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2017**

## **TECHNICAL GUIDELINES FOR FLOOD HAZARD MAPPING**

Central Lake Ontario Conservation

Grand River Conservation Authority

Toronto and Region Conservation Authority

Environmental Water Resources Group Ltd.

Credit Valley Conservation

Ganaraska Conservation

Nottawasaga Valley Conservation Authority

Dr. B. Adams & D. Haley



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MARCH, 2017

*prepared for:*



*prepared by:*



Environmental Water  
Resources Group Ltd.


in association with Dr. B. Adams, and D. Haley

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## 1.0 INTRODUCTION

### 1.1 Background

The need for flood plain management has been emphasized over the last six (6) decades after major floods have taken numerous lives and generated hundreds of millions of dollars in damages. Some of the major Ontario floods that have occurred over the last six decades have been located in Toronto (1954), Cambridge (1974), Dover Township (1979), Field Township (1979), Nipissing French River (1979), Port Hope (1980), Windsor (1981), Chatham, Dover, Dresden, Huntsville, and Fort Albany (1985), Winisk (1986), Harrow (1990), Peterborough (2002-2004), Toronto (2005), Mississauga (2009), Toronto and Mississauga (2013), and Burlington (2014).

The objectives of flood plain management in Ontario are to:

- ( i ) Prevent the loss of life;
- ( ii ) Minimize property damage and social disruption; and
- ( iii ) Encourage a coordinated approach to the use of land and the management of water in reducing flood risk.

The three (3) basic components of flood plain management to achieve a reduction in flood risk include the following:

- PREVENTION through land use planning and regulation of development;
- PROTECTION through structural and land acquisition measures; and
- EMERGENCY PLANNING and RESPONSE through flood warning and disaster relief.

Flood hazard maps are used to support all of the three (3) basic components of flood plain management. Flood hazard maps are used in identifying the following:

- Undeveloped flood prone areas that can be regulated;
- Flood risk in existing developed areas to allow for protection through structural and land acquisition measures; and
- Properties that will be at risk during flood events.

For the Province of Ontario the following applies:

*"The flooding hazard limit is the greater of:*

- i) the flood resulting from a rainfall actually experienced during a major storm such as the Hurricane Hazel storm (1954) or the Timmins storm (1961), transposed over a specific watershed and combined with the local conditions, where evidence suggests that the storm event could have potentially occurred over watersheds in the general area;*
- ii) the one hundred year flood; or*

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- iii) a flood which is greater than i) or ii) which was actually experienced on a particular watershed or portion thereof, for example as a result of ice jams and which has been approved as the standard for that specific area by the Minister of Natural Resources; and

*The exception is where the use of the 100 year flood or actually experienced event as the flood standard for a specific watershed, even though it does not exceed the Hazel or Timmins event, has been approved by the Minister of Natural Resources, (where past history of flooding supports the lowering of the standard)."*<sup>1</sup>



Essa, October 20<sup>th</sup>, 1954

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<sup>1</sup> page 11, Technical Guide - River and Stream Systems: Flooding Hazard Limit, 2002, Ontario Ministry of Natural Resources<sup>1</sup>

## 1.2 Document Purpose and Scope

The Technical Guidelines serve several purposes including the following:

- To provide guidance to staff of the Steering Committee agencies, and to Consultants undertaking flood hazard mapping studies for those agencies;
- To provide a consistent approach in the development of flood hazard maps; and
- To establish "good engineering practice" in the development of flood hazard maps. This will provide a technical framework for evaluating the acceptability and adequacy of flood hazard maps during Regulatory and technical reviews.

The Technical Guidelines are intended for Steering Committee agencies and their consultants. The Technical Guidelines will be considered as "good engineering practice" during review of external consultants' flood hazard maps produced for new land development sites.

Although the Technical Guidelines represent commonly accepted best practices, it remains the users' responsibility to recommend and justify procedures, computation methods, and parameters that best represent conditions in study areas of concern. It is presumed and recommended that users of the Technical Guidelines have a good working knowledge of hydrologic and hydraulic engineering principles.

The Technical Guidelines do not replace a project's Terms of Reference but should be used in conjunction with a project's Terms of Reference to determine how flood hazard limits are to be developed. The Terms of Reference should document the intended use of the hazard limits, and the requirements of the Conservation Authority. Too little information in a Terms of Reference may result in a product that does not meet the needs of the Conservation Authority.

This document does not replace, but rather complements the Ontario Ministry of Natural Resources (OMNR) River & Stream Systems: Flooding Hazard Limit, Technical Guide, 2002. This document updates the 2002 Guide with respect to hydrologic models, hydraulic models, survey techniques, and GIS procedures. In addition, it clarifies certain hydrologic and hydraulic procedures.

This document covers both the development of new flood hazard maps and the updating of existing maps due to new development at the watershed, reach and site levels.

### 1.3 Flood Hazard Mapping Study Components

A flood hazard mapping study includes the following components:

- Data Requirements - Section 2;
- Hydrologic Analysis - Section 3;
- Hydraulic Analysis - Section 4;
- Flood Hazard Maps - Section 5; and
- Flood Hazard Map Updates - Section 6.

Not all components are necessarily conducted during the same study.



Rescue mission during the floods on CNR in Tecumseth Township, ON, October 15<sup>th</sup>, 1954.

