility location.

Specific references to 1D hydraulic modelling terminology are used throughout this section (e.g., cross-sections) and may not be applicable to all model types. Where 2D modelling is employed for the inundated valley/floodplain area, as applicable, these should be replaced with comparable 2D specific data and data sources. In a 2D modelling environment, this will require the modeller develop a 2D computational mesh with sufficient faces/cells/elements to produce a detailed velocity distribution for the desired locations, as appropriate and include consideration of the components and structures identified herein. Where applicable, specific references to 1D and separate 2D guidance criteria have been made in this section.

3.4.1 Channel Bathymetry and Floodplain Topography

Robust channel and valley/floodplain topographical information is fundamental to understanding flood inundation and supporting accurate mapping of the flooding hazard, regardless of the dimensionality of the model employed. Acquisition of channel bathymetry and floodplain surface data must be planned to collect the relevant topographical, geomorphologic, and bathymetry measurements needed to generate representative data sets whether acquired using traditional field surveys or remote sensing technologies.

An accurate representation of conveyance in the river channel requires channel bathymetry and bed characterisation. It is common to have incomplete bathymetric surfaces to support flood hazard modelling. For instance, channel cross section survey data may be available at a few locations within the area of study, but the distance between cross sections is often too great to be used as the only source of bathymetric data.

There are four main methods for acquiring bathymetry data which include RTK/total station survey, ADCP (with integrated GNSS), SONAR and LiDAR. The optimal approach can be determined by comparing costs vs. benefits but should mainly be guided by where information is needed vs. where assumptions can be made. Any method should consider the on-the-ground data needs in the professional judgement of the modeller.

Considerations for choosing an optimal approach for bathymetry acquisition:

- RTK/total station – Optimal if a channel can be walked;
- ADCP with integrated GNSS – Optimal if only a small number of cross sections are required;
- SONAR – Optimal if only a small number of cross sections are required; and
- LiDAR - Optimal if a larger channel (width and length) where a more contiguous survey is required.

The breadth of approaches available (as outlined above) to obtain these important data, assists in their collection, particularly in cases where instream wading for data collection may be unsafe or otherwise difficult.

Emerging methods, such as spectral photogrammetry, which uses images at different wavelengths to estimate river-bed bathymetry, are limited to shallow (<2m) channels where visible light can penetrate the water surface and reach the bed, necessitating clear water conditions devoid of vegetation and algae to support accurate estimates (Legleiter et al, 2015). While these and other methods may continue to evolve, they are generally unacceptable for widespread use at this time.

Field surveyed channel cross section data should be used whenever possible, particularly for smaller (i.e., local), reach-based, flood hazard studies, and moreover for studies where detailed documentation of the onset of flooding is sought or where detailed ‘between the banks’, flow and level information is important for the study. For these, a longitudinal profile of the thalweg should be obtained to represent the low flow channel and include the main slope inflections to plot the bed profile. Water depths should be collected at each acquisition point.

As LiDAR data from earth-surface aquisitions do not penetrate the water surface, channel bathymetry is depicted as a flat line and representative of the water surface, where water is present between the banks. When applied indiscriminantly these data can significantly underestimate channel characteristics (e.g., channel depth and changes in depth) and channel area. The morphological characteristics of the channel (e.g., wide, shallow channels vs. narrow and deep channels) as well as water surface elevation at the time of acquisition can impact the suitability of near stream LiDAR for modelling and mapping purposes. Stream channel cross sectional survey data can be useful to compare against detailed topographic LiDAR for assessing the accuracy of the LiDAR surface as a representation of the channel. In cases where LiDAR was collected when water levels were low, particularly for shallow channels, much of the bed profile may be accurately reflected in the LiDAR data and these data may be a suitable proxy for channel bathymetry surveys. If water levels were high during LiDAR acquisition and/or the channel is deep, these data will most likely not be sufficiently accurate. Use of best professional judgement is required when evaluating LiDAR as a source of bathymetric data and should be considered and used on a case-by-case basis, when corroborated by bathymetric field validation.

While modelling software may include provisions to support the use of assumed or interpolated bathymetry, their use should be avoided whenever possible, and should not be be a replacement for actual field data. For watershed scale flood hazard studies, it is a best practice to collect detailed bathymetric data in areas of interest and develop approximate data for the reaches that are of less concern, where justified (e.g., estimated channel shape approximates the channel area with satisfactory accuracy). In the context of having sufficient topographic data with limited or no channel data, it is reasonable to to conclude that for watershed scale flood hazard studies, approximating channel bathymetry in some locations is an improvement in the representation of the site relative to using the water surface elevation as represented on LiDAR, as the bed of the channel. Practitioners should apply best professional judgment whether additional bathymetric information is required for a specific studey. Relevant factors include the influence of channel bathymetry on flood inundation relative to the flood magnitude(s) being modelled, the stream and river morphological characteristics, valley setting, and suitability of available data.

It is recommended that cross section length be at least 20 times the bank full width and extend at a minimum, the cross-sectional area of the floodplain during high flow conditions expected under *flood standard* being modelled. Hydraulic structures or other structures, including natural landforms and related features that may impede flow in the channel must also be obtained to include in cross sections/model.

Where a DEM is available for overbank areas, and it meets or exceeds the respective accuracy classes for the risk levels outlined in Table 3-1, surveys or cross-sections do not need to extend the full extent of the floodplain, but rather can rely on the DEM data.

For discerning river vally/floodplain topography, where available, LiDAR data that meets or exceeds the risk level criteria outlined in Table 3-1, is suitable for discerning out of bank, floodlplain transects (i.e., for 1D modelling as appropriate) and for the purposes of 2D model computational mesh development. It is also worthwhile noting that in some cases, LiDAR floodplain surface topographic data may not reflect current or recent changes in topography due to known natural proceses or human unduced landscape change. Under these circumstances the LiDAR data should be supplemented with other sources of data including as built drawings, and or OLS surveys, as appropriate.

3.4.1.1 Location of Cross Sections

Cross sections should be taken perpendicular to the river flow (i.e., the stream centreline), and in riffle areas with irregular crests, it is recommended that an additional cross section perpendicular to the riffle crest be taken to ensure that the bed elevation is accurately represented in the cross section. Since reach features may be irregularly spaced, no set spacing is recommended as long as all relevant features are captured. Cross section location and spacing is a function of stream size, slope, and the uniformity of cross section shape. Cross section spacing must be laid out to accurately describe the channel and floodplain geometry. Iincluding relevant features of each reach such as riffles, riffle crests, pools, bar forms, and any other components identified as important to the river hydraulics, are particularly important for studies examining the onset of ‘out of bank flooding, or for smaller, local reach-based mapping studies.

There must be enough representative cross sections throughout a stream reach to adequately describe the following:

- Contractions or expansions of the channel and/or floodplain;
- Changes in bed slope, and roughness; and
- Significant changes in discharge.

Cross sections must also be added immediately upstream and downstream of the following features:

- Tributary inflow locations;

- Dams and other inline structures that act as internal boundaries (e.g., weirs, drop structures, natural drops in the bed profile);
- Bridge and culvert crossings; and
- Where any lateral hydraulic structures exist (e.g., levees, dykes).

Where abrupt changes occur in these parameters, several cross sections should be used to describe the change, regardless of the distance between cross sections. For instance, to adequately characterise the the effect of structures (e.g. culverts, bridges etc.) on water surface elevations and flows, in addition to surveys and modelled cross sections upstream and downstream of the structure (as highlighted above), extra cross sections should also be surveyed and modelled at a sufficient distance away from the structure (upstream and downstream) where it no longer affects flows or levels. These distances are often referred to as the contraction and expansion lengths. Additional essential locations for the positioning of cross sections to inform modelling, include at:

- The model limits;
- Sites of key interest to the modeller and project; and
- All flow and level gauging stations.

All features and attributes outlined above should be adequately captured to support robust hydraulic simulations and considering the intent of the modelling (e.g., flood hazard delineation), must sufficiently document the physical attributes that affect flood propagation, as determined by storage, conveyance, and controls. In some circumstances, additional cross sections including other features and attributes than those listed may be required to adequately characterise water surface elevations under flood conditions.

A useful starting point for estimating the spacing of cross sections has been presented by Samuels (1990) and Fread (1993).

While conventional wisdom has suggested that closer cross sections make for a more stable model, this is not necessarily true. Having cross section spacing too close can overestimate energy loss and introduce significant error leading to model instability. In contrast, when cross sections are spaced too far apart and changes in hydraulic properties are great, the solution can become unstable. Research into cross section spacing has generally suggested that inaccuracy of model results in terms of mean absolute error has been found to increase as the spacing between the cross sections increases (Samuels, 1990). Further guidance can also be found in the "Cross Section Spacing and Hydraulic Properties" section of the *HEC-RAS Hydraulic Reference Manual* (USACE, 2022).

Map contours are used to align the cross section, to abstract cross section points, and to plot flood lines between cross sections. Surveyed cross sections must include the entire floodplain of the main channel and any tributaries. The general approach to laying out cross sections in the hydraulic model is to ensure that the cross sections are perpendicular to the main channel as well as flow lines expected in the flood plain. This requires that an estimation of what the flow lines will look like in the overbank areas away from the main channel also be undertaken (Figure 3-2). Occasionally it is necessary to layout cross sections in a curved or dog legged alignment to meet this requirement (Figure 3-2). Regardless, every effort should be made to employ data that accurately represent the stream and floodplain geometry.

Where large distances exist between cross sections, hydraulic models assume a straight-line interpolation between these cross sections. These data are unsuitable when 2D models are used (for instance with a coupled 1D-2D model), as it increases the potential for discrepancies between bank elevations interpolated between the cross sections and the bank elevations represented in the 2D topographic data. A general best practice with regards to channel bathymetry requirements for coupled 1D-2D models, includes extraction of the channel bathymetry from the detailed 2D topography at distance intervals between 5 to 20 times the size of the 2D model grid cell/mesh elements. To support this process, additional detailed channel bathymetric information may be required.

3.4.1.2 Data Collection at Cross Sections

While aerial surveys may be used to generate cross sections from processed data, the generated cross sections should be inspected and verified. If they are not suitable for use, field surveys must be used to provide cross section data.

All cross sections should include the following data:

- All points must be georeferenced and shown as geospatial point features;
- Points must represent significant breaks in ground slope and changes in hydraulic characteristics of the floodplain;
- Bank elevations to the channel bed and the deepest part of the stream must be measured;
- Water depth measurement at each wetted survey point;
- All surveyed cross sections must be tied in vertically to established benchmarks and horizontally to permanent structures;
- In areas of consistent slope, readings must be taken at a maximum spacing of 15 m;

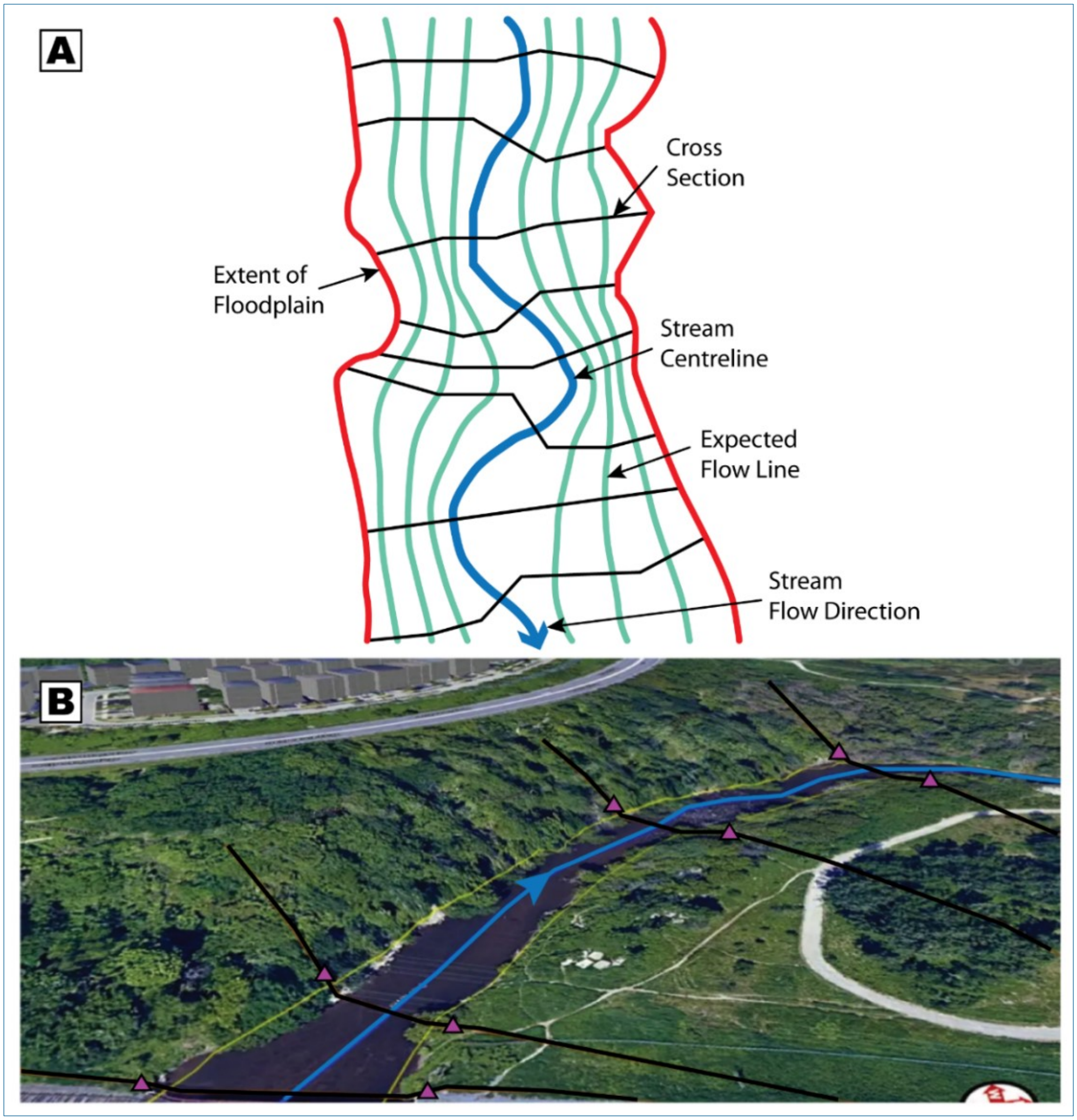

Figure 3-2: Cross sections (cut lines) in 1D hydraulic model showing perpendicular orientation at river centroid as well as: (A) how flow lines are anticipated to look in overbank areas (source: Goodell, 2012); and (B) cross sections with respect to the broader landscape topography and land use, with bank stations shown as purple triangles (image adapted from CivilGEO, 2022). Symbology adapted from federal guidance (NRCan, 2019a).

- Supplementary readings must be taken in areas of major change in relief;
- For irregular features, the survey must include points at significant bends in the feature, and at a maximum distance of 10 m; and
- Survey must include points at the following if they are in the cross section: deepest part of the active channel benchmark pins, erosion pins, channel bar, island, edge of water, bank of island, rail berm, rail berm toe, corner slab front left and front right, upper pad front left and front right (e.g. single point load structures), edge of water on island, tributary confluence, and wetland drainage.

The list below shows the codes that should be used to describe each point feature that can be stored for cross sections and geomorphology points. Features along a cross section survey profile are shown in Figure 3-3. Alternate survey codes may only be used if a full table of survey codes and descriptions are included with the data submission.