## 1.4 Public Consultation

A public consultation process is recommended for flood hazard mapping studies. For new flood hazard mapping, two public contacts are recommended. One to inform the public a flood hazard mapping study is underway and to collect information from the public. The second contact would present the draft flood hazard maps and request any comments on the maps. For flood hazard map updates, one public contact is recommended to present the draft flood hazard maps.

A public contact can be an information centre, if there are a significant number of properties at risk from inundation or can be a personal contact if there are only a few properties at risk.



Albion Hills Conservation Area, Caledon, ON, 2015.

## 2.0 DATA REQUIREMENTS

### 2.1 General

Section 2 outlines the data required to develop flood hazard maps. The required data includes the following:

- |    |                          |                  |
|----|--------------------------|------------------|
| 1. | Digital Elevation Data   | Section 2.2;     |
| 2. | Feature Data             | Section 2.3; and |
| 3. | Hydraulic Structure Data | Section 2.4.     |

The methodology for a flood hazard mapping project must be specified in the project's Terms of Reference. Methodologies will be based on existing data, required data, the intended future use of digital elevation data, and follow up studies that may be required. An example of a follow up study would be a Two Zone analysis where flood depths, and flood velocities are required. Project costs could differ depending on the methodology used to develop the flood hazard maps. It is important that the project Terms of Reference list the intended use and the methodologies to be used when developing flood hazard maps.

Flood hazard limits can be delineated on (1) line maps with contours and spot elevations; (2) ortho-photo maps with contours and spot elevations; and (3) ortho-photos with an elevation grid. Typically, contours and spot elevations will be used to display the results of 1-D hydraulic models, and an elevation grid will be used to display the results of 2-D hydraulic models.

Figure 2-1 identifies digital elevation data options available for a flood hazard mapping project. There are options for collecting digital elevation data, there are options for input to the hydraulic model, and there are options for displaying the results of the hydraulic model. The collection and processing of digital elevation data will probably be conducted by agencies external to those conducting the hydrologic and hydraulic analyses. These agencies include a Conservation Authority's Geographic Information System (GIS) department or an external mapping firm. Each method used to collect digital elevation data has its associated strengths and weaknesses. A balance must be struck between cost and accuracy when choosing the data collection method.

The digital elevation data for input to the hydraulic analysis will include contours and cross section points for 1-D modelling and gridded elevation data or DEMs for 2-D modelling.

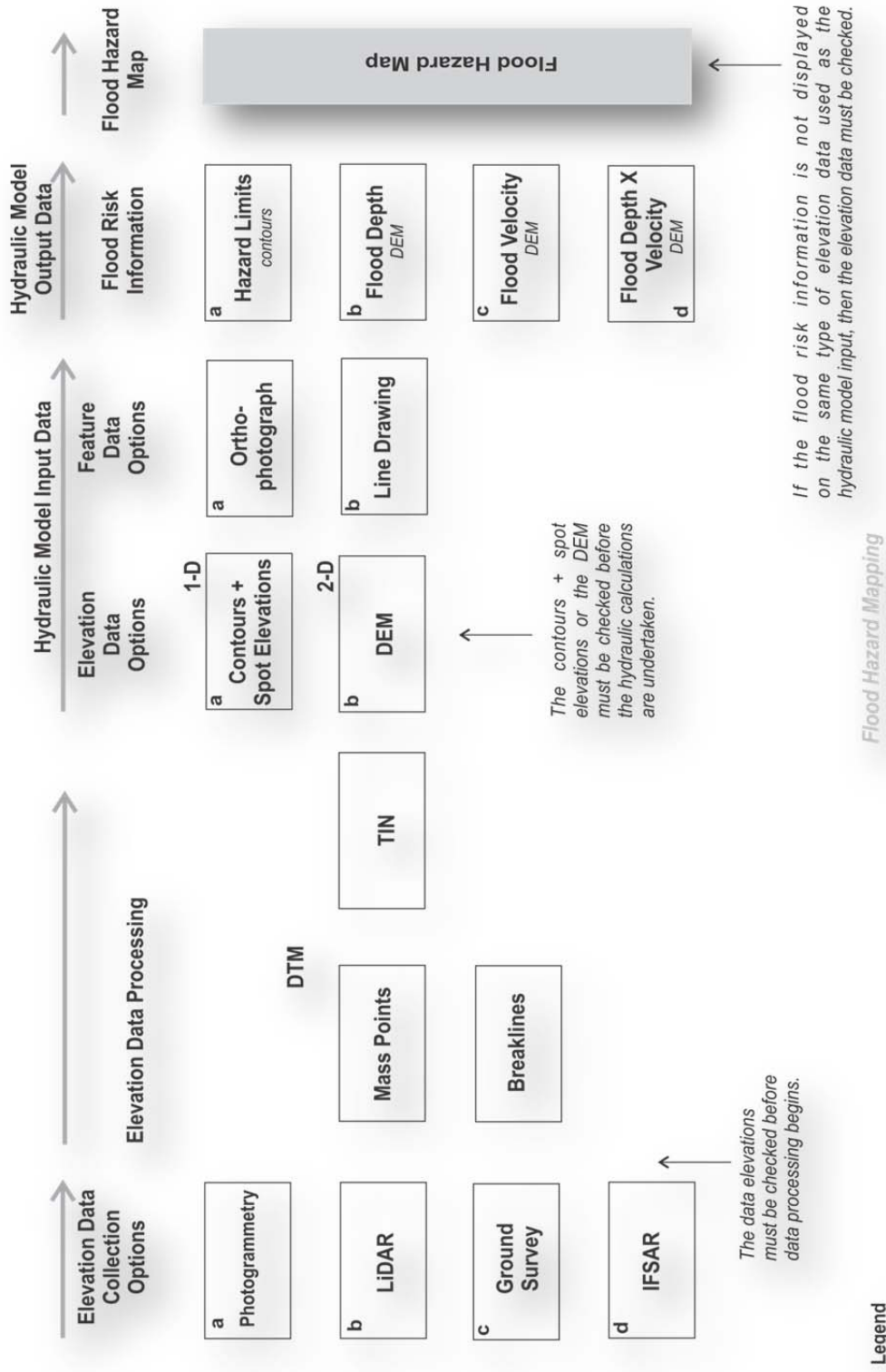
Digital elevation data sources, used for input to the hydraulic model, must be field survey checked prior to use. Also, if the results of the hydraulic analysis are placed on digital elevation data sources different from the input data, then the output digital elevation data sources must also be checked. As an example, water surface elevations may be created from contours and spot elevations while the flood elevations are plotted on a grid such as a DEM. This example would require two checks, one for the contours and spot elevations and one for the DEM. Survey data collected to check contours and spot elevations could be used to check the DEM.

The collection and processing of data must be conducted using established procedures, and must be easily reproducible. Qualified persons are to be able to recognize and understand all methods, approaches, basic data and rationale and any assumptions used in the analysis. Qualified persons are to be able to recreate the entire work without referring to other documents. Documentation must include the following:

- What analysis was done including purpose, alternative methods, and the rationale for the chosen method;
- How the analysis was conducted including input data, data sources, measurements of data, verification, corroboration, uncertainty analysis, calibration, validation, and sensitivity analysis;
- The results of the analysis;
- How the results were checked; and
- What are the limitations of the analyses.

Minimum Upstream Drainage Area For Flood Hazard Mapping - currently there is no Provincial minimum upstream drainage area requirement for the development of flood hazard limits. During the 1970's and 1980's a minimum drainage area of 125 ha was utilized presumably not to conflict with the Ontario Drainage Act. Headwater tributaries can have a significant impact on downstream flooding. The effective management of headwater tributaries may require flood hazard limits. It is currently up to the individual Conservation Authorities to define and implement flood hazard mapping or regulations on headwater tributaries based on their established watershed management needs and not upon any set drainage area.

Figure 2-1 - Flood Hazard Map Options





## 2.2 Digital Elevation Data - Contours, Cross Section Points and Grids

### 2.2.1 General

Hydraulic programs that model one-dimensional (1-D) flow usually require cross section points as part of the input. Cross sections are represented by a series of points located along a line or series of line segments that are perpendicular to flow. These points have a location specified by UTM co-ordinates and an elevation referenced to a datum. Cross section points represent the ground in the channel and the flood plain. Contours are required to (1) align cross sections, to abstract cross section points; (2) to identify ineffective flow areas; and (3) to plot hazard limits between cross sections. Contours are imaginary lines with all points on the line having the same elevation.

Hydraulic programs that model two-dimensional (2-D) flow usually required a grid or mesh to model the ground surface. Grids can be irregular in size or can be rectangular of the same size. DEMs (Digital Elevation Model) are one example of a grid.

Contours, cross section points, and grids can be manually or automatically developed from several different types of surface models that include mass points, breaklines, DTMs, TINs, and DEMs.

Mass Points - mass points define the horizontal and vertical location of specific points on the earth. Mass points can be generated using photogrammetry, LiDAR, IFSAR, ground based laser scanning, ground surveys (GNSS, Total Station) as well as other methods that meet the required accuracy.

*Photogrammetry* - can be used to gather digital elevation data for use in mass point data sets. Photogrammetry is the science of making accurate measurements from aerial photographs. Adjustments must be made to account for distortions in the camera system, and the curvature of the Earth. Photogrammetric mapping is accomplished through four processes that include aerial photograph acquisition, ground control acquisition, adjustment of the aerial photographs to the Earth, and feature collection.

*LiDAR (Light Detection and Ranging)* - Airborne LiDAR systems can gather digital elevation data to be used in mass point data sets, and in DEMs. LiDAR is composed of an airborne GPS with a GPS base station, an Inertial Measurement Unit (IMU), and light-emitting scanning laser. The airborne GPS determines the in-flight three-dimensional position of the sensor, and the IMU determines the attitude of the sensor i.e., the roll, pitch and heading. Automated and manual processing are required to identify vegetation, anthropogenic features and artifacts to produce a bare-earth model. LiDAR generates first return data that represents tree tops, roof tops, etc. Also, LiDAR produces last return data that represents points on bare-earth.

*Ground Surveys* - are typically conducted using GNSS (Global Navigation Satellite System) surveys or total station surveys. GNSS receivers can gather digital elevation

data to be used in mass point data sets. GNSS receivers capture data from several satellites to determine position coordinates (Northing, Easting, elevation) of a survey station. Total Stations can be used to gather digital elevation data to be used in mass point data sets. A Total Station measures horizontal and vertical angles as well as horizontal and vertical distances. Recorded data is stored in a data collector.