Survey Codes for Channel Geomorphology and their descriptions (OFMTWG, 2015) include:

- CC: Centre of channel
- STN1: Station number
- TBM: Temporary benchmark
- XS-1: Cross section number
- XS-1B: Bank at cross section
- XS-1BF: Bank full at cross section
- XS-1EW: Edge of water at cross section
- XS-1W: Wetted part of the cross section
- XS-1F: Flood plain at cross section
- XS-1V: Valley in cross section
- XS-1PIN: Benchmark pins at cross section
- XS-1EP: Erosion Pin at cross section
- XS-1BAR: In channel bar in cross section
- XS-1ISLAND: Island in cross section
- XS-1EWI: Edge of water at bar in cross section
- XS-1BI: Bank of Island at cross section
- XS-1RAILBRM: Rail berm at cross section

- XS-1RAILBRMTOE: Rail berm toe at cross section
- CRESTB: Bank at crest
- CRESTBF: Bank full at crest
- CRESTEW: Edge of water at crest
- CRESTW: Wetted part of crest
- FLCSLAB: Front left corner slab
- FRCSLAB: Front right corner slab
- FRUPAD: Front right upper pad
- FLUPAD: Front left upper pad
- EDGEISLAND: Edge of water on island
- TRIBCONFL: Tributary confluence
- WLNDRAIN: Wetland drainage

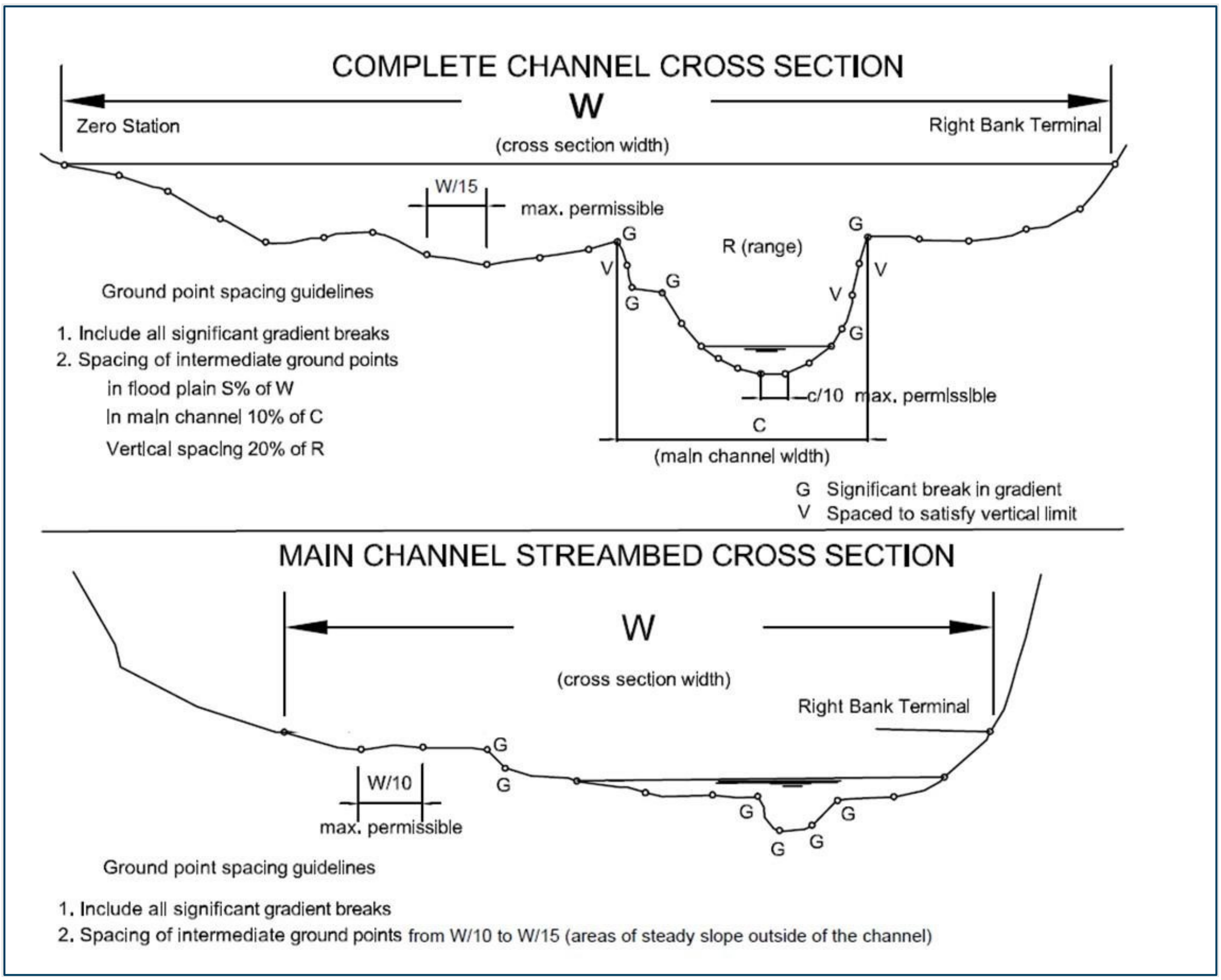

Figure 3-3: Features of a basic cross section survey.

Spot Elevations to be shown in mapping should be taken at the following points by either remote sensing or field survey:

- Intersections of all roads, railways, trails and foot paths;
- End of runways;
- All bridges, culverts and watercourse crossings;
- Dams, docks, piers, and wharfs; and
- All water bodies (in accordance with Ontario's large scale hydrographic data capture specifications (MNRF, 2011).

3.4.2 Buildings and Structures

Buildings or other constructed features that may impede flood flow must also be represented in the DEM or cross sections used for hydraulic modelling. In large area models, some structures that do not impede flow to a noticeable degree, such as decks, should not be represented. A table for hydraulic structure survey codes is included as Table 3-3. As previously identified, alternate survey codes may only be used if a full table of survey codes and descriptions are included with the data submission.

Flood control structures and roadways near the watercourse should also be represented. The following data should be collected for hydraulic structures:

- Photographs of each hydraulic structure, upstream face, downstream face, looking across the overtopping section from left to right, looking upstream, looking through the structure, and looking downstream;
- All photographs taken in the field will be geo-referenced and organized and named according to feature of interest;
- Highwater Marks and Debris Lines;
- Highwater or flood marks: ice scars, scour marks, signs of relief flow and deposition scour, and location, type and size of debris should be surveyed and photographed;
- Data sheets shall be prepared for all hydraulic structures; and
- Bridges, dams and embankments, road / rail crossings, and any other structures that impact river hydraulics.

Each hydraulic data sheet should contain the information shown below and where applicable those additional data listed.

Data for all hydraulic structures:

- Vendor / Survey Team
- Date
- Street Name
- Datum (horizontal and vertical)
- UTM Co-ordinates (UTM zone, complete easting and northing values in metres)
- Skew Angle
- Crossing Length
- Entrance (vertical abutments, headwalls, wingwalls, mitered to slope, projecting)
- Parapet Type and Dimensions, Length and Height

Additional data regarding hydraulic structures (include where applicable):

- Deck Thickness
- Number of Cells
- Each Cell Shape
- Each Cell Dimensions – Span, Height
- Each Cell Material
- Pier Width
- Top of Road Elevation
- Road Sag Elevation
- Upstream and Downstream Crossing Invert Elevations
- Upstream and Downstream Soffit Elevations
- Crossing Material
- Assessment of Scour / Deposition, and Potential for Debris Blockage
- Top-of-dam elevation
- Normal pool elevation
- Principal spillway type
- Inlet and outlet elevations and dimensions
- Emergency spillway type, elevation and dimensions

Table 3-3: Survey Codes for Hydraulic Structures

Code	Description	Field Survey Location
ABT	Abutment	Face / foot of abutment of bridge
BOCEDS	Back of Curb Edge Downstream	Where slope meets top of culvert or top of headwall above culvert centreline on downstream end for determining outlet projection.
BOCEUS	Back of Curb Edge Upstream	Where slope meets top of culvert or top of headwall above culvert centreline on upstream end for determining inlet projection.
BRCL	Bridge Centreline	Centreline of bridge in overtopping section.
CH	Channel	Stream bottom between TOS shots.
CUL	Culvert Shape	Multiple CUL codes can be used to define shapes for culverts, especially irregular shapes.
CULCL	Culvert Centreline	Centreline of culvert in overtopping section
CULDSCR	Culvert Downstream Crown	The highest point of the downstream end of a culvert.
CULDSINV	Culvert Downstream Inlet	The lowest point of the downstream end of a culvert.
CULUSCR	Culvert Upstream Crown	The highest point of the upstream end of a culvert.
CULUSINV	Culvert Upstream Invert	The lowest point of the upstream end of a culvert
DAMCL	Dam Centreline	The high point of a dam.
DH	Dune Heel	Landward toe of primary frontal dune.
DP	Dune Peak	Peak or rear shoulder of primary frontal dune.

Code	Description	Field Survey Location
DT	Dune Toe	Seaward toe of primary frontal dune.
EOB	End of Bridge	End of bridge desk at the road / rail elevation.
ERM	Election Reference Mark	Permanent elevation monument. An ERM must be set at every structure and at cross sections if they are more than half a mile to the nearest structure.
FBCL	Foot Bridge Centreline	Centreline of non-vehicular bridges in overtopping section.
GDR	Guardrail	Top of guardrail at ends to define limit and height.
GDRBOT	Guardrail at Bottom	Base of guardrail at ends to define and height.
GR	Ground	On ground to show elevation changes, used outside TOB shots, between TOB and TOS, and to indicate islands or bars within the channel. When used in channel cross section surveys, a GR point must be placed at least 15 feet past the top of bank or until there is no overhead obstruction from foliage. If overhead foliage is too thick for the entire overbank area, full valley cross sections should be consideration for modelling.
HWMARK	High Water Mark	Historical high-water marks-mud / stain lines, drift lines, parole evidence, etc.
INVDS	Invert Downstream	Channel invert at downstream end of structure, used to define paved aprons.
INVUS	Invert Upstream	Channel invert at upstream end of structure, used to define aprons.

Code	Description	Field Survey Location
LC	Low Chord	Change in bridge deck thickness, usually at centre of a pile row or pier. Multiple low chord codes can be used to define irregular shaped bridges such as arched bridges with the explanation of the multiple LC shots shown in the sketch for the structure.
LCDSL	Low Chord Downstream Left	Bottom of deck and beam at the downstream left corner of bridge[1].
LCDSR	Low Chord Downstream Right	Bottom of deck and beam at the downstream right corner of bridge[1].
LV	Levee	Centreline of the top of a levee.
PIER	Pier	The up and downstream centreline of a pier.
PILE	Pile	The up and downstream centreline of a row of piles.
RAIL	Rail	Top of rail to define limits and height of railing on structures.
RAILBOT	Rail Bottom	Bottom of rail to define limits and height of railing on structures.
RDCL	Road Centreline	The centerline on a crowned road or the high side of a road with super elevation.
SFLOOR	Sea Floor	Shots either direct or combination of bathymetric and conventional / Global Positioning System (GPS) survey of coastal area which can be collected during structure or transect survey.
TEMP	Temporary Control Point	Temporary control point used for data collection of cross sections and structures. TEMPs are established when ERMs are not present.
TOB	Top of Bank	Top of bank in a multiple channel scenario.
TOBL	Top of Bank Left	Break point from over bank to channel on the left side when looking downstream.

Code	Description	Field Survey Location
TOBR	Top of Bank Right	Break point from over bank to channel on the right side when looking downstream.
TOD	Top of Deck	To show an irregular arch or dip in a bridge deck between the bridge corner shots.
TODDSL	Top of Deck Downstream Left	Downstream left corner of a bridge on the deck directly above the LCDSL shot to measure deck thickness and width[1].
TODDSR	Top of Deck Downstream Right	Downstream right corner of a bridge on the deck directly above the LCDSR short to measure deck thickness and width[1].
TODUSL	Top of Deck Upstream Left	Upstream left corner of a bridge on the deck directly above the LCUSL shot to measure deck thickness and width[1].
TODUSR	Top of Deck Upstream Right	Upstream right corner of a bridge on the deck directly above the LCUSR shot to measure deck thickness and width[1].
TOS	Toe of Slope	The toe in a multipole channel scenario.
TOSL	Toe of Slope Left	Break point from channel bank to channel bed on the left side when looking downstream.
TOSR	Toe of Slope Right	Break point form channel bank to channel bed on the right side when looking downstream.
WALL	Wall	Top of a retaining wall, also used outside TOBL and TOBR when the stream banks are vertical walls or rock cuts.
WALLBOT	Wall Bottom	Bottom of retaining wall, also used outside TOBL and TOBR when the stream banks are vertical walls or rock cuts.

Code	Description	Field Survey Location
WEIR	Weir	Top of dam spillways and outlet structures. Multiple weir codes may be used to collect data for gates, flashboards, and other operable structures. The explanation of the multiple shots should be shown in the structure sketch.
WW	Wing Wall	Top face of each end of a wing wall or headwall on a structure to define height and length.
WWBOT	Wing Wall Bottom	Base of each end of a wing wall or headwall on a structure to define height and length.

[1] The four bridge corner shots need to be taken outside of any rail to accurately measure hydraulic length.

3.4.3 Remote Sensing Data

3.4.3.1 Aerial LiDAR

LiDAR collection should conform to the Federal Airborne LiDAR Data Acquisition Guideline (NRCan, 2022b). All elevation data collected should be collected to conform to the required accuracy standards presented in Sections 3.3 and 0 of this Technical Bulletin, including checking (Sections 0 and 3.6.6) and metadata standards (Section 3.8).

3.4.3.2 Bathymetric LiDAR

An optional enhancement to flood plain modeling can include the use of Bathymetric LiDAR data. Costs, best practices and limitations should be considered before acquiring this type of data. The Federal Airborne LiDAR Data Acquisition Guideline – Appendix 5 Airborne topo-bathymetric LiDAR (NRCan, 2022b) provides guidance on bathymetric LiDAR surveys.

3.4.3.3 Imagery

Imagery data including orthophotos should be collected under the guidelines outlined in Chapters 5, 6, and 9 of the Imagery and Elevation Acquisition Guidelines V 1.2 (Mapcon Mapping Ltd., 2009). All elevation and imagery data collected should be collected to conform to the required accuracy standards presented in Sections 3.3 and 0 of this Technical Bulletin, including checking (Sections 0 and 3.6.6) and metadata standards (Section 3.8).

3.4.3.4 Unmanned Aerial Vehicles (UAV)

UAV data collection flights must be conducted according to the rules and regulations established by Transport Canada. Windy conditions make accurate data collection with a UAV more difficult. (OFMTWG, 2015). All remote sensing data should be collected to conform to the required accuracy standards of the remote sensor types employed on the UAV as described in the previous sections above (see Section 3.3).

3.4.3.5 Map Scanning and Digitization

In some instances, the scanning of historical hard copy flood hazard maps may be required to support a range of business requirements such as archiving, change detection, or legal matters. Digitization of features on scanned flood hazard maps should focus on flood hazard lines. If base features are required for a flood hazard mapping project, modern digital geospatial data should be obtained from sources such as municipal, provincial, or federal governments as well as conservation authorities.
A minimum resolution of 600 dpi should be used for scanning into geospatial image files. Control points, or reliable feature points, on the map should be captured in the scanned image to assist with geo-referencing.

3.4.4 Ground Control

New or existing ground control points must be at minimum three times more accurate at the 95% confidence level than the required accuracy of the data at the 95% confidence level that will be verified against them. New ground control points must meet the specifications to be included in COSINE for accuracy and monumentation and be redundantly tied into existing COSINE control points in accordance with provincial specifications. The Ontario Specification for GPS Control Surveys, the Provisional MNRF Specifications for Digital Levelling, and the Ontario Monumentation Specifications for Horizontal and Vertical Control Surveys are all available as PDF downloads through the Geodesy Ontario website. Any questions regarding these specifications can be clarified through the contact channels provided on the Geodesy Ontario website. In the case where direct geo-referencing based on the combination of GPS and IMU data is being used then there must be sufficient ground control points meeting the above criteria to allow for a verification of the geo-referencing accuracy.

Ground control that is used or established to support the calibration and processing of the data (LiDAR or otherwise) must be completely independent of the check points used or established to support the verification of the accuracy of the data product. Different ground control points or methods must be used in the verification of the accuracy of the data by an independent contractor/consultant or by the client receiving the data (if they have the capability to conduct the control survey/accuracy verification). For example, if COSINE ground control points are used to support the calibration and processing of the data, then alternate methods for accuracy verification could include using geodetic GPS receivers with long occupation times (several hours or 3 to 4 hours minimum) and submitting the independent data gathered for Precise Point Positioning (PPP) solutions. Another alternative could be the independent private sector Real-Time Kinematic (RTK) Networks if the project area is within their areas of coverage.

Care must be exercised when PPP or private sector RTK Networks are used. Users must understand the datum(s) and accuracy of positional data. If the datums used for independent data collection differ from the elevation base acquired for the project, the appropriate transformation must be applied so that the datums are consistent for the purpose of assessing accuracy. Also, one set of control points should be collected to calibrate and process the LiDAR and derivative data; and another set of independent check points of higher accuracy should also be collected to validate and estimate the accuracy of the LiDAR data and any derivative products produced (ASPRS, 2014a). Without a clear understanding of these parameters and principles an independent accuracy check will be invalid.

3.5 Data Processing and Derivative Products

3.5.1 DEM

If appropriate, DEM data should be hydroenforced to meet the project standards (hydroenforcement for hydrologic modelling and hydraulic modelling may require different processes) and include building elevations and other structure data to reflect flow path impedance. All elevation data must be processed to the bare earth terrain in the vicinity of floodplains that will require hydraulic modeling. This may include editing out bridge and overpass information to substitute a realistic streamflow surface, though additional data processing may be needed if it is determined that the elevations of the bridge may impede flood flows. Keep in mind, with regards to bridges and culverts, that the upstream flood line should make allowance for the backwater effects caused by the structure, whereas downstream of these structures the flood line should make no allowance for the temporary upstream ponding.

The acceptable level and type of artifacts in the data should be predetermined by the vendor and client to direct effort and budget.

3.5.2 Geospatial Rasters

Geospatial rasters developed from DEM / DTM data should meet the required resolution for their intended purposes.

3.5.3 Breaklines

Standards for production of breaklines can be found in the Ontario Specifications for LiDAR Acquisition (Government of Ontario, 2020). Breakline classification is further outlined in Imagery and Elevation Guidelines V 1.2 (Mapcon Mapping Ltd., 2009).

Breaklines are sometimes used for hydro-flattening elevation data and can be delivered as part of an acquisition project. However, hydro-flattening is not required for flood hazard mapping purposes but can be useful for identifying low confidence areas or data voids (see Section 3.6.5).

When required, breakline features must be classified and separately attributed for the following features:

a) Water Body Features:
    - Shorelines of water bodies and islands with constant elevation (lakes, reservoirs, etc.);
    - Created in a polygon feature class of a geospatial database (all polygons closed) with an elevation reflecting the water elevation at time-of-capture; and
    - Water features having a width of greater than 5x the desired accuracy level for the project shall be considered a polygonal water feature.

b) Linear Hydrographic Features:
    - Linear hydrographic breakline features (streams, shorelines, canals, culverts etc.) with varying elevations; and
    - Linear water features can be considered as less than 5x the desired accuracy level for the project (from shoreline to shoreline – not top of bank) and should be represented as line feature class in a geospatial database for use in identifying hydrological breaklines.

c) Road Features:

- Road features, not including bridges and overpasses, will be captured as edge of pavement breaklines as required.

d) Overpasses and Bridges:
   - The surface of overpass and bridge features will be captured as breaklines.

e) Ditches and any other linear surface features that divert hydrologic flow but are not covered by previous categories.

f) Attribute of the line breakline feature class should identify breakline type - 'Stream, 'road', 'bridge', 'ditch'.

g) Obscured Areas:
   - These are defined as vegetated (or in some rare cases densely shadowed) areas that are considered obscured to the extent that adequate vertical data cannot be clearly determined in order to accurately define the DTM;
   - These are the only features that may be captured as either a 2D or 3D closed polygon; and
   - These features are for reference information indicating areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation.

h) Soft Features:
   - In areas where the mass point elevation data and the above breakline features are not sufficient to create a hydrologically correct DTM, soft features such as ridges, valleys, top-of- banks, etc. will be captured as soft breaklines of varying elevations.

Water body and linear hydrographic breaklines can also be used to create a large-scale hydrographic dataset to enhance flood hazard mapping and modelling efforts. Refer to the Data Capture Specifications for Hydrographic Features: Large Scale (MNRF, 2011) for more guidance in compiling large scale hydrographic data.

3.5.4 Contours

Although contours are no longer used as the primary source of elevation data for generating flood hazard lines, they do still serve a cartographic purpose. Contours can serve as a reference layer on flood hazard mapping. It is recommended that contours are generated from the same source elevation data used to generate the flood hazard line to avoid data alignment issues. The following provides guidance on how to generate contours for cartographic purposes:

- Contours can be generated using a combination of elevation mass points, polygons, and breaklines to generate a TIN. In the case of LiDAR, contours can be generated from the source DTM or LAS point cloud;
- Contours should be extracted from the elevation surface without the application of any smoothing, splining, or other modifications to the contour;
- The contours should be a true reflection of the surface and should be reproducible based on the metadata provided;
- Contours should only be generated at an interval that is at least two or more times greater than the accuracy standard of the least accurate of features used to build the surface;
- If the contours show an area to be in error or suspect, the input mass points and breaklines should be reviewed and edited as appropriate prior to rebuilding the surface and regenerating the contours;
- If there is excessive noise in certain areas (e.g., complex undulating wetlands and steep slopes), selectively dropping intermediate contours to improve readability in these areas would be acceptable. If noise is prevalent across the entire study area, consider increasing the contour interval;
- The geospatial database containing the contours shall have an attribute to indicate if it is an index or intermediate contour, a depression contour, or if it is in an obscured area; and
- Contours should have metadata that identifies all the source data inputs used to create the surface the contours were derived from. The contour generation method, software and settings employed should also be stated in the metadata.

Refer to section 5 for further guidance on cartographic and accessibility considerations when portraying detailed information on a map.

3.6 Accuracy Assessment, Validation and Checking Recommendations

All survey data must be checked using approved checking methods and data of a higher accuracy to confirm its suitability and accuracy. It is recommended that the control survey check points, or check points established from control survey points be at least two times more accurate in their horizontal or vertical positioning/heighting to be effective as check points (ASPRS, 2023). The appropriate redundancy must be included in the field methods, for example, to ensure accuracy of points heighted with GPS, especially RTN/RTK points, all check points must be independently occupied at least two times. If base data for base mapping is not the same as the checked survey data used for modelling, it must also be checked to verify accuracy. Minimum requirements should be met for GPS control surveys for the Province of Ontario as specified in *Ontario Specification for GPS Control Surveys* (Government of Ontario, 2004) or in the *GO-ITS 45.3 Ontario Specification for GPS Control Surveys* (Government of Ontario, 2005) and in the Natural Resources Canada (NRCan) *Guidelines for RTK/RTN GNSS Surveying in Canada* (Donahue et.al., 2015).

The quality control (QC) checks of the project may be completed by the data producer or ideally under a standalone contract by a different firm or agency than the one who produced the data or by the client. If the QC finds data that does not meet the guidelines, then that data may be rejected and be required to be corrected and redelivered. The warranty period for reporting of errors will be for a period of one to two years after final delivery of all products, though final delivery may be delayed if errors are found earlier. The following accuracy checks conform to the Framework shown in Figure 2-1: and should be conducted as applicable:

a) Vendor accuracy verification of field survey or DEM. This should also be independently verified with a second set of check points provided by the vendor;
b) Data must be appropriately processed, documented, and checked to ensure it meets the relevant standards for accuracy, resolution, and ground classification. This can be independently verified by ground truthing or orthophotos; and
c) The client must confirm on handover that all required data products have been included, meet the requirements of the project, and that the metadata sets are complete. Geospatial files will be tested to ensure that all data have attributes populated with valid data, are topologically clean, and match geometrically to other layers as appropriate. If included, all orthorectified image tiles should be inspected to ensure that they meet the image quality guidelines in Imagery and Elevation Acquisition Guidelines Sections (5) Imagery and (9) Orthophotos (Mapcon Mapping Ltd., 2009). Mosaics of orthorectified image tiles will be inspected to ensure that there are no problems with matches across tile boundaries. GeoTIFFs will be tested to ensure that all files (100%) are populated with valid image data, have complete GeoTIFF headers, cover the correct area without gaps or overlaps, and are seamlessly balanced with all others.

3.6.1 Quality Control Reporting

The following information must be included in the quality control section of the report or separate quality control report:

- All agencies, conservation authorities, companies, and contractors involved in data collection and processing, including how they were involved and what areas of data they worked on;
- The hardware used to produce the data sources (manufacture, make and model of sensors, cameras, field survey equipment, etc.);
- Software products including manufacturer and version numbers, and what portion of the analysis they were used for;
- The source of all ground control points, their geographic and UTM coordinates, their type of control (local, municipal, COSINE, or CSRS – or first second or third order) and their accuracy classification for NAD83-CSRS control (Class A, B, C or D) and for NAD83-Orig control (first, second or third order) and for associated orthometric elevations (first, second or third order, as appropriate);
- The QC steps carried out, including sample rate and findings;
- Steps taken to mitigate any problems identified in the QC, and recommendations for future projects based on these problems and mitigation; and
- A letter indicating how data meets the agreed-upon requirements. If data could not meet the requirements, an explanation must be given and agreed to in writing before the acceptance of the data and final payment. Data not meeting the agreed-upon guidelines may be rejected in part or in entirety.

3.6.2 Field Survey Verification

All field survey points must be collected in accordance with best practices and verified for accuracy with respect to at least one existing benchmark.

3.6.3 Survey Data Checking – Flooding Hazard Limit and Elevation

Data used for checking accuracy should be established to be at least three times more accurate than the data set being checked (Government of Ontario, 2020).

The required number and type of check points should be decided on between the data vendor (data provider) and customer (end user). At least 20 vertical check points must be established to provide a 95% confidence level for a dataset, but the distribution of checkpoints can vary based on the general proportion of vegetated and non-vegetated area in the project. Checkpoints should also be distributed generally proportionally among the various vegetated land cover types in the project study area (ASPRS, 2014a). US FEMA guidelines suggest a minimum of 20 checkpoints in each of three to five of the available land cover categories (seven total) as they exist within the project area, for a total of 60 to 100 checkpoints established (ASPRS, 2014a). ASPRS provides a table of minimum check points needed by project area broken into points for non- vegetated area and vegetated area (shown in Table 3-4). Ten checkpoints should be added to each of the NVA and VVA surfaces for every additional 500 km^2 above 2500 km^2. These total check points represent a minimum number and establishing more check points will lead to a higher confidence in the accuracy of the data set. Vertical accuracy of point clouds from remote sensing data must be established before classification and development of derivative data products. The results of the accuracy check before the classification must be reported.

Vertical check points should be established to minimize interpolation errors from the collected dataset that is being checked and surveyed on flat or uniformly sloping open terrain with slope of less than 10%. Abrupt changes in vertical elevation or areas of dataset artefacts should be avoided. The U.S. Federal Geographic Data Committee standard suggests in areas that are largely rectangular and non-vegetated, checkpoints may be spaced at intervals of at least 10% of the diagonal distance across the data set, and at least 20% of the data points may be located in each quadrant of the data set (FGDC, 1998). Many data sets are irregular and vegetated with different types of growth, however, and in some areas, it may be difficult to establish field check points due to access issues for different terrain types. Since there is no generalized method for establishing check point locations, the decision of appropriate location and distribution of check points must be decided on in advance with respect to the project area to be studied.

Table 3-4 : ASPRS Recommended Number of Check Points

Project Area (Square km)	Number of Check Points in NVA	Number of Static Checkpoints in NVA	Number of Static Check Points in VVA	Total Number of Check Points
≤500	20	20	5	25
501 – 750	25	20	10	30
751 – 1000	30	25	15	40
1001 – 1250	35	30	20	50
1251 – 1500	40	35	25	60
1501 – 1750	45	40	30	70
1751 – 2000	50	45	35	80
2001 – 2250	55	50	40	90
2251 – 2500	60	55	45	100

3.6.4 Classification Consistency

Classification of LiDAR data for the purpose of flood hazard mapping must meet the basic classification scheme adopted by the *Federal Airborne LiDAR Data Acquisition Guideline* (2020). Point classification is to be consistent across the entire project. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, lifts, or other non-natural divisions will be cause for rejection of the entire deliverable (Government of Ontario, 2020).

3.6.5 Low Confidence Areas

Two-dimensional closed polygons should be created for “low confidence areas” (ASPRS, 2014a) where the bare-earth elevation values may not meet the overall data accuracy requirements. Generally, low confidence areas may be areas where:

- the ground is completely obscured by foliage or other features or shadow, or
- the nature of the surface is such that accurate elevations cannot be computed using normal techniques (for example – open water), and
- sparse elevation data interpolated over large distances may not adequately represent the terrain in the area.

There are two distinctly different types of low confidence areas formally recognized (ASPRS, 2014a), including:

1) Low confidence areas identified by the data producer in advance of the acquisition, highlighting areas where passable identification of the bare earth is expected to be unlikely or impossible. Candidate areas for this advance delineation include wetlands such as swamps and marshes. No control or checkpoints should be located in these areas and if contours are produced for these areas they should be dashed, and these areas should be exempt from accuracy assessment; and
2) Valid vegetated vertical accuracy areas, typically forests, that are delineated subsequent to classification, and are usually identifiable by the reduced density density of bare-earth points. These low confidence areas should be depicted with dashed contours; however, checkpoints should be surveyed, and accuracy assessments performed within these areas.

Elevation breaklines for water bodies would be an ideal reference for determining low confidence areas in open water. These breaklines could be captured by the vendor for new acquisition projects or as part of a field survey.

The Ontario Elevation Accuracy Guidelines (MNRF, 2020) contains more detailed guidance on defining low confidence areas in an elevation product.

3.6.6 Feature Data Horizontal Accuracy Check

A minimum of 20 points per project area will be used to check the horizontal accuracy of features on a line drawing or features on an ortho-photograph. The checkpoints will be located at 20 well-defined, identifiable and accessible features that are evenly distributed throughout the project area. If the observations for horizontal surveys meet the requirements for vertical accuracy, these points could be used for both accuracy checks. Conversely, vertical points typically would not be useful for horizontal checks as they are usually not feature specific.

3.7 Accuracy Accounting, Quantification and Reporting Recommendations

Criteria for data accuracy, raster resolution, and hydrologic and hydraulic modelling established in Section 3.3 guide the necessary reporting metrics to track the cumulative topographical error associated with each data set. Refer to Section 3.8 for geospatial metadata accuracy reporting considerations and Section 5.5.3 for mapping accuracy reporting considerations. Verification of the required data accuracy should always be performed independently of data collection as described in Section 3.4.4.