*IFSAR (Interferometric Synthetic Aperture Radar)* - airborne systems can gather digital elevation data to be used to create bare earth DEMs and associated data products. LiDAR transmits and receives pulses using lasers. IFSAR transmits and receives radar pulses. IFSAR is side looking where LiDAR is centered over the terrain features. IFSAR pulses can penetrate clouds where LiDAR pulses are absorbed by water. IFSAR operates at high altitudes (6,000 to 10,000 m) and speeds approaching 750 km/hr. LiDAR operates at approximately 200 km/hr. and at elevations of 300 m to 1,880 m. Vertical accuracy for LiDAR is about 15 - 50 cm RMSE and IFSAR is approximately 60 cm RMSE. Generally, LiDAR has greater accuracies than IFSAR for small urban and forested areas. IFSAR is more cost efficient for large areas where lower accuracies are required.

Breaklines - are linear features that describe a change in the slope, smoothness, or continuity of a surface. Breaklines should be produced using either stereo photogrammetric procedures or digital ortho-photography, where breakline features are digitized as two-dimensional features. Breaklines are created for stream centerlines, drainage ditches, tops and bottoms of streambanks, ridge lines, road crowns, levees, bulkheads, seawalls, road/highway embankments, and features that constrict the flow of water.

DTMs (Digital Terrain Model) - is the combination of mass points and breaklines that can be used to generate a TIN. See Table 2.5 for more details.

TINs (Triangulated Irregular Networks) - a TIN is a set of adjacent, non-overlapping triangles computed from point, line, and polygon data interpreted from mass points and breaklines. The TIN model stores the topological relationship between triangles and their adjacent neighbors. A TIN allows for the efficient generation of surface models for the analysis and display of terrain surfaces. A TIN model can be used to generate contour lines and DEMs. DEM accuracy is a function of the accuracy of the mass point data and the grid spacing.

DEMs - represent the elevation of bare earth at regularly spaced intervals in eastings and northings. DEMs are usually displayed as uniformly spaced grids. DEMs may neglect breakline information, as the DEM is grid based. DEMs are normally produced from irregularly spaced mass points. DEMs are slightly less accurate than TINs, or mass points from which they are averaged or interpolated. DEMs can be produced by a variety of methods. See Table 2.4 for more detail.

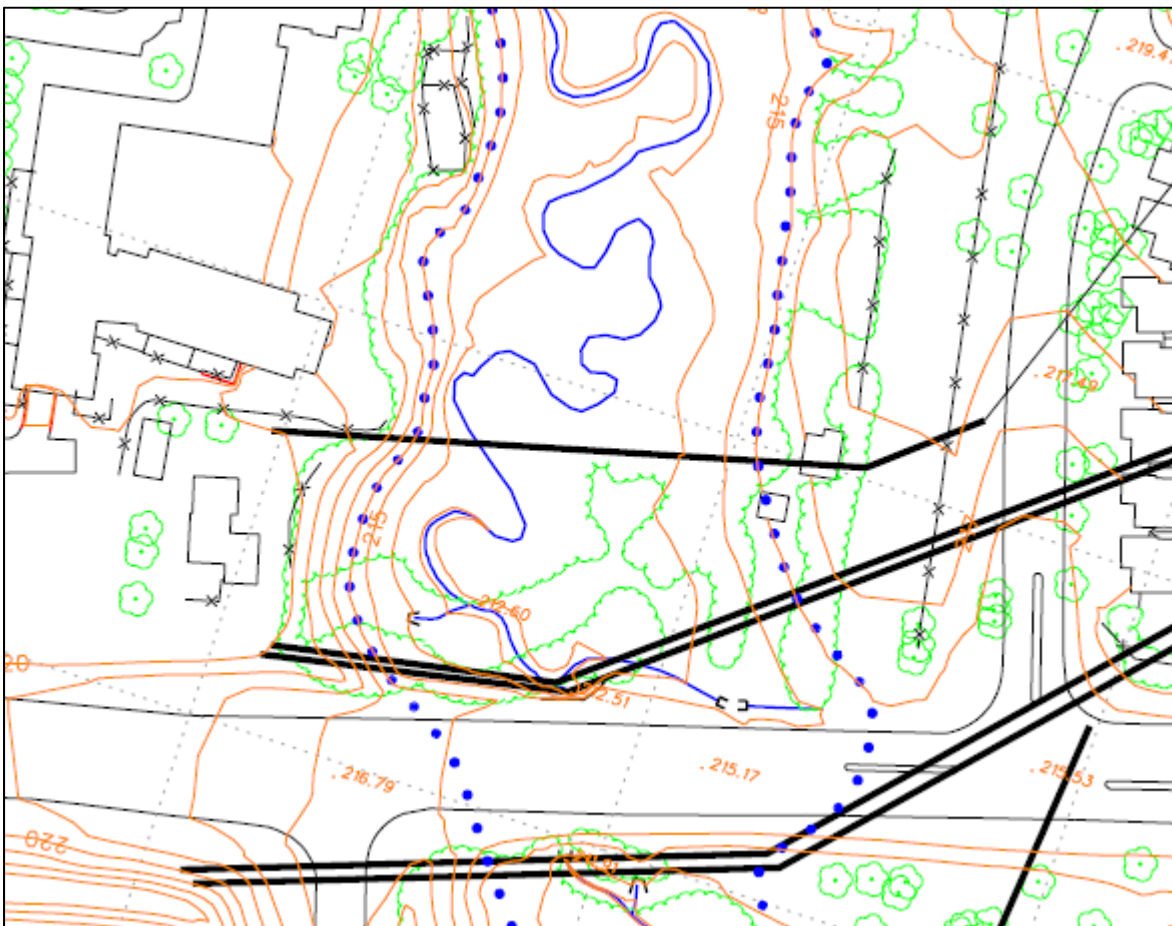
DEM cells may not accurately represent a watercourse (i.e., puddles) due to the averaging or interpolation nature of a grid cell. A hydro-enforced DEM uses breaklines to lower DEM cell

elevations to accurately represent watercourses and water bodies. Breaklines must be manually entered in the DEM. Thus, errors are introduced when the DEM is hydrologically conditioned.