Collection under best practices and verification of the survey data is not necessarily enough to quantify the accuracy of a flood modelling and mapping process; other data sources and the modelling will also introduce uncertainty and impact the accuracy of the flooding hazard limit (flood line). Calibration and sensitivity analysis of these modelled data may reduce these issues. However, quantification of those non-survey data or modelling errors are beyond the scope of this Technical Bulletin. For provincial guidance related to hydrologic and hydraulic model calibration, validation, and sensitivity analyses, please refer to other available MNRF technical guidance.

Modellers should also keep in mind the practical use of their results. Hydraulic models can produce mapping with extremely high precision, but these outputs often need to be aggregated or generalized to a coarser scale for map readability and communication purposes. Therefore, it is important that modellers take great care in communicating uncertainty, according to the different needs of end users and the various formats of mapping information that is released (Dottori et.al., 2013).

3.8 Project Deliverables, Metadata and Data Storage

The recommended documentation and data that should be included in the project deliverables are provided in the bulleted list below. This list may be used as a checklist with included notes on the file name and file path of each item. Additional data may be required for the project based on the project type and survey technology used. All documents should be compiled as PDF files and the source files (e.g., MS Word file) should be kept with the project. Created PDF files must allow text to be copied and pasted to another document.

Any supporting data that are tiled must have an accompanying index spatial file. Tiles must be topologically correct and have only one part and cannot self-intersect (must be simple). Adjacent tiles must not overlap or have gaps between them.

Recommended project deliverables and descriptions for various report types are listed below:

- Project Report
    - Describing analysis purpose, possible alternate methods of analysis and rationale for the chosen method, limitations of the analysis, and a QA / QC

section detailing procedures for analysis, accuracy assessment, and validation of the point data (NVA, relative vertical accuracy), bare-earth surface data (NVA and VVA), any other checking procedures, and any other relevant information to report.

- Survey Report
    - Detailing calibrations, assumptions, collection of all ground control, including control points used to calibrate and process the data, checkpoints used to validate the data, the accuracy of all input control used, including the date of creation / acquisition, who it was created by, and if for another client, the original client or project for which it was created, and any other relevant information to report. The control survey report should include a diagram of all the control stations/benchmarks involved, raw data, processed GPS baselines (as appropriate), input and output data from any least-squares adjustment software (as appropriate), session plans and a report – it is worth noting that, the returns of survey should comply with provincial/COSINE standards.
- Field Survey Data
    - All information surveyed and measured in the field should be stored in a geospatial database. This includes hydraulic structures (road crossings, dams, stormwater ponds, benchmarks, monuments, etc.). All field survey notes including electronic files (ASCII files), and paper copies of the notes and files should be included. All ground control and accuracy data.
- Processing Report (if applicable)
    - Detailing calibration, classification, and product generation procedures including methodology for breakline creation and hydroflattening or hydroenforcing. If applicable, an independent set of check points is to be used for independent accuracy verification.
- Elevation – Acquisition Report (e.g., LiDAR)
    - A report detailing mission planning and including detailed flight logs. Flight logs are expected to include:
        - A unique ID for each lift;
        - The take-off and landing times for each lift;
        - The aircraft make, model, and tail number;
        - The instrument manufacturer, model, and serial number;
        - The date of the instrument's most recent factory inspection/calibration;
        - General weather conditions;
        - General observed ground conditions;
        - All inflight disturbances and notable head/tail/crosswinds; and

        - All inflight instrument anomalies and any inflight changes in settings.
    - See the Ontario Specifications for LiDAR Acquisition for more information (Government of Ontario, 2020).
- Elevation – DEM
    - The DEM used to generate the flood hazard line. Based on source elevation data primarily containing ground elevation values, with conditioning as described in this guidance.
- Elevation – Source Data
    - Original source point data used to generate the DEM including attributes for point datum, UTM Zone, easting, northing, and elevation. Also include any breaklines as well as any data used to enhance the DEM such as hydro-conditioning features or building footprints.
- All Aerial Survey
    - Planned and Actual flight paths with overlaps.
- Source Data Extents
    - Georeferenced digital spatial representation of the extent of each delivered dataset representing the actual LiDAR source or derived product data, exclusive of TIN artefacts or raster void areas. A union of tile boundaries or minimum boundary rectangles is not acceptable for this deliverable. For point clouds, no line segment in the boundary will be further than four times the ANPS from the nearest LiDAR point. This must be delivered as a polygon feature in a geospatial database.
- UAV Flight Data
    - Any metadata of the UAV flight should be included as a report in the deliverables, along with the data produced in accordance with the project deliverable standards already listed.
- Map Digitization (if applicable)
- Any scanned mapping as well as any derivatives.Imagery
    - Any imagery used as an input dataset or as a reference layer to illustrate the location of the flood hazard line.
- Cross Sections
    - Cross section line features including labels. Cross section points including Order in profile (1, 2, 3, etc.), point number, easting, northing, distance, elevation, point code, water depth, water surface elevation, survey date.

- Local Infrastructure
  - Any local infrastructure data used to generate the flood hazard line (e.g., DEM conditioning).
- Base Mapping
  - Any base mapping used as a reference layer to illustrate the location of the flood hazard line.

3.8.1 Additional Project Deliverable Recommendations

a) The intellectual property rights for the survey data and mapping should be contractually secured by the regulatory authority that commissions the flood hazard mapping if possible. Securing intellectual property rights to data produced for flood hazard mapping survey ensures that the data will remain available for inspection and increase confidence in the flood hazard mapping results. It will also allow data to be reused for additional mapping products if it meets the required standards.

b) A digital stamp from the qualified responsible surveyor on the completion of the survey data portion, and a digital stamp from the qualified responsible engineer upon the completion of the mapping must be included with the final product. A digital/PDF Signature Block from the surveyor which includes their OLS qualifications and indicates that the control survey work complies with provincial/COSINE specifications would be sufficient on a cover letter, or in a report. These signed files must refer to the specific work completed, contain dates, and remain with the mapping project metadata. If the mapping project is updated, a note should be saved with the digital stamps that are rendered obsolete and the new stamp must be preserved similarly.

c) All relevant survey data products required to document the work and ensure it is accurate and reproducible for the hydraulic, hydrologic, and base mapping should be included in the project deliverables. The result of the accuracy checks of all data must be reported in project metadata.

d) All geospatial databases will have the following attributes filled out: Horizontal Datum including version and epoch date (e.g., NAD83 CSRS v7, Epoch 2010.0), Vertical Datum, Spatial Projection, Horizontal Accuracy, Vertical Accuracy, Vendor Collecting Data, Date Data Collected, Client, Survey Method, Project Name, Details (describe any projection / processing), Use Limitations, Update History, and Contact Information. Additional required attributes are described by data type in this section.

e) Geospatial databases should have clean geometry using geometry checking tools.

f) Tolerance, resolution and domain: Geospatial databases have associated tolerance, resolution and domain settings for the X, Y, Z and M coordinates.

g) Topology: If geospatial database topologies have been created, the topological rules and relationships, as well as the reasons for implementing the topologies, should be fully documented in the metadata.

h) All geospatial data referenced in the project and layer files must be included as project deliverables.

3.8.2 Metadata Requirements

Metadata on each mapping project and survey will be collected, maintained, and updated along with the mapping project. This set of metadata will be a critical part of the project, and important to maintain as the regulatory map, since it provides the lineage of the mapping product and its basis for reliability. Where applicable, project metadata shall be produced in XML format compliant with the rules of the North American Profile (NAP) of ISO 19115 and include:

a) A geospatial file of the footprint of the area the XML file refers to (note that this is to be an outline of the area(s) covered, not a minimum bounding rectangle);
b) There shall be an XML file for each data type (e.g., LiDAR, Orthophoto, Planimetric data, Topographic data, etc.);
c) All North American Profile of ISO 19115 mandatory fields must be populated;
d) The dates components shall be represented by a date range including year, month, and day for the start and end dates of the source data layer (acquisition of the imagery, LiDAR, etc.);
e) The accuracy statements are to be fully populated with the results of the accuracy tests as performed by the data provider listing the calculated accuracy values for the various data sets;
f) The production procedures sections are to be populated with information on:
    - Organizations used to acquire, compile, and produce each deliverable;
    - Sensor hardware used for each data set;
    - Software used in the data production;
    - Procedures followed to complete the production and QC; and
    - Any outstanding issues regarding non-compliance with the guidelines of the final data sets; and

g) There shall be an attribute defined in the XML file for each Feature Type produced in the project

In addition to the XML files, the tables in APPENDIX 2 will be completed and submitted in an .xls file.

3.8.3 Data Storage

All survey data, documents and metadata required for creation of flood hazard mapping must be stored for access. Storing these documents together ensures the reliability of the final mapping product and allows for review and updates to be conducted with ease. These standards assume that all survey data is the property of the regulatory authority relying on the maps, and available for reuse.

All previous versions of mapping projects along with their submitted reports, data, and metadata must be preserved as archives after updates. Previous maps should be maintained and archived indefinitely, but the underlying data and metadata should have a retention period of at least 5 years or until it is replaced with newer mapping.

4. Data Update Recommendations

4.1 Scope

This chapter provides considerations for flood hazard mapping update cycles and update schedules related to the risk criteria levels described in Section 3.3. It also provides instructions on the update process including update triggers as well as update project considerations.

4.2 Update Schedule

Mapping inventories should be updated on an annual or biannual basis to ensure that new flood risk studies are included. Geospatial databases of mapping should include appropriate metadata to describe the survey data used and other pertinent information about the data processing. Mapping should be reviewed and possibly redone to ensure applicability for use in predicting flood risk when topographical or land use has changed significantly, or every 5 years for urban areas and 10 – 15 years for rural areas. Updates should be timed to precede land use plan updates, so their findings may be considered during the planning update process. Refer to Table 4-1 for mapping update standards.

Update cycle length recommendations included in this Technical Bulletin, were developed based on a literature review and jurisdictional scan of recommended flood mapping updates and conform to the recommendations presented in the *National Floodplain Mapping Assessment – Final Report* (MMM, 2014). They are prioritized by the criteria levels set forth in Section 3.3.

Table 4-1: Mapping Update Recommendations

Level	Description	Review Cycle	Review and Update Cycle
1	Densely populated urban areas, including urban and rural areas behind flood structures and / or where critical infrastructure is within or expected to be within the flooding hazard limit.	5 years	5 – 10* years
2	Densely or moderately populated urban areas that are expected to fall near or within the flooding hazard limit, that are expected to experience potentially high impacts of flooding, including property damage.	5 years	5 – 10* years
3	Moderately to sparsely populated areas near or within areas potentially prone to flooding, primarily surrounded by agricultural and / or forested lands with low to very low potential flooding impacts or other land-based risk.	10 years	10 – 15 years

**10 years is maximum length of time*

4.3 Update Process

An update should be triggered from a review if there have been significant changes to the hydrologic or hydraulic flow regimes since the last mapping project was completed. This may include encroachment on the watercourse, land use change or an increase in development in the catchment. An update should also be triggered if errors have been found in the previous mapping project data or modelling.

An update may be triggered from a review if more accurate terrain information is available, more streamflow data is available for model calibration and frequency analysis, or if updated technologies or modelling programs that may produce more accurate results are available.

If a mapping update only occurs for some maps in a series, the replacement flood hazard maps must be edge matched with the existing flood hazard maps. Any existing mismatches in floodplains and flood hazard information between communities and municipalities must be resolved as part of a map update. Effective and revised flood hazard data must be tied in with no discontinuities. Where discontinuities cannot be resolved, they must be documented, but not until the discontinuity is accepted by the municipalities impacted and by the conservation authority, as appropriate.

When flood hazard mapping is updated, it must be based on the most accurate existing topographic data available, and this data must have documentation that it meets the vertical accuracies stated in this guidance. If data is not available that meets these requirements, new elevation data should be obtained. Any new survey data must be approved by the responsible surveyor and the new mapping must be approved by the responsible professional engineer. The current stamp file must be updated, and the previous mapping project must be archived with reference to the updated mapping project.

If the methodology used to update flood hazard modelling is changed in a mapping update process, the reasons for choosing a new methodology must be documented in the project report.

5. Mapping Products: Flood Hazard Map Dissemination and Sharing

5.1 Scope

Hazard maps will display the extent of the inundation for the regulatory flood and may also show the extent of additional flooding events. This chapter describes the different media for hazard maps that may be produced and the content to be included on the map. The map layout, including information and base map layers used for flood hazard mapping should conform to the mapping standards outlined here. Below are some useful resources to consider when creating public facing products or documents described in this chapter:

- General recommendations on how to best design maps – *Map Design Considerations for Accessibility* (MNRF, 2017);
- Sample map symbology for key features – *Federal Geomatics Guidelines for Flood Mapping, Appendix 2* (NRCan, 2019). Note this is not a comprehensive list. The practitioner may want to highlight specific features that are important to the project keeping in mind design and accessibility considerations above; and
- Sample map layout for digital and paper maps – *Federal Geomatics Guidelines for Flood Mapping, Appendix 4* (NRCan, 2019).

5.2 Digital Maps

Due to their increased availability and advantages in scale, we recommend that digital maps serve as the regulatory maps for hazard mapping in Ontario. The digital stamp files of the responsible surveyor and responsible engineer must be maintained as a PDF with the regulatory map.

The desired scale of the maps will depend on the extents of the project or section being mapped and the level of accuracy that needs to be portrayed. The finer the risk level criteria defined for a project, the larger the map scale that will be required to accurately and clearly portray features on the map. A guiding principle to keep in mind: assuming the normal reading distance of 40 cm (~16” as defined in the U.S., Yanoff and Duker, 2009), the normal naked eye can discern objects clearly down to a size of approximately 0.1 mm. Therefore, with a ground sample distance (GSD) of 10 cm for example, the smallest scale you should use to clearly discern this distance on a map would be 1: 1 000. A similar principle would apply to paper maps.

5.3 Paper Maps

While digital maps will be the regulatory standard, paper maps will still be produced to promote communication of flooding hazards and enable other flood hazard management work. Paper flood hazard maps should display the same information as the digital flood hazard map for the area they represent.

Line thickness and contrast become important considerations when producing paper maps and can affect how features are clearly represented at a given map scale. Paper maps also depend on the quality of the printing plotter and medium used on which to print. The paper type and ink quality chosen can mitigate the level of impact the elements and the environment may have on the product over time (e.g., shrinking, expansion, warping, smearing, fading). Choosing a larger print scale than what normally would be required for digital mapping may also help alleviate some clarity issues. Consult the *Map Design Considerations for Accessibility* (MNRF, 2017) document for more information concerning line thickness, contrast and other considerations.

5.4 Web Mapping and other Online Formats

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. Web map services 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. An online open data portal is another platform that supports accessing and using collections of open flood hazard mapping data.

5.5 Map Content

This section describes the mapping layers, features and elements to include on a hazard map.

The ‘base map’ is the horizontal reference data shown on flood hazard maps to assist in interpreting the areas impacted by the flood information shown. The term base map does not include topographic or elevation data. The following types of base map features must be depicted on the map if they occur within the community: transportation features including roads and railroads, hydrographic features, hydraulic structures, boundaries that identify municipal and provincial boundaries, corporate limits, military lands, and First Nation communities/reserves. See APPENDIX 3 for a comprehensive list of other data to consider in the mapping.