The remainder of Section 2 has been divided into the following sub-sections:

- 2.2.2 Digital Elevation Data - Contours and Spot Elevations
- 2.2.3 Digital Elevation Data - Ground Surveys
- 2.2.4 Digital Elevation Data - Datum
- 2.2.5 Digital Elevation Data - Vertical Accuracy
- 2.2.6 Digital Elevation Data - Vertical Accuracy Checking
- 2.2.7 Digital Elevation Data – Deliverables

**Figure 2-2 - Example of Flood Hazard Map**



## 2.2.2 Digital Elevation Data - Contours and Spot Elevations

Contours are used to align cross sections, to abstract cross section points, and to plot floodlines between cross sections. Contours can be created in several different ways including a Triangular Irregular Network (TIN), a Digital Terrain Model (DTM), or a DEM. All methods must, at a minimum, generate contours at the following interval:

### Contour Interval

- Maximum contour interval shall be 1 m for line maps and ortho-photo maps with 0.5 m interpolated contours.

The contour interval for any project will be based on the intended use of the hazard limits, and should not be greater than the maximum contour interval. The project contour interval should be defined in the Flood Hazard Mapping Terms of Reference.

### Spot Elevations

Spot elevations will be shown at the following locations:

- 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.

## 2.2.3 Digital Elevation Data - Ground Surveys

Low-flow Cross Section Points - A representative low flow section shall be field measured for each reach between crossings and applied to each cross section in the hydraulic model.

Flood plain cross section points can be abstracted from digital elevation products (mass points, contours, TINs, DEMs, etc.) or from ground surveys. All surveyed cross section points must conform to the following:

- All points must be geo-referenced, and shown in ESRI shapefiles;
- All points must be referenced to the datum in Section 2.2.4 and must conform to the accuracies specified in Section 2.2.5;
- Surveyed points must represent significant breaks in ground slope and at changes in the hydraulic characteristics of the floodplain;
- Bank elevations to the channel bed and the deepest part of the stream must be measured;

- Underwater cross section elevations may require measurement (as per study Terms of Reference);
- Surveyed cross sections must include the entire flood plain of the main channel and any tributaries. Surveyed cross sections must be tied in vertically to established benchmarks and horizontally to permanent structures;
- In areas of uniform slope, readings must be taken at a maximum spacing of 15 metres. Supplementary data readings will be taken in areas of major change in relief (e.g. ditch centerline, top of fill slopes, etc.); and
- For irregular features such as watercourses, the survey must include points at significant bends in the feature. The maximum distance between data readings for irregular features is 10 meters.

### 2.2.4 Digital Elevation Data – Datum

Contours should be based on the following datum and projections:

- The vertical datum will be based upon the most current Geodetic Survey of Canada (Canadian Geodetic Vertical Datum CGVD28 - 1978 Version);
- The horizontal projection and datum for all the imagery and digital elevation data will be 6-degree Universal Transverse Mercator Projection (UTM) grid coordinates on NAD83 - CSRS (Canadian Spatial Reference System);
- The Canadian Gravimetric Geoid 2000 (CGG2000) with HTv2.0 will be used; and
- Imagery and data will be expressed in UTM Easting, UTM Northing, and elevation in metric.

### 2.2.5 Digital Elevation Data - Vertical Accuracy

The Terms of Reference for a flood hazard mapping project must define the level of accuracy of the digital elevation data to be used for the project. Each flood hazard mapping project is unique. The level of accuracy should not be greater than the level of accuracy required for the intended use. Levels of accuracy greater than what is required will result in increased costs, increased project schedules, and decreases in the number of studies that can be completed. The accuracy of the digital elevation data should be based on data needs related to the project Terms of Reference.

The vertical accuracy of a point is defined as the difference in elevation of a point on a map, and the elevation of the point on Earth. Geodetic or ground surveying is used to determine the location and elevation of a point on Earth. The horizontal accuracy of a point or spot elevation is defined as the difference in location between a point on the terrain data model and a point on Earth.

The following vertical accuracy must at a minimum be used for flood hazard mapping projects:

## Vertical Accuracy

All contours, spot elevations, breaklines, TINs, and DEMs that have been used to develop cross section data for the hydraulic model will have an accuracy of 0.30 m at the 95% confidence level. This implies that 38 of 40 checkpoints must be within plus or minus 0.30 m of their true elevation.

### **2.2.6 Digital Elevation Data - Vertical Accuracy Checking**

The accuracy of the digital elevation data will be checked for all flood hazard mapping projects. Checkpoints are defined as points in the digital elevation data that will be field surveyed. The surveyed UTM Northing, UTM Easting, and elevation will be compared with the digital elevation data values to determine the accuracy of the digital elevation data.