The base map must clearly show sufficient current ground features to enable clear interpretation of the flood hazard data displayed on the base map.

5.5.1 Mapping Layers

Table 5-1 shows the minimum layer requirements for digital mapping, including feature type and associated attributes.

Table 5-1: Digital Mapping Layers

Layer	Feature Type	Notes
Map Layout	Text / Metadata.	Blocks as outlined in Section 5.5.3.
Base Map	Orthophoto or Polyline / Polygon / Point features in geospatial database.	Features must be labelled as indicated in Section 5.5.3 and the bulleted list in Section 5.5.2
Cross Sections	Polyline features in geospatial database.	Cross Sections must be displayed as outlined in Section 3.4.1.
Flood Hazard	Polyline features in geospatial database.	Regulatory Flood must be specified for the jurisdiction.

5.5.2 Map Features

The following list outlines the features required to be shown on orthophoto base maps and line base maps. As a general principle, any feature that may impede flow or may be impacted by flooding should be displayed on the orthophoto or line base map. See APPENDIX 3 for an updated data list of example datasets that can be used to satisfy most of these map feature requirements and recommendations. In the absence of suitable existing data, the feature should be captured by aerial or onsite survey.

Features to be shown on maps (e.g. community names, streets, parks etc.) should conform to the names used by local planning authorities.

The list of features to be shown on orthophoto base maps and line base maps includes:

- Features of Ortho-Photo Maps and Line Maps (minimum required features for all maps if the features exist in the study area)
  - Benchmarks / Monuments
  - Watercourse Names
  - Cemetery Names
  - Contour lines (Intermediate, Index, Auxiliary, Indefinite and Depressions)
  - Spot Elevations

  - Control Points (horizontal and vertical)
  - Watercourse Centre Lines and Flow Direction
  - Parks (National, Provincial, Amusement, Conservation Areas, Campgrounds, Tennis Courts etc.)
  - Road Names (Highway, County, Township, Access, Runways etc.)
  - Boundaries (International, Provincial, District, Municipal)
  - Township, Native Reserve, Lot and Concession, Approximate, Annotation, Parking Lots, and Park Dump

- Additional Features for Line Maps
  - Wharfs, Docks, Ferry Slips, Groynes and Piers
  - Dams, Ditches and Dykes
  - Walls, Fence, Headwalls, and Breakways
  - Flooded Lands
  - Benchmarks / Monuments
  - Bridges (Foot, Road and Railroad)
  - Buildings (including ruins)
  - Forests, Plantations, Wooded Areas
  - Rivers, Streams, and Canals (including direction of flow)
  - Lakes, Ponds, Reservoirs, Shorelines
  - Roads (Highway, Country, Township, Access, etc.)
  - Culverts
  - Falls, Rapids
  - Shoals
  - Depressions, Pits, Quarries
  - Marshes, Swamps, Wetlands
  - Cliffs, Piles, Rocks
  - Swimming Pools
  - Chimneys, Piles
  - Conveyors, Ski Lifts
  - Cemeteries
  - Trails, Bush Road, Rail Lines
  - Tanks, Storage Bins
  - Transmission Lines (Poles, Pylons and Tunnels, etc.)
  - Feature Outliers (buildings under construction)
  - Airport Runways
  - Towers, Antennae, Masts
  - Pipelines
  - Aerial Cableways
  - Light Standard, Poles, Utility Poles and Lines

5.5.3 Mapping Elements

The following map elements should be included on flood hazard maps:

a) Base Map / Photo and Flood information:
   - All benchmarks and survey monuments shown;
   - All streamflow gauges and climate stations;
   - Names of roads, streets, parks, cultural information;
   - Boundaries of political units, including cities, municipalities, regions, counties, townships;
   - All hydrographic features (streams, lakes, ponds, and bays) that have an identified flood hazard associated with them shall be labeled;
   - Watercourse flow arrows;
   - Major water control structures and names;
   - All cross sections and cross section labels with a relevant water surface elevation at each;
   - Gridded flood characteristic name and color ramp categories (could be in legend);
   - Upstream and downstream study limits and mapping limits;
   - Match lines for overlapping map sheets; and
   - Topographic information.

b) Base Map Author and Stamp:
   - To contain collection date or date range of the data used in the mapping in addition to stamp.

c) Flood Hazard Author and Stamp:
   - Contain the name of the responsible engineer, the stamp, and the date of the relevant flood study completion.

d) Legend:
   - Should contain all annotations used on the map.

e) North Arrow and Datum:
   - Both horizontal and vertical datums should be included. All digital maps must be oriented so that grid north points to the top of the map sheet.

f) Scale and Contour interval:
   - Should contain a metric unit scale; and
   - Should contain contour interval of topographic information as well as any interpolated contours.

g) Map Sheet index:
   - Identify location and number of all map sheets for the study area;
   - Show location of the current sheet; and
   - Show the major transportation features of the area included for context.

h) Client Logo:
   - Client name, address, contact information, and logo of the responsible authority.

i) Title:
   - Title should include the watercourse name, watershed name, project title and a description of the study limits or the mapped flood profiles; and
   - Sheet Number.

j) Data Accuracy Confirmation Block:
   - This block should confirm that the accuracy of the displayed base map and flood hazard data has been verified to meet required accuracy and resolution standards, and
   - Accuracy reporting could be simplified by keeping the accuracies of each dataset in an included table and indicating on the map that all datasets meet the required accuracy criteria as outlined in the table.

5.5.4 Flood Hazard Mapping Details

Each map will show the flooding hazard limit based on the relevant jurisdictional regulatory flood (e.g. Hurricane Hazel, Timmins Storm, 100 year flood, etc.) and name the relevant jurisdictional regulatory flood (MNRF, 2002; MMAH, 2020).

a) All cross sections used in the hydraulic model:

- Will be shown with jurisdictional regulatory flood (i.e. Hurricane Hazel, Timmins Storm or other as approved by Minister of Natural Resources), water surface elevations in the label, as well as the 100-year flood elevation label (numerically) on the same transect (if the 100-year flood is not the regulatory flood);
- Must not cross one another unless technical justification is provided;
- May be divided into major and minor, with corresponding larger and smaller circles for labels;
- Must be labelled with a cross section number in the hydraulic model, and be labelled with that same number on the map;
- Must have the same elevation as the label;
- Care should be taken to place section labels in an organized way which provides all necessary information;
- Map length of cross section must match the cross-section length in the hydraulic model;
- All cross-section endpoints must be outside the floodplain;
- Labels must have a white background to improve readability;
- The flooding hazard limits, flood lines or cross sections must not be shown beyond mapping sheet match lines or study limits;
- Cross sections that overlap map sheets must be labelled on each sheet; and
- Must be bounded by tic marks at both ends in the map to denote the start and end of each cross section.

b) Two flood lines may not intersect;

c) Flooding hazard limits, flood lines, and cross sections must not be shown beyond mapping sheet match lines or study limits;

d) Flooding hazard limits or flood lines must join at the edge of sheets and match on adjacent sheet, with no overlap information on the sheets;

e) Flooding hazard limits or flood lines must be continuous;

f) Flooding hazard limits, flood lines, cross section labels, water surface elevations, must be identical to the legend depiction;

g) Crossings are represented by two small circles with a line over the road profile;

h) All channel drops must be shown with two circles. A small circle for the cross section at the bottom of the drop (no water surface elevations), and a standard cross section label for the crest of the drop. Crest of the drop is a major cross section, and bottom of drop is a minor cross section;
i) Water-surface elevations shown on the flood profiles for 1D models shall not rise from an upstream to downstream direction unless technical justification is provided; and
j) If a flow path other than the stream centerline is more representative of the direction of flow, the case must be documented, and the flow path shown and labeled on the map as the "Profile Baseline". Flow distances in one-dimensional models must be referenced to the profile baseline.

Additional text notes to be included if applicable are:

a) Study Limits at upstream and downstream boundaries of the flood profiles must be marked, and minor watercourses must be marked with a study limit;
b) Starting and ending chainage should be located where the watercourse enters and leaves the mapping sheet;
c) Notes where topographic mapping does not match surveyed data, if applicable;
d) Street names adjacent to watercourse; and
e) Spills – Denoted as a "SPILL" and an arrow showing the relative direction of the spill on the map, with additional effort undertaken to model and map the spill inundation area as a component of the flooding hazard, rather than simply plotting a large arrow and an open flood line.
f) In maps showing contour data, spot elevations will be shown at intersections of all roads, railways, trails, and foot paths, ends of runways, all bridges, culverts, and watercourse crossings, dams, docks, piers, and wharfs, and all water bodies.

6. Glossary of Terms

Datum:

Any quantity or set of such quantities that may serve as a basis for calculation of other quantities.

Digital Elevation Model (DEM):

A generic term for digital topographic and/or bathymetric data that is comprised as x/y coordinates and z-values to represent an elevation surface.

The term “DTM” and “DSM” should be used over the term “DEM” to more specifically reference ‘bare-earth’ or ‘surface elevation’ model product when possible.

The term “DEM” is to be used as a broader term when referencing a generic elevation data product. The Provincial DEM is an example of a generic elevation product, given that it has been constructed using a combination of both ‘DTM’ and ‘DSM’ elevation datasets to achieve Provincial coverage.

Digital Surface Model (DSM):

The highest reflective surface of ground features captured by the sensor. This surface may also be referred to as the first reflective surface or LiDAR first return. The DSM may include treetops, rooftops, and tops of towers, telephone poles, and other natural or constructed features; or it may include the ground surface if there is no vegetative ground cover. Photogrammetry, IFSAR, LiDAR and sonar can all provide this type of surface, yet characteristics such as accuracy and degree of detail (ability to resolve desired surface features) may vary significantly across technologies and even within the same technology. With sonar, the DSM may include sunken vessels and other artifacts, whereas the bathymetric surface reflects the natural underwater terrain. Similarly, with photogrammetry, LiDAR, and IFSAR the reflective surface may include any artifact present when the sensor mapped the area, including passing cars and trucks and similar features not normally considered to be part of a digital terrain model.

Like a DTM, a DSM can be structured either as a vector dataset (comprised of mass points and optionally 3D breaklines) to model surface elevations or a raster dataset that is interpolated from the vector elevation data to model surface elevations.

Using modern elevation point cloud classification algorithms and file formats, such as LAS, a DSM can represent a mass point dataset that has been classified for ‘surface’ elevation features.

Digital Terrain Model (DTM):

The bare earth surface (lowest surface, last reflective surface, or LiDAR last return) represents the surface of the "bare-earth" terrain, after removal of vegetation and constructed features.

Photogrammetry has traditionally generated DTMs when elevations are generated by manual compilation techniques. Unless specified to the contrary, the bare-earth surface includes the top surface of water bodies, rather than the submerged surface of underwater terrain.

Like a DSM, a DTM can be structured either as a vector dataset (comprised of mass points and optionally 3D breaklines) to model bare-earth elevations or a raster dataset that is interpolated from the vector elevation data to model bare-earth terrain elevations.

Using modern elevation point cloud classification algorithms and file formats, such as LAS, a DTM can represent a mass point dataset that has been classified for ‘bare-earth’ terrain elevations.

Geodetic Datum:

A set of constants specifying the coordinate system used for geodetic control, e.g., for calculating coordinates of points on the earth. At least eight constants are needed to form a complete datum: three to specify the location of the origin of the coordinate system, three to specify the orientation of the coordinate system, and two to specify the dimensions of the reference ellipsoid. (Before geocentric geodetic datum became possible, it was customary to define a geodetic datum by five quantities: the latitude and longitude of an initial point, the azimuth of a line from this point, and the two parameters of a reference ellipsoid. In addition, specification of the components of the deflection of the vertical at the initial point, or the condition that the minor axis of the ellipsoid be parallel to the Earth’s axis of rotation provided two more quantities. The datum was still not complete because the origin of the coordinate system remained free to shift in one dimension. This meaning does not conform to modern usage.)

Geospatial Database:

Gridded raster files should be provided in an open industry standard format such as GeoTIFF. Vector files should be provided in an open geospatial data format. For simpler data schemas the Shapefile format may be appropriate. For more complex schemas the proprietary Esri file geodatabase format may be appropriate for feature types like topology, geometric network, and linear referencing functionality. Geospatial data made available using other current Open Geospatial Consortium (OGC) geospatial data standards can be delivered provided they are compatible and agreeable with all recipients involved.

Horizontal Datum:

A geodetic datum specifying the coordinate system in which horizontal control points are located. The North American Datum of 1983 – CSRS is the official horizontal datum in Canada.

Hydrologically-Conditioned (Hydroconditioned):

Processing of a DEM or TIN so that the flow of water is continuous across the entire terrain surface, including the removal of all spurious sinks or pits. The only sinks that are retained are the real ones on the landscape. Whereas "hydrologically-enforced" is relevant to drainage features that are generally mapped, "hydrologically-conditioned" is relevant to the entire land surface and is done so that water flow is continuous across the surface, whether that flow is in a stream channel or not. The purpose for continuous flow is so that relationships/links among basins/catchments can be known for large areas.

Hydrologically-Enforced (Hydroenforced):

Processing of mapped water bodies so that lakes and reservoirs are level and so that streams flow downhill. For example, A DEM, TIN or topographic contour dataset with elevations removed from the tops of selected drainage structures (bridges and culverts) to depict the terrain under those structures. Hydro-enforcement enables hydrological and hydraulic (H&H) models to depict water flowing under these structures, rather than appearing in the computer model to be dammed by them because of road deck elevations higher than the water levels. Hydro-enforced TINs also utilize breaklines along shorelines and stream centerlines, for example, where these breaklines form the edges of TIN triangles along the alignment of drainage features. Shore breaklines for streams would be a 3-D breaklines with elevations that decrease as the stream flows downstream; however, shore breaklines for lakes or reservoirs would have the same elevation for the entire shoreline if the water surface is known or assumed to be level throughout.

Hydrologically Flattened (hydroflattened):

Processing of a lidar-derived surface (DEM or TIN) so that mapped water bodies, streams, rivers, reservoirs, and other cartographically polygonal water surfaces are flat and, where appropriate, level from bank-to-bank. Additionally, surfaces of streams, rivers, and long reservoirs demonstrate a gradient change in elevation along their length, consistent with their natural behavior and the surrounding topography. In traditional maps that are compiled photogrammetrically, this process is accomplished automatically through the inclusion of measured breaklines in the DTM. However, because lidar does not inherently include breaklines, a DEM or TIN derived solely from lidar points will depict water surfaces with unsightly and unnatural artifacts of triangulation. The process of hydro-flattening typically involves the addition of breaklines along the banks of specified water bodies, streams, rivers, and ponds. These breaklines establish elevations for the water surfaces that are consistent with the surrounding topography and produce aesthetically acceptable water surfaces in the final DEM or TIN. Unlike hydro-conditioning and hydro-enforcement, hydro-flattening is not driven by any hydrologic or hydraulic modeling requirements, but solely by cartographic mapping needs.

LAS:

A public file format for the interchange of 3D point cloud data between data users. The file extension is .las (LASer) as per the American Society for Photogrammetry and Remote Sensing (ASPRS).

LiDAR:

An instrument that measures distance to a reflecting object by emitting timed pulses of light and measuring the time difference between the emission of a laser pulse and the reception of the pulse’s reflection(s). The measured time interval for each reflection is converted to distance, which when combined with position and altitude information from GPS, IMU, and the instrument itself, allows the derivation of the 3D-point location of the reflecting target’s location.

Mass Points:

Irregular spaced points, each with x/y location coordinates and z-value, typically (but not always) used to form a TIN. When generated manually, mass points are ideally chosen to depict the most significant variations in the slope or aspect of TIN triangles. However, when generated automatically, e.g., by

LiDAR or IFSAR scanner, mass point spacing, and pattern depend upon the characteristics of the technologies used to acquire the data.

Point Cloud:

One of the fundamental types of geospatial data (others being vector and raster), a point cloud is a large set of three-dimensional points, typically from a lidar collection. As a basic GIS data type, a point cloud is differentiated from a typical point dataset in several key ways:

- Point clouds are almost always 3D,
- Pint clouds have an order of magnitude more features than point datasets, and
- Individual point features in point clouds do not typically possess individually meaningful attributes; the informational value in a point cloud is derived from the relations among large numbers of features.

Reach (River Reach):

Refers to a section of a stream or river along which similar hydrologic and hydraulic conditions exist, such as discharge, depth, area, and slope.

Thalweg:

Line connecting the deepest points of successive cross-sections along a stream channel.

Triangulated Irregular Network (TIN):

A set of adjacent, non-overlapping triangles computed from irregularly spaced points with x/y coordinates and z-values. The TIN data structure is based on irregularly spaced points, line, and polygon data interpreted as mass points and breaklines and stores the topological relationship between triangles and their adjacent neighbors. The TIN model may be preferable to a DEM when it is critical to preserve the precise location of narrow or small surface features, such as levees, ditch or stream centerlines, isolated peaks, or pits in the data model. In LiDAR, the vertices of each triangle are LiDAR points with *x*, *y*, and *z* values. In most geographic applications, TINs are based on Delaunay triangulation algorithms in which no point in any given triangle lies within the circumcircle of any other triangle.

Vertical Datum:

A set of constants defining a height (elevation) system. It is defined by a set of constants, a coordinate system, and points that have been consistently determined by observations, corrections, and computations.

7. References

American Society for Photogrammetry and Remote Sensing (2014a). *Positional Accuracy Standards for Digital Geospatial Data* (Edition 1 v.1). ASPRS.

American Society for Photogrammetry and Remote Sensing (2014b). *LAS Specification* (Version 1.4 - R13). ASPRS.

American Society for Photogrammetry and Remote Sensing (2023). *Positional Accuracy Standards for Digital Geospatial Data* (Edition 2, v.1.0). ASPRS.

CivilGEO (2022). GeoHECRAS - *Workflows: Digital Terrain Cross Section Cutting* [Photograph]. CivilGeo, Ready to Engineer. https://www.civilgeo.com/products/geohecras/

DHI Water and Environment Inc (DHI). (2018). *MIKE FLOOD Modelling Approaches for Floodplain Mapping* (DHI Project #: 42801316). Toronto and Region Conservation Authority.

Donahue, B., Wentzel, J., and Berg, R. (2015). *Guidelines for RTK/RTN GNSS Surveying in Canada* (Verson 1.2). Natural Resources Canada, Earth Sciences Sector.

Dottori, F., Di Baldasarre, G., and Todini, E. (2013). Detailed data is welcome, but with a pinch of salt: Accuracy, precision, and uncertainty in flood inundation modeling. *Water Resources Research*, 49(9), 6079-6085.

Federal Emergency Management Agency (2016a). *Guidance for Flood Risk Analysis and Mapping: Automated Engineering*. FEMA.

Federal Emergency Management Agency (2016b). *Guidance for Flood Risk Analysis and Mapping: Elevation Guidance*. FEMA.

Federal Emergency Management Agency (2021). 2D Watershed Modeling in HEC-RAS Recommended Practices. November, 2021.

Federal Emergency Management Agency (2023). *Flood Risk Analysis and Mapping* (FEMA Policy #204-078-1, Revision 13). FEMA.

Federal Geographic Data Committee (1998). *Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy* (FGDC-STD-007.3-1998). Subcommittee for Base Cartographic Data.

Fread, D.L. (1993). Handbook of Hydrology, ed. by D.R., Maidment. McGraw-Hill, New York.

Goodell, C. (2012). *How to draw cross sections.* The RAS Solution, The Place for HEC-RAS Modelers. https://www.kleinschmidtgroup.com/ras-post/how-to-draw-cross-sections/

Government of Ontario (2004). *Ontario Specification for GPS Control Surveys*, Version 1.2, June 2004, Geomatics Office, MTO and Provincial Georeferencing, MNR

Government of Ontario (2005). *Ontario Specification for GPS Control Surveys, Government of Ontario IT Standards (GO-ITS), Document No. 45.3*, Version 1.0

Government of Ontario (2020). *Ontario Specifications for LiDAR Acquisition (Version 1.2)*. Elevation Coordination and Consultation Committee.

Legleiter, C. J., Overstreet, B. T., Glennie, C. L., Pan, Z., Fernandez-Diaz, J. C., & Singhania, A. (2015). Evaluating the capabilities of the CASI hyperspectral imaging system and Aquarius bathymetric LiDAR for measuring channel morphology in two distinct river environments. *Earth Surface Processes and Landforms*, *363*, 344–363.

Mapcon Mapping Ltd. (2009). *Imagery and Elevation Acquisition Guidelines,* (Version 1.2). Guidelines Prepared for the Government of Ontario by Mapcon Mapping Ltd, Burnaby BC.

MMM Group Limited (2014). *National Floodplain Mapping Assessment – Final Report*. National Floodplain Management Framework. Public Safety Canada.

National Coastal Data Development Center (2012). *Geographic Information – Metadata, Part 2: Extension for imagery and gridded data workbook* (ISO 19115-2). National Oceanographic Data Center, National Oceanic and Atmospheric Administration.

Natural Resources Canada (2018). *Federal Flood Mapping Guideline Series: Federal Airborne LiDAR Data Acquisition Guideline, V2.0* (General Information Product 117e). NRCan.

Natural Resources Canada (2019). *Federal Flood Mapping Guideline Series: Federal Geomatics Guidelines for Flood Mapping, V1.0* (General Infrmation Product 114e). NRCan.

Natural Resources Canada (2022a). *Conversion grids between CGVD28 and CGVD2013.* Government of Canada, Geoid Models. https://webapp.scsrs-scrs.nrcan-rncan.gc.ca/geod/data-donnees/geoid.php?locale=en

Natural Resources Canada (2022b). *Federal Airborne LiDAR Data Acquisition Guideline, V3.1* (General Information Product 117e). NRCan.

Natural Resources Canada (2022c). High Resolution Digital Elevation Model (HRDEM) – CanElevation Series – Product Specifications Edition 1.4 2022-11-15 Government of Canada Natural Resources Canada

Ontario Flood Mapping Technical Working Group (2015). 2014-2015 Floodplain Mapping Case Studies. OFMTWG

Ontario Ministry of Municipal Affairs and Housing (2020). *Provincial Policy Statement, 2020: Under the Planning Act*. MMAH, Queen`s Printer for Ontario.

Ontario Ministry of Municipal Affairs and Housing (2023). *Review of proposed policies adapted from A Place to Grow and Provincial Policy Statement to form a new provincial planning policy instrument* (ERO number 019-6813). Environmental Registry of Ontario.

Ontario Ministry of Natural Resources and Forestry. (2001). *Great Lakes – St. Lawrence River Shorelines, Flooding, Erosion and Dynamic Beaches - Technical Guide*. MNRF.

Ontario Ministry of Natural Resources and Forestry (2002). *Technical Guide – River and Stream Systems Flooding Hazard Limit*. MNRF.

Ontario Ministry of Natural Resources and Forestry (2011). *Data Capture Specifications for Hydrographic Features: Large Scale* (Version 1.3). MNRF.

Ontario Ministry of Natural Resources and Forestry (2017). *Map Design Considerations for Accessibility*. MNRF.

Ontario Ministry of Natural Resources and Forestry (2020). *Elevation Accuracy Guidelines*. MNRF

Samuels, P.G. (1990). Cross-section location in 1-D models. In *International Conference on River Flood Hydraulics*. Hydraulics Research Ltd., Wallingford, UK.

United States Army Corps of Engineers (2022). *HEC-RAS River Analysis System: HEC-RAS Hydraulic Reference Manual* (Version 6.3). USACE.

United States Geological Survey (2021). *LiDAR Base Specification Rev. A.* National Geospatial Program (NGP).

Yanoff, M., and Duker, J.S. (2009). *Ophthalmology, 3rd Edition*. Mosby Elsevier (Ed.). pp. 54, 89. ISBN 978-0444511416.

APPENDIX 1

The model diagrams below illustrate the hydrology and hydraulic workflows that can be used in a flood hazard mapping project. Each workflow assumes the use of ArcGIS, Visual OTTHYMO and HEC-RAS software*. Diagrams were created by Halton Region Conservation Authority in the fall of 2021 and reviewed by the provincial Flood Mapping Techical Team's, Data Survey and Mapping Task Team.

*References to specific software names is for illustration purposes only and should not be interpreted as Ministry endorsement, exclusive or otherwise, of the software.

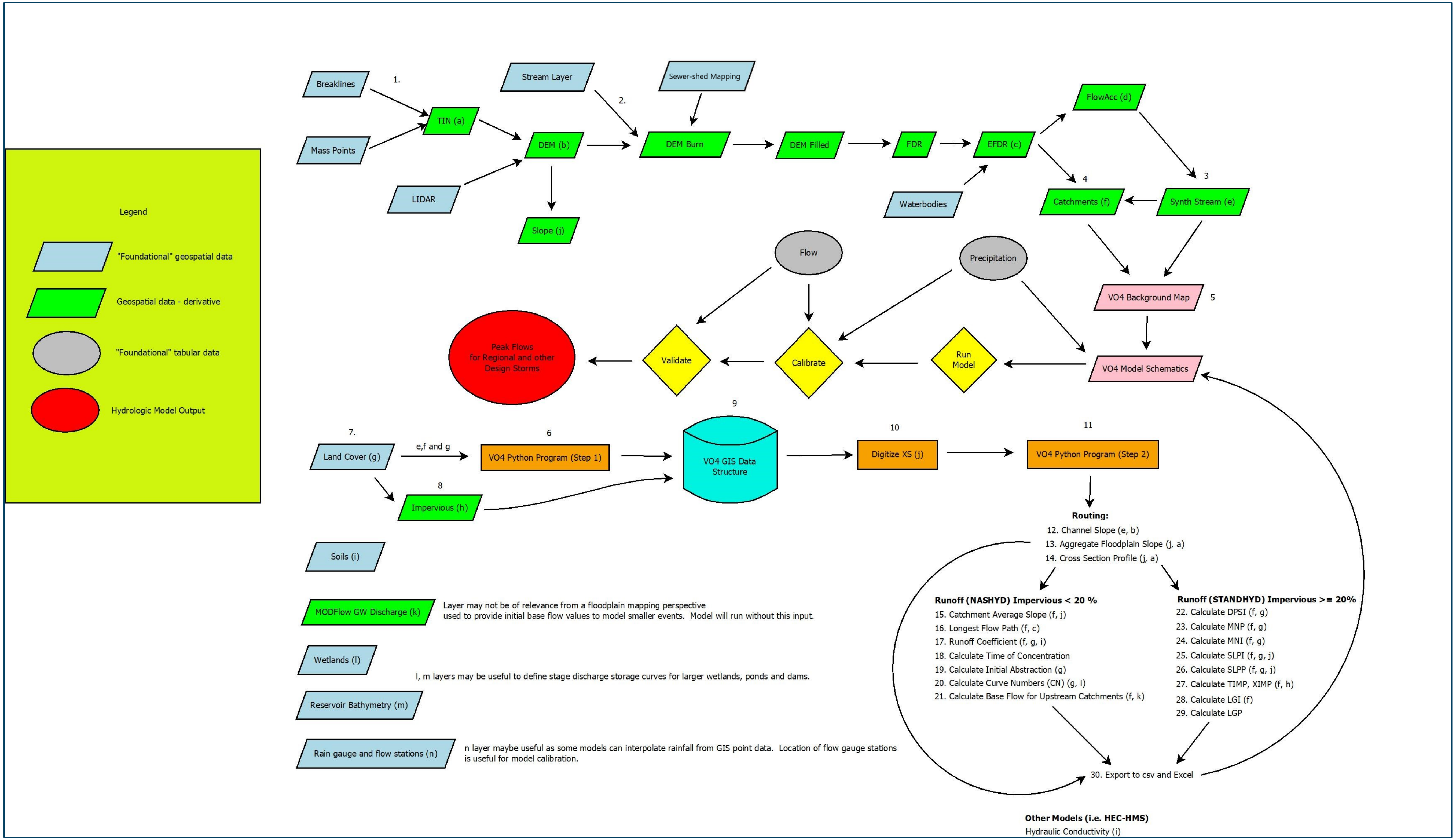

Figure A1 -1: Geographic/spatial data components of hydrological model development, paramaterization and workflow (based on Visual OTTHYMO model)

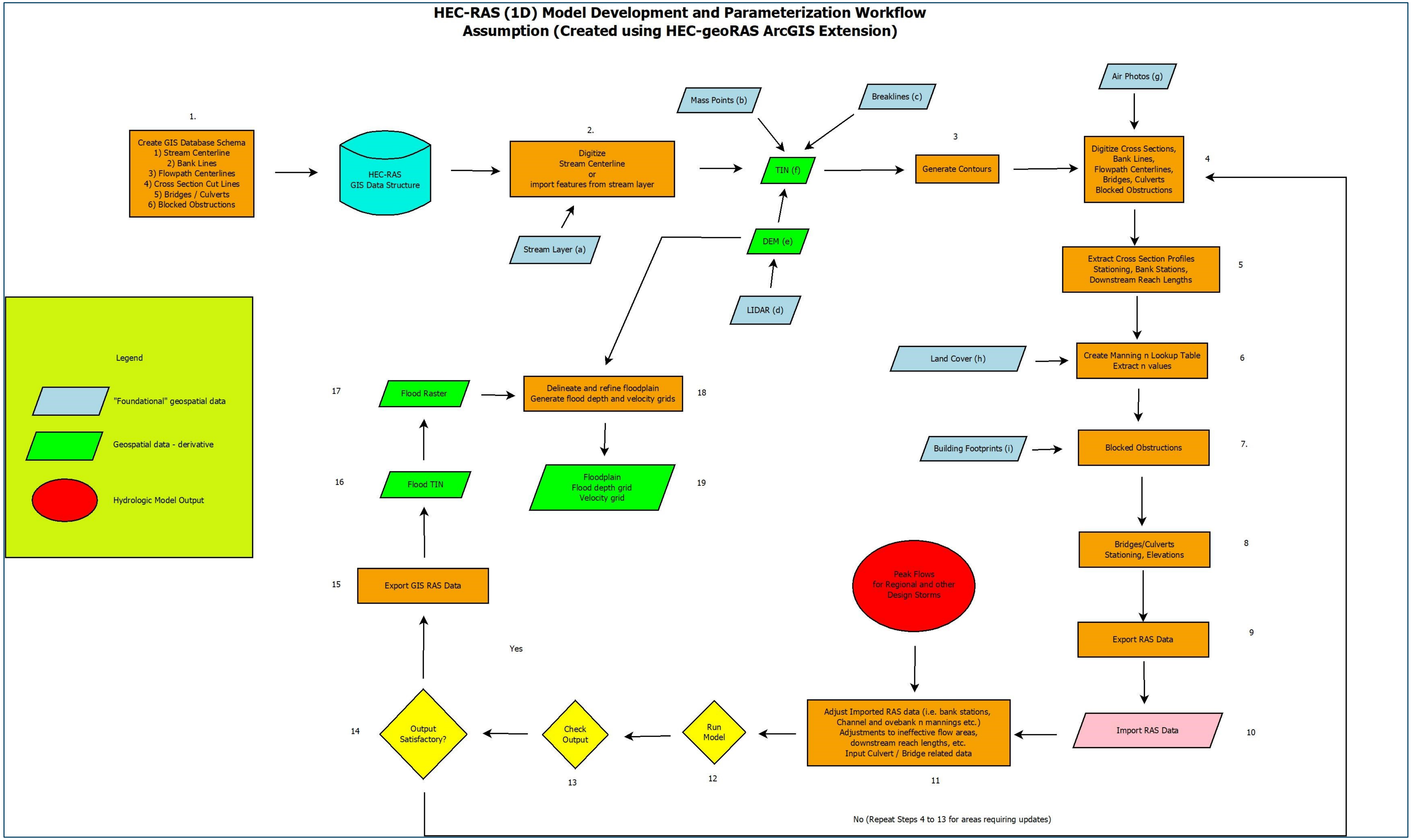

Figure A1 -2: Hydraulic model development and parameterization workflow (based on HEC-RAS 1D & HEC-GeoRAS extension)

APPENDIX 2

This series of tables are adapted from the Metadata Inventory of Existing Conservation Authority Flood Mapping project administered by MNRF and Conservation Ontario. This metadata table is meant to collect the most important data about the submission in an easily read format and will be compatible with the already-conducted mapping inventory effort. Several of the parameters have been removed and some response fields have been edited. Pre-set responses are included in some fields, and other are labelled ‘Open Field’ for individualized response.