Checkpoints will be located within a Check Area or a block of land with an area of approximately 2 km<sup>2</sup>. More than one Check Area with checkpoints may be required to determine the accuracy of digital elevation data and surface models. Checkpoints should be located on public/government owned land to avoid the need for obtaining private property owner permission for conducting the field survey. Checkpoints should be located in flood plain areas if possible. Checkpoints will be evenly distributed across a Check Area.

Check Areas will be selected by the project manager. The number of Check Areas should not be more than 10% of the total surface model area. At least one Check Area will be selected per project to determine the accuracy of the digital elevation data. If the number of Check Areas is greater than one, then the Check Areas will be evenly spaced within the surface model.

#### Digital Elevation Data Vertical Accuracy Check - Contours & Spot Elevations

A minimum of 40 checkpoints will be used to check the elevation accuracy of a Check Area. The checkpoints will be distributed as follows:

- A minimum of 15 checkpoints will be located on a contour;
- A minimum of 15 checkpoints will be located on a spot elevation; and
- A minimum of 15 checkpoints will be located within the estimated flood hazard limit.

The contours and spot elevations are acceptable if it meets the required accuracy from Section 2.2.5.

#### Digital Elevation Data Vertical Accuracy Check - DEMs

A minimum of 40 checkpoints in a Check Area shall be used to determine the acceptability of the DEM. The checkpoints shall be selected in terrain that is flat or uniformly sloped. The uniform slope must not exceed 20 percent.

The checkpoints must never be located near to breaklines, such as bridges or embankments. The checkpoints should be evenly distributed in each of the following categories and evenly spaced across the Check Area:

- A minimum of 10 checkpoints will be located on bare earth and low grass;
- A minimum of 10 checkpoints will be located on impervious surfaces; and
- A minimum of 10 checkpoints will be located in high grass, weeds, and crops.

Areas of heavy vegetation may be less accurate than lightly vegetated areas, bare earth areas and impervious surfaces.

The DEM is acceptable if it meets the required accuracy in Section 2.2.5.

### **2.2.7 Digital Elevation Data - Deliverables**

The following shall be submitted in the Accuracy Check Report:

- All field survey notes including electronic files (ASCII files), and paper copies of the notes and files;
- ESRI shapefiles showing the following:
  - Benchmarks, temporary benchmarks, and monument locations;
  - Contour locations used in the elevation data model check; and
  - All surveyed checkpoints;
- A table comparing the field surveyed contour line elevations with the digital elevation model shown contour line elevations;
- A table comparing the field surveyed spot elevations with the digital elevation model shown spot elevations;
- A table comparing the field surveyed UTM coordinates of the checkpoint locations with the abstracted terrain data model values; and
- A table comparing all checkpoints used to determine the acceptability of the DEM.

## 2.3 Feature Data

### 2.3.1 General

Generally, flood hazard limits can be displayed on either ortho-photo maps or line maps. The use of either line maps or ortho-photo maps as a base for floodlines should be specified in the project Terms of Reference. Contour lines, and spot elevations will be added to either the ortho-photo maps or the line maps. Features such as buildings, road outlines, etc. appear in the ortho-photos. For line maps those features must be digitized from aerial photos.

#### Ortho-photographs and Line Drawings

Ortho-photo maps and line maps should show contours, spot elevations, grids, property lines, political boundaries, geographic names, planimetric features, cultural features, etc. Features (property lines, political boundaries, etc.) must be digitized from aerial photos or images. As a result line maps may be more expensive than ortho-photos.

Ortho-photos are a combination of aerial photographs and a DEM after undergoing process call ortho-rectification. The process includes (i) acquisition of photographs; (ii) scanning of non-digital photographs; (iii) ground control point selection for rectification of the photographs to its geographical position; (iv) acquisition of a DEM; (v) merging of the DEM with the aerial photograph with radiometric correction; and (vi) tiling and formatting of the ortho-photos.

Table 2.1 lists some of the features required for ortho-photo maps and line maps.

Deliverables for ortho-photo maps and line maps are shown in Tables 2.2 and 2.3 respectively.

### 2.3.2 Feature Data - Datum

The horizontal projection and datum for all the imagery and digital elevation data will be 6-degree Universal Transverse Mercator Projection (UTM) grid coordinates on NAD83 - CSRS (Canadian Spatial Reference System).

### 2.3.3 Feature Data - Accuracy

Features shown on ortho-photos or line maps for hazard maps should at a minimum have the following horizontal accuracy:

- 95% of the features are within a 1 m radius of their true position. Features will include buildings (building corners), fire hydrants, utility poles, or other single fixed points. This implies that 19 of 20 points must be within a 1 m radius of their true position.



### 2.3.4 Feature Data - Accuracy Checking

A minimum of 20 points per Check 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 Check Area. The feature data locations are acceptable if it meets the required accuracy shown in Section 2.3.3.



Brooklin, ON, July 2008.