This metadata file should be reviewed regularly by the party storing the flood mapping project to determine if updates are needed or record any new updates. Sections on project modelling are included for reference but have not been reviewed as a part of this Technical Bulletin.

Table A2 -1: Metadata fields and attributes – Project Data

Field	Description	Attributes	Notes
Project ID	“Used as a unique identifier to link the projects to a spatial database.” (All dataset project IDs must be the same for the same project)	Open field	If a standardized numbering system for flood mapping is adopted in Ontario, this number should be used
Project Name	“Unique name given to each project, this can be the title of a report or identify a section of watercourse.”	Open field	
Flood Hazard Standard	“The regulatory zone and standard applied to a particular project.”	“Zone 1 – Hazel, Zone 1 – 100yr, Zone 1 – Other Zone 2 – 100yr, Zone 2 – Other Zone 3 – Timmins, Zone 3 – 100yr, Zone 3 – Other”	If the response is an ‘Other’ option, the standard should be identified explicitly.
Official Watercourse Name	“The name of the primary watercourse or waterbody.”	Open field	
Watershed	“The name of the primary watershed applicable to the project.”	Open field	

Field	Description	Attributes	Notes
Jurisdiction	Jurisdiction the mapped area falls within.	Open field	
Undertaking: Conservation Authority	Use to identify if the project was managed by a conservation authority if the response was yes, the name of the conservation authority is entered.	Open field	
Undertaking: Municipality	Used to identify if the project was partially or wholly funded by the Municipality, if the response was yes, then name of the Municipality is entered.	Open field	
Undertaking: Private	Used to identify if the project was partially or wholly funded by a private entity, if the response was yes, the name of the organization is entered.	Open field	
Undertaking: Other	Used to identify if the project was partially or wholly funded by an ‘other’ agency, if the response was yes, the name of the agency is entered.	Open field	
Report Year	This is the recorded year of the latest version of the report (if there was no report then the year of the mapping was entered)	Open field	
Flood Line Dataset Status	Used to identify the status of the flood line mapping project this allows for near complete projects to be entered	Complete, Ongoing, Planned	

Field	Description	Attributes	Notes
Project Update Frequency	A description of how often the project is planned to be updated	As-needed, Never, 1 – 5 years, 5 – 10 years, 10 – 20 years	
Partially Updated	Provides an indication if portions of the project have been updated. This would only include small updates done for such things as culvert replacements, development etc., that do not affect most of the project.	Yes, No	
Update Currently Required	Provide an indication as to whether an update to the flood hazard mapping is currently required. Responses are to be based on staff knowledge and responses to subsequent questions	Yes, No	
Required Update Purpose	Provides a description of why an update is currently required. Multiple reasons could be entered, with the following suggestions provided: Age-Mapping, Quality-Mapping, Age-Modelling, Development, New Data or Other	Open field	
Project Category	An indication of the type of flood hazard mapping project	Watercourse, Inland Waterbody, Great Lakes Shoreline, Great Lakes Connecting Channel, Other	

Field	Description	Attributes	Notes
		Natural Hazard Project	
Drainage Area	The total drainage area for the reported project from the downstream most point. If area was unknown, the OFAT III tool was used to estimate	Open field	
Summary Report Available	Used to identify if a project summary report is available for the study that provides pertinent background information	Yes, No	If the report is available (all new mapping projects should be) that storage location of the report should be identified
Update Since Original	Provided an indication if the flood hazard mapping has been updated since the original mapping was created. Original generally defined as being the RDRP mapping	Yes, No	
Update 1 Date	Date of Project Updates	Open field	
Update 1	Describe each update to the project data, project reporting, project storage – as many update fields as needed should be included. If “Update since Original” is marked yes, at least one numbered update field must be populated	Open field	

Field	Description	Attributes	Notes
Update 2, 3…Date (For example)	Date of Project Updates	Open field	
Update 2, 3…Date (for example)	Describe each update to the project data, project reporting, project storage – as many update fields as needed should be included. If "Update since Original" is marked yes, at least one numbered update field must be populated	Open field	
Local Watercourse Name	An additional field to allow for the name of a watercourse or waterbody as it is locally known if it differs from the official watercourse name	Yes, No	
Watercourse Length	Identifies the length of mapped watercourse or shoreline within the hydraulic portion of the floodplain	Open field	
Widest Cross Section Width	The width of the widest mapped cross section on the flood hazard map. Can be used to estimate floodplain extent if digital data does not exist to estimate	Open field	
Maximum Flood Hazard Extent	The actual mapped area or inundation area if known (area of the flood hazard, not map sheet area). If the area is not known the watercourse length is multiplied by the widest cross section measurement (within reason)	Open field	

Field	Description	Attributes	Notes
Percent Level 1 Criteria	An approximate present of the mapping classified as Level 1, per Section 4	Open field	
Percent Level 2 Criteria	An approximate present of the mapping classified as Level 2, per Section 4	Open field	
Percent Level 3 Criteria	An approximate present of the mapping classified as Level 3, per Section 4	Open field	
Percent Level 4 Criteria	An approximate present of the mapping classified as Level 4, per Section 4	Open field	
Urban Flood Concerns	General indication of the potential for flood input from urban infrastructure (urban overland flow). High being probable input, medium being possible or uncertain input and low being no input.	High, Medium, Low	
Planning Designation 2-Zone	Used to indicate if all or a portion of the project area is a designated two-zone area	Yes, No	
Planning Designation SPA	Used to indicate if all or a portion of the project area is a designated special policy area	Yes, No	
Major Event Since 1980	Indication of whether there has been a major flood event within this project area since 1980 (typically defined as a flood with greater than 50yr return period)	Yes, No	
Structures Within the Flooding Hazard	If the data was available, respondents entered the number of structures along the watercourse within the flooding hazard,	Open field	

Field	Description	Attributes	Notes
	structures include bridges, culvert and dams (only counted hydraulic structures that would be included in modelling)		
Buildings at Risk	If the data was available, respondents entered the number of buildings within the regulatory flood hazard that would be at risk of flooding during such an event	Open field	
Other Event Buildings at Risk	If the data was available, respondents indicated if an analysis was undertaken to determine the number of buildings at risk during other events (e.g., 2 to 100 yr. floods)	Yes, No	
General Comments Project	This is an open field where any additional information about the project or data can be provided	Open field	

Table A2 -2: Metadata field and attributes – Imagery Information

Field	Description	Attributes	Notes
Project ID	Used as a unique identifier to link the projects to a spatial database. (All dataset project IDs must be the same for the same project)	Open field	If a standardized numbering system for flood mapping is adopted in Ontario, this number should be used.
Year of Acquisition	This is the recorded year in which the imagery was obtained (orthophotography)	Open field	
Data Description	Provides any descriptive information about the imagery data (e.g., Orthophotography, RGB bands, GeoTiff, etc.)	Open field	
Season of Acquisition	Used to indicate the season imagery data was captured	Spring, Summer, Fall, Winter	
Horizontal Reference	This field defines the horizontal reference system if known.	NAD83, Other	If 'Other', a Note must be added describing what and why
Vertical Reference	This field defines the vertical reference system if known.	CGVD28, CGVD28-Pre1978, CGVD2013	
Field	**Description**	**Attributes**	**Notes**

Stated Horizontal Accuracy	This field defines the horizontal accuracy if known.	Open field	
Field	**Description**	**Attributes**	**Notes**
Accuracy Derivation Method	This field provides the accuracy derivation method if known. RMSE, Limited information was available from conservation authorities to define the accuracy of imagery data	RMSE, Other	If 'Other', a Note must be added describing the method
Spatial Resolution	Provides the elevation data resolution, which is dependent on the type of data. Data entered can be a raster or point density, or a contour interval. Typically, data entered was a contour interval	Open field	
Secondary Data Source	Where applicable, respondents provided the secondary data source used for the base mapping. This does not include ground surveys for hydraulic cross sections unless they have been fused with the primary underlying elevation data. As many secondary sources should be listed as were used in the project	LiDAR, Photogrammetry, Radar, Sonar, Satellite, UAV, GPS, Ground Survey, Other	If 'Other', a Note must be added describing the method
Field	**Description**	**Attributes**	**Notes**

Peer Review	Indication if the elevation products were independently verified (QA / QC) by an external entity	Yes, No	
General Comments Elevation	This is an open field where any additional information about the elevation product can be provided.	Open field	

Table A2 -3: Metadata fields and attributes – Hydrology Information (Not in scope of this Technical Bulletin, provided as example)

Field	Description	Attributes	Notes
Project ID	Used as a unique identifier to link the projects to a spatial database (All dataset project IDs must be the same for the same project)	Open field	
Hydrology Method or Model	Provides the name of the hydrology model or method used to derive the regulatory flow	SSFFA, RFA, IFM, MTOMFIM, Water Level FA, HYMO, SWMM, HEC-HMS, MIKE, GAWSER, MIDUSS, Other	
Year of Hydrology	Indicates the latest year the model was run in determining regulatory flows for the project, or, the latest year in the dataset for flood frequency type analysis	Open field	
Years in Dataset	The total number of years in the dataset (e.g., 27), applicable only to flood frequency type analysis or long-term simulation	Open field	
Events Modelled	Provides a description of other return period events that were modelled or analyzed as part of this project (e.g., 2, 5, 10, 25, 50 100)	Open field	
Calibrated Model	Provides a general indication if the hydrology model has been calibrated with rainfall / water level / flow measurements or other forms of verification	Yes, No	

Field	Description	Attributes	Notes
Hydrology Quality of Calibration	Provides an indication of the quality of the calibration / verification. Examples include: High – Modelled flows were confirmed with gauged data during significant event, Medium – Small dataset of gauged flows / levels, Low – Model calibrated on similar watershed	High, Medium, Low	
Hydrology Quality of Input Parameters	Provides a general indication of the quality of the input parameters, such as run off coefficients, curve numbers, etc., or such things as rating curves for gauged stations. This is a subjective response, respondents entered ‘Low’ if not known.	High, Medium, Low	
Hydrology Quality of Input Comments	Provides an indication of the quality of the calibration / verification. Examples include: High – Modelled flows were confirmed with gauged data during significant event, Medium – Small dataset of gauged flows / levels, Low – Model calibrated on similar watershed	High, Medium, Low	
Hydrology Quality of Input Parameters	Provides a general indication of the quality of the input parameters, such as run off coefficients, curve numbers, etc., or such things as rating curves for gauged stations. This is a subjective response, respondents entered ‘Low’ if not known.	High, Medium, Low	
Hydrology Quality of Input Comments	This field provides for any comments about the quality of the input parameters to support the selection above.	Open field	

Field	Description	Attributes	Notes
Planning Horizon	If known, this field provides the year the model represents. This indicates if the model took into account proposed planning scenarios (e.g., official plan build-out, if the model assumed full build-out of a 20-year OP in 1995, users entered ‘2015’)	Open field	
Snowmelt Incorporated	Provides an indication of whether the effect of snowmelt has been considered in determining peak flows for this project (Regulatory flow)	Yes, No	
Peak or Volume Reduction	Provides an indication if there are any artificial structures such as dames, levees, berms, large SWM ponds, etc. that provide a reduction in the natural peak flow or volume of flood waters, and what type of low is sued for regulatory purposes	Yes – Regulated flow, Yes – Unregulated flow, Yes – Flow assuming failure, Yes – Other, No	
Catchments Discretized	Indicates if the model was properly discretized or if lumped catchments were used	Yes, No	
Adequate Supporting Documentation	Indicates if there is adequate supporting documentation / reports to support the hydrology (e.g., sufficient information that a qualified person could fully understand and reproduce the results)	Yes, No	
Climate Change Considered	Provides an indication if any consideration for climate change was used in developing the hydrologic model or peak flows used for regulatory purposes. No definition of climate change was provided.	Yes, No	

Field	Description	Attributes	Notes
Peer Review	Indication if the hydrology products were independently verified (QA / QC) by an external entity	Yes, No	
General Comments Hydrology	This is an open field where any additional information about the hydrology product can be provided	Open field	

Table A2 -4: Metadata fields and attributes – Hydraulics Information (Not in the scope of this Technical Bulletin, provided as an example)

Field	Description	Attributes	Notes
Project ID	Used as a unique identifier to link the projects to a spatial database. (All dataset project IDs must be the same for the same project)	Open field	
Year of Model Run	Indicates the latest year the model was run in determining regulatory elevations for the project, or the date elevations were derived	Open field	
Hydraulic Model	Provides the name of the hydraulic model or method used to derive regulatory elevations	HEC-2, HEC-RAS, SWMM(PCSWMM), Mike 11 / 21 / Flood, Estimated, Gauged FA	
Flow Condition	Indicates the flow regime in which the hydraulic model was run	Sub-Critical, Super- Critical, Mixed	

Field	Description	Attributes	Notes
Calibration Process	Provides a general indication as to whether a process was undertaken to calibrate the model, perform sensitivity analysis or verify the model ('Yes', indicates that at least one of the three processes was undertaken)	Yes, No	
Hydraulics Quality of Calibration	If a calibration process was undertaken, this field represents the quality of that process. Example: High – calibrated with significant gauged data; Medium – Sensitivity analysis, with verification of high-water marks; Low – Sensitivity analysis only	High, Medium, Low	
Hydraulics Quality of Input Parameters	Provides a general indication of the quality of the input parameters, such as Manning's 'n', reach lengths, etc. This is a subjective response, respondents entered 'Low' if not known	High, Medium, Low	
Hydraulics Quality of Comments	This field provides for any comments about the quality of the input parameters to support the selection above	Open field	
Estimated Flood Line	This field indicates if the regulatory flood line for this project is estimated. A flood line is considered to be estimated when it	Yes, No	

Field	Description	Attributes	Notes
	was derived using methods that do not meet the FDRP or 2002 MNRF standard		
Adequate Supporting Documentation	Indicates if there is adequate supporting documentation / reports to support the hydraulics (e.g., sufficient information that a qualified person could fully understand and reproduce the results)	Yes, No	
Elevation Source	Indicates the source of the elevation data used within the hydraulic model (e.g., data for cross sections)	Ground Survey - GPS, Ground Survey - Total Station, Ground Survey - Leveling, Ground Survey and Base Elevation Data, Base Elevation Data, Other	
1D Modelling Appropriate	Provides a general indication as to whether 1- dimensional modelling is appropriate for all or part of the project area. 1D modelling is considered appropriate when flow is uni-directional and non- complex (e.g., limited urban inputs / street flow / buildings). This is a somewhat subjective response.	Yes, Partial, No	

Field	Description	Attributes	Notes
Peer Review	Indication if the hydraulic products were independently verified (QA / QC) by an external entity	Yes, No	
General Comments Hydraulics	This is an open field where any additional information about the hydraulics products can be provided	Open field	

APPENDIX 3

The chart below highlights key data themes that are commonly used in flood hazard mapping. It contains a list of provincial holdings where available which can be referenced as a starting point for the scoping and data collection phases of a flood mapping project. This is not a comprehensive list and does not necessarily include datasets that are important in later stages of the flood mapping process.

The importance of each dataset for the purpose of supporting flood hazard mapping has been ranked as follows:

- **High** = Required for Model / Feature Extraction / Mandatory and high quality where possible;
- **Medium** = Useful for some modeling parameters or project scoping / Can be used to enhance modeling but quality may not significantly impact results; and
- **Low** = Nominal improvement to modeling / Reference data / Cartographic representation.

The two columns regarding provincial data give the practitioner a starting point when considering which datasets to use for project scoping or modeling purposes. However, the practitioner is encouraged to use the ‘best available data’ whenever possible, and this may include local Conservation Authority (CA), municipal or federal data sources where appropriate. For this purpose, the ‘Other Data Sources and Notes’ column has been included as an opportunity to highlight further sources that can be leveraged.

Table A3 -1: Data list to support flood hazard mapping - Elevation

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
Digital Terrain Model (DTM) Digital Surface Model (DSM)	High	Essential for hydrology / hydraulic modeling Primary reference for heights (height of riverbank, road, building, etc.) DSMs are useful for feature extraction (water, buildings, hydro transmission lines, flood control structures, bridges, etc.)	1. Ontario Digital Terrain Model (LiDAR-Derived) 2. Ontario Classified Point Cloud (LiDAR-Derived) 3. Ontario Classified Point Cloud (Imagery-Derived) 4. Ontario Raw Point Cloud (Imagery-Derived) 5. Provincial DEM 6. Ontario Digital Surface Model (LiDAR-Derived) 7. Ontario Digital Surface Model (Imagery-Derived)	1. and 6. are typically at 50 cm horizontal resolution except for LEAP acquisition at 1m. 2. can be used if finer resolution is required. Imagery-derived DTM rasters products are currently not available and would have to be generated by the user from 3. or 4. Note the resulting product may not meet the current accuracy level criteria in all cases (e.g., dense conifer). For more information: Ontario Elevation Mapping Program Geohub Page	Government of Canada - High Resolution Digital Elevation Model (HRDEM) – CanElevation Series - DTM and DSM derived data (1m for areas in Ontario).
Topo bathymetry	Medium	Can enhance terrain model providing accurate volumetric storage parameters for hydraulic modeling	1. Bathymetry, Line 2. Bathymetry, Point 3. Bathymetry Index 4. Historic Bathymetry Maps	Measures are recorded as depths from water surface. They would have to be converted to topo bathymetric heights to be incorporated into an elevation model.	A few local CA/municipality acquisitions.

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
Benchmarks & monuments	High	Essential for referencing datasets & QA/QC	Ontario COSINE database (ontario.ca)	Horizontal and vertical geodetic control data (survey monumentation). Ongoing maintenance. Data sourced from MNRF, MTO, municipalities, NRCan and commercial survey network providers (Cansel, Sokkia, Topcon).	1. Fisheries and Oceans Canada – Station Benchmarks 2. Natural Resources Canada – Passive Control Networks
Survey control & checkpoints	High	Essential for referencing datasets & QA/QC	Checkpoint Database (unpublished)	Contact the Provincial Mapping Unit for more information.	
Contours	High	Required to produce final flood hazard line(s)	Contour	Interpolated from antiquated Ontario Basic Mapping and related vintage elevation sources and not actively maintained. Should not be used in the production of flood hazard mapping.	Interpolated as part of flood hazard mapping process. Therefore, based on project area.
Flow direction derivative datasets	Medium	Important for hydrology modeling	1. Ontario Integrated Hydrology (OIH) Data 2. Ontario Watershed Information Tool	Dataset uses Ontario Hydro Network and Provincial DEM as primary inputs and is maintained according to a 4-year update cycle.	Project based data

Table A3 -2: Data List to support flood hazard mapping – Break Line & Spot Height

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
Stream Cross section points & lines	High	Essential for hydraulic modeling			Project-based data.
Hydrographic Features • Rivers & streams (banks & centrelines) • Waterbodies, reservoirs & shorelines • Canals & ditches • Falls & rapids	High	Essential for hydraulic & hydrology modeling	Ontario Digital Terrain Model (LiDAR-Derived) Breaklines	LiDAR-derived breaklines for larger rivers and water bodies used for elevation flattening are available for some acquisitions under the 'Additional Documentation' section on Ontario GeoHub.	Local surveys and LiDAR acquisitions.
Hydraulic Control Structures • Dams, weirs, docks, piers & wharfs • Dikes, berms & flood walls • Bridges & overpasses • Culverts • Storm sewers (for sewer routing)	High	Critical infrastructure, important consideration for hydraulic & hydrology modeling			Local surveys and feature extraction from LiDAR acquisitions.

Data Set or Feature Type	Importance High / Medium / Low	Importance Notes Describing how the data is important to Flood Hazard mapping.	Provincial Data Source(s) Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	Provincial Data Notes Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	Other Data Sources and Notes **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
Urban Features • Building Footprints • Road edges & runways • Embankments	Medium/High	Buildings can alter flood line delineation Surrogate for impervious area calculation.	Ontario Digital Surface Model (LiDAR-Derived)	DSM raster product could be used for building feature extraction. Could also use point cloud datasets listed under DTM above if a finer resolution is required.	Local surveys and feature extraction from LiDAR acquisitions
Hard/Soft Terrain Features • Ridges & cliffs • Hilltops & valleys	Medium				Local surveys
Void or Low Confidence areas	High	Important to highlight any deficiencies in elevation model; spatial metadata			Project-based data

Table A3 -3: Data List to support flood hazard mapping – Imagery

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
Digital imagery (orthophotos)	High	Important base for mapping and potential feature extraction	Leaf-off Imagery Leaf-on Imagery (FRI)	Leaf-off - Annual acquisition on 5-year repeat cycle. Prioritized for populated areas in Ontario. For more information: Ontario Imagery Program Geohub Page	Provincial/Local CA/municipal acquisitions
Onsite survey photos	Medium	Aid in understanding terrain features and critical infrastructure			Project-based data.
Historical photography	Low	Detect changes and urban encroachment of the flood plain over time; records of actual flooding events.	Ontario Imagery service (contact geospatial@ontario.ca for more information)		Provincial/CA and municipal sources.
Satellite Imagery	Medium	Near real-time satellite imagery would be useful to estimate soil conditions, snow cover, ice conditions etc.	LANDSAT 8 SPOT Sentinel 2 (under review)	Range of satellite imagery acquired primarily for remote northern communities 2000-2015. New Sentinel 2 (10m) imagery is currently being reviewed for possible future development.	

Table A3 -4: Data List to support flood hazard mapping – Land & Urban Features

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
Land cover	High	Important data for hydraulic modeling.	1. Southern Ontario Land Resource Information System (SOLRIS) 3.0 2. Far North land cover 3. Great Lakes Shoreline Ecosystem Inventory	Consult with NRIS group for currency & update cycle information.	
Soils	High	Important data for hydrologic modeling	Soil Survey Complex	Updates are being made based on LiDAR acquisitions. Consult with OMAFRA for details.	
Impervious areas	High	Important data for hydraulic modeling			Project-based data (typically derived from land cover).
Buildings (See 'Breaklines-Urban Features' above for elevation derived building footprints)	Medium	Useful later in flood hazard mapping process to identify buildings in the flooding hazard and floodplains.	1. Building to Scale 2. Building as Symbol 3. Built-Up Area	1 and 2 based on antiquated Ontario Basic Mapping and not actively maintained. 'Built-Up Area' is based on SOLRIS depicting small hamlets to large cities. Consult with NRIS group for	Some CA's/municipalities may have local data derived from imagery. Not consistent. Efforts by the federal government for building feature extraction. Follow-up with David Belanger (possibly at next DSM meeting).

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
				currency & update cycle information.	
Roads, railways & trails (Centrelines)	Medium	Good for establishing locations for survey control and checkpoints. Roads could be viewed as a surrogate for built-up density.	1. Ontario Road Network (ORN) Segment with Address 2. Ontario Road Network (ORN) Road Net Element 3. Ontario Railway Network (ORWN) 4. Ontario Trail Network (OTN) Trail Segment		1. Railway Association of Canada – Canadian Rail Atlas (railcan.ca) More up to date than ORWN. 2. Some municipalities may have more details like road edges and allowances 3. Municipal centreline data for urban rail systems (e.g., TTC in Toronto, LRTs in Hamilton or Ottawa). 4. Local trail organizations, municipal trails data

Table A3 -5: Data List to support flood hazard mapping – Water Features

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
Watercourses	High	Used in hydrologic modeling. Important for watershed delineation, flow accumulation, and drainage density calculations.	1. Ontario Hydro Network (OHN) - Watercourse 2. Constructed Drain 3. OIH Enhanced Watercourse	Medium scale mapping (increasingly derived from large scale data sources in southern Ontario)	Natural Resources Canada National Hydrographic Network
Water bodies	Medium/High	Used in hydrologic modeling Important for watershed delineation, flow accumulation, and drainage density calculations.	Ontario Hydro Network (OHN) - Waterbody	Medium scale mapping (Increasingly derived from large scale data sources in southern Ontario).	Natural Resources Canada National Hydro Network v2 (Future name to be determined).
Wetlands	Medium	Larger wetlands used for volumetric storage parameters in hydraulic modeling	Wetlands		

Table A3 -6: Data List to support flood hazard mapping – Boundaries

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
Watersheds & sub-catchments	Medium	Important for modelling flows in both gauged and ungauged systems	Ontario Watershed Boundaries (OWB)	Useful for scoping projects and assessing DTM resolution requirements and limitations. Areas in Ontario last updated 2019.	Future NHNv2 model includes catchments and drainage areas as a co.
Parcels & Zoning	Low (For hazard mapping)	More useful later in the flood hazard mapping process to assist in emergency response and assessing risk.	Ontario Parcel	Consult links for access and use restrictions. E.g., Ownership information may be restricted.	1. Municipal Property Assessment Corporation (MPAC) 2. Environics Analytics 3. Municipal zoning / official plans
Geopolitical	Low	Reference on a map	1. Municipal Boundary - Upper Tier and District 2. Municipal Boundary - Lower and Single Tier 3. Geographic Township Improved		Mapping from municipalities.

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
Indigenous Communities	Low	Assessing potential impacts on communities Reference on a map			Natural Resources Canada – Canada Lands surveys
Lots & Concessions	Low	Reference on a map	Lot fabric improved		
Census	Low	Criteria for population centres			Statistics Canada - Population Centre and Rural Area Classification 2016 (statcan.gc.ca)

Table A3 -7: Data List to support flood hazard mapping – Monitoring

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
Hydrometric data - stream flow stations	High (Monitoring rankings provided by SWMC)	Hydraulic model calibration and input parameter	MNRF District hydrometric monitoring sites	Contact the MNRF Surface Water Monitoring Centre (SWMC) for access to their provincial and federal holdings. Select stations are available for viewing on MECP's Source Protection Information Atlas.	1. Conservation Authorities hydrometric monitoring sites 2. Environment Canada – Water Survey of Canada hydrometric monitoring sites 3. Ontario Power Generation hydrometric monitoring sites
Meteorologic data (rain gauge stations)	High	Hydraulic model input parameter	1. MNRF Fire Weather Stations. 2. Ontario Ministry of Transportation weather monitoring sites. 3. MECP weather / precipitation and climate monitoring stations.	Contact the MNRF Surface Water Monitoring Centre for access to their provincial and federal holdings. Select stations are available for viewing on MECP's Source Protection Information Atlas.	1. Conservation Authorities precipitation monitoring sites 2. Environment & Climate Change Canada – NOAA weather stations in the Great Lakes Basin

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
Hydrometric data - water level stations	Medium	Hydraulic model input parameter (estimating flow volumes) Useful for lake shoreline hazard modeling	MNRF District hydrometric monitoring sites	Contact the MNRF Surface Water Monitoring Centre for access to their provincial and federal holdings. Open data available: Monitoring station locations	1. Fisheries and Oceans Canada – Tides and water levels data archive 2. National Oceanic and Atmospheric Administration (NOAA) – Great Lakes Water Levels 3. Environment Canada – Water Survey of Canada hydrometric monitoring sites 4. Ontario Power Generation hydrometric monitoring sites
Storm event modeling / hydrographs	Low		MNRF SWMC Storm Surge Forecasts	Contact the MNRF Surface Water Monitoring Centre for access to their provincial holdings.	1. Environment Canada forecasts – Wave Model Charts (weather.gc.ca) 2. NOAA - Operational Forecast System (noaa.gov)

Table A3 -8: Data List to support flood hazard mapping – Other Supporting Reference Data

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
Geographic names	Low	Where available, official names for streams / waterbodies and streets within the flooding hazard should be included on mapping.	Geographic Names Ontario	Geographic names on Ontario.ca website	
Census data	Low	Criteria for population centres			Statistics Canada - Population Centre and Rural Area Classification 2016 (statcan.gc.ca)
Transmission & utility lines/poles	Low	Assessing impacts on critical infrastructure	1. Utility Line 2. Utility Site	These datasets are not actively maintained.	Local infrastructure data from municipalities.
Water crossings	Low	Possibly useful where not captured by the watercourse network (water routing in headwaters)	1. MNRF road crossing water - non-bridge 2. MNRF road crossing water - bridge	Coverage limited to the Forestry Area of Undertaking (central Ontario). Culverts and bridges are represented as point locations.	
Historical flood hazard mapping	Low	Detect changes to flood plain over time. Could be used for project scoping.			Conservation Authority or Municipality.

Table A3 -9: Data List to support flood hazard mapping – Metadata

Data Set or Feature Type	**Importance** High / Medium / Low	**Importance Notes** Describing how the data is important to Flood Hazard mapping.	**Provincial Data Source(s)** Often intended for regional scale applications (except for LiDAR and Orthoimagery) and therefore should be used in the absence of better data.	**Provincial Data Notes** Can include general data quality comments, but the more detailed "State of Data" discussion is Out of Scope here for the purpose of the DSM guidance.	**Other Data Sources and Notes** **Cite examples** (federal or local) where applicable or **general comments/methods** where data could be obtained. This is not intended to be a comprehensive list but aims to highlight the best available data to date.
• Project Reports • Data Descriptions • Survey Reports • Processing Reports • Aerial Survey Report	High	Metadata & reporting is a mandatory component for all data acquired, produced, or referenced within a flood mapping project. Not all documents listed may apply depending on the project area.	Refer to links above	Published provincial datasets will have metadata and user guide information available on Ontario GeoHub	Can include project reports & data descriptions, survey reports, processing reports, aerial survey report if new data acquired for the project, and external data that is used.