**Table 2.1 Feature Collection**

Ortho-photo Maps & Line Maps

- Contour lines (Intermediate, Index, Auxiliary, Indefinite, and Depressions)
- Control Points (horizontal and vertical)
- Benchmarks/Monuments
- Watercourse Centre Lines & Flow Direction
- Boundaries - (International, Provincial, District, Municipal, Township, Native Reserve, Lot and Concession, Approximate, Annotation, Parking Lots, and Park Dump)
- Parks (National, Provincial, Amusement, Conservation Areas, Campgrounds, Tennis Courts, etc.)
- Spot Elevations
- Road Names (Highway, County, Township, Access, Runways, etc.)
- Cemetery Names
- Watercourse Names

Line Maps

- Aerial Cableways
- Antennae
- Marshes/Swamps/Wetlands
- Woods, plantations, etc.
- Lakes, Ponds
- Bridges (Foot, Road, and Railroad)
- Buildings (Ruins, )
- Cemeteries
- Chimneys
- Control Points (horizontal and vertical)
- Benchmarks/Monuments
- Shoals
- Conveyors, Ski Lifts,
- Culverts
- Dams, Ditches, and Dykes
- Flooded Lands
- Feature Outliers (buildings under construction)
- Fencing
- Light Standard, Poles,
- Depressions, Pits, Quarries
- Rocks
- Rivers, Streams, and Canals (including direction of flow)
- Piles
- Pipelines
- Rail Lines
- Roads (Highway, County, Township, Access, Runways, etc.)
- Trail/Brush Road
- Swimming Pools
- Tanks, Storage Bins,
- Towers
- Trails
- Transmission Lines (Poles, Pylons, and Tunnels, etc)
- Utility Poles & Lines
- Walls, Fence, Headwalls, & Breakwalls
- Wharfs, Docks, Ferry Slips, Groynes, & Piers
- Wooded Areas
- Reservoirs
- Masts
- Cliffs, Pits, and Piles
- Falls, Rapids,
- Shorelines

**Table 2.2 – Ortho-Photo and Images**

All ortho-rectified imagery will be delivered in 8-bit/band GeoTIFF; with multi-spectral imagery packaged as either two 3-band files (RGB and CIR) or one 4- band file; with the panchromatic band provided as a separate file.

Breaklines shall be placed on features such as overpasses, bridges, water crossings, dams, cliffs and other features that may cause vertical shifts in the imagery.

Delivery formats: GeoTIFF, JPEG2000, JPEG, ECW (ER Mapper Compress Wavelets), and MrSID (Multi-resolution Seamless Image Database). File extensions. Image files should predefined, format-specific file extensions, listed in the table below.

World files. Each image dataset should be accompanied by a valid world file with format-specific file extension (see table below) or generic extension “.wld”. For example, a GeoTIFF image file “sample.tif” should have associated world file “sample.tfw” or “sample.wld”.

For GeoTIFF files, it is desirable that files contain the GeoTIFF tag “Coordinate System” which contains the full definition of the spatial reference system in the Well-Known Text (WKT) format.

Image Format	File Extension	World File Extension
GeoTIFF	.tif	.tfw
JPEG	.jpg	.jgw
JPEG2000	.jp2	.j2w
ECW	.ecw	.eww
MrSID	.sid	.sdw

Point and tabular data in X/Y or X/Y/Z format can be delivered in ASCII (comma or tab separated) Excel, MS Access, ESRI geo-database table, dBase formats.

GeoTIFF based raster imagery will have all the projection parameters correctly defined in the GeoTIFF headers.

The rasterized version of a DEM will also be delivered in an uncompressed 32 bit GeoTIFF file at the same post spacing.

Data Tiling - All processed tiles should be uniquely identified and labelled using the lower left (southwest) coordinate values for position and uniqueness.

**Notes:**

Portions of the text have been abstracted from Flood Inundation Mapping Guidelines by Environmental Water Resources Group Ltd. in association with 4DM for the Ontario Power Generation, March 2009.

Portions of the text have been abstracted from Imagery and Elevation Acquisition Guidelines by Mapcon Mapping Ltd. for the Ministry of Natural Resources, November 2009.

**Table 2.3 – Line Maps**

Shapefiles should have a clean geometry as indicated by the ArcGIS Check Geometry tool.

Data submission should include the relevant “.shp”, “.shx”, “.dbf” and “.prj” files; optionally the relevant “.sbn” and “.sbx” files may be included.

Tolerance, resolution and domain: Feature classes and feature datasets in ESRI geodatabases have associated tolerance, resolution and domain settings for the X, Y, Z and M coordinates.

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

All datasets referenced in the project and layer files must be submitted.

Vector data and other shapefile based data such as LiDAR Point Clouds will be delivered in ESRI shapefile format, along with the appropriate ArcGIS projection file (\*.prj) indicating the above projection and datum.

Contours will be delivered as an ESRI LineZ Shapefile. Each contour line will have an attribute to indicate if it is an index or intermediate contour and whether it is a depression contour and if it is in an obscured or low reliability area. Contours shall be developed using a combination of elevation mass points, polygons, and breaklines to generate a TIN.

Spot elevations will be shown at the following locations:

- 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.

The edited topologically correct breakline and other planimetric features as ESRI LineZ or PolygonZ shapefiles as is appropriate will be submitted.

AutoCAD DWG and DXF or Bentley Microstation V8 DGN will be submitted in addition to the shapefile listed above. Non data element such as drawing borders, title blocks, north arrows, etc. shall be placed on a separate layer.

The original collected mass points and a raster data which may be interpolated from the TIN created by the mass points and breaklines) as ESRI PointZ.

All shapefiles will be full 3D files.

Notes:

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Portions of the text have been abstracted from Imagery and Elevation Acquisition Guidelines by Mapcon Mapping Ltd. for the Ministry of Natural Resources, November 2009

**Table 2.4 – Mass Points/DEM**

Deliverables:

Mass Point Data X/Y or X/Y/Z Format

- ASCII (comma or tab separated)
- Excel
- MS Access
- ESRI Geo-database table
- dBase

ESRI ASCII Grid

- ESRI Binary Grid.
- ESRI file geodatabase raster, ArcGIS version 9.2 or later.

GeoTIFF

- GeoTIFF files should have an associated valid world file with extension “.tfw” (or “.wld”);
- GeoTIFF files should have an associated valid spatial reference system definition file (“.prj”) in a well-known text (WKT) format;

The GeoTIFF tag “Coordinate System” which contains the full definition of the spatial reference system in the well-known text (WKT) format will be submitted.

Breakline features must be classified and separately attributed for the following features:

- Water Body Features, Shorelines (lakes, reservoirs, etc.)
- Water features (such as wide rivers)
- Linear Hydrographic Features - streams, shorelines, canals, etc. with varying elevations
- Road Features - not including bridges and overpasses
- Overpasses and Bridges
- Ditches and other constructed features
- Obscured Areas - vegetated areas that are  considered obscured to the extent that adequate vertical data cannot be clearly determined.

Notes:

Portions of the text have been abstracted from Flood Inundation Mapping Guidelines by Environmental Water Resources Group Ltd. in association with 4DM for the Ontario Power Generation, Draft March 2009.

Portions of the text have been abstracted from Imagery and Elevation Acquisition Guidelines by Mapcon Mapping Ltd. for the Ministry of Natural Resources, November 2009.

**Table 2.5 – DTM**

Deliverables:

Mass points, breaklines, obscured areas, and optionally contours, shall be referred to herein as the Digital Terrain Model.

Elevation data will include mass point data with a posting not greater than ten times the specified accuracy.

Elevation data will include breakline data for any hydrologically significant features to support the development of a hydrologic terrain surface. A hydrologic terrain surface is defined here as a 3D elevation surface created from elevation points and line and/or polygon breaklines that accounts for any barriers to hydrologic flow.

Breakline features must be classified and separately attributed for the following features:

- Water Body Features, Shorelines (lakes, reservoirs, etc.)
- Water features (such as wide rivers)
- Linear Hydrographic Features - streams, shorelines, canals, etc. with varying elevations
- Road Features - not including bridges and overpasses
- Overpasses and Bridges
- Ditches and other constructed features
- Obscured Areas - vegetated areas that are  considered obscured to the extent that adequate vertical data cannot be clearly determined.

Contours shall be developed using a combination of elevation mass points, polygons, and breaklines to generate a TIN.

Notes:

Portions of the text have been abstracted from Flood Inundation Mapping Guidelines by Environmental Water Resources Group Ltd. in association with 4DM for the Ontario Power Generation, Draft March 2009.

Portions of the text have been abstracted from Imagery and Elevation Acquisition Guidelines by Mapcon Mapping Ltd. for the Ministry of Natural Resources, November 2009.

## 2.4 Hydraulic Structure Data

Hydraulic structure data is required to undertake the hydrologic and hydraulic analyses required for flood hazard maps. Generally, the data is acquired through field surveys, field investigations, and as built drawings. Hydraulic structure data includes the following:

- Photographs;
- Highwater Marks and Debris Lines; and
- Hydraulic Structure Dimensions and Elevations.

### Photographs

- 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; and
- All photographs taken in the field will be geo-referenced and will be located in ESRI shapefiles.

### Highwater Marks and Debris Lines

The following should be photographed and surveyed/measured:

- Highwater or flood marks;
- Ice scars, scour marks, etc.;
- Signs of relief flow and any signs of scour or deposition; and
- The location, type, size and amount of debris.

### Hydraulic Structure Dimensions and Elevations

Hydraulic structure data sheets should be prepared outlining the physical characteristics of each structure. The data sheets shall be prepared for all hydraulic structures (bridges, dams and embankments, road/rail crossings, etc.).

- Included on the data sheets for bridges/culverts will be the following:
  - Street Name;
  - UTM Co-ordinates;
  - Skew Angle;
  - Crossing Length;
  - Entrance (vertical abutments, headwalls, wingwalls, mitered to slope, projecting);
  - Parapet Type and Dimensions, length and Height;
  - 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; and
  - Assessment of Scour/Deposition, and Potential for Debris Blockage.
  
- Included on the data sheets for dams/weirs will be the following:
  - Top-of-dam elevation;
  - Normal pool elevation;
  - Principal spillway type;
  - Inlet and outlet elevations and dimensions; and
  - Emergency spillway type, elevation and dimensions.
  
- Surveyed profiles across each hydraulic structure. The surveyed profile will be used in the hydraulic model and the points surveyed in the field will be included in the ESRI shapefiles;
  
- Channel and bridge/culvert drawings used to develop the hydraulic models; and
  
- All information surveyed and measured in the field will be submitted in ESRI shapefiles. This includes hydraulic structures (road crossings, dams, stormwater ponds, benchmarks, monuments, etc.).



## 2.5 References

Parts of Section 2 has been abstracted from the following documents:

- Guidelines for Digital Elevation Data v1.0, by National Digital Elevation Program (NDEP), May 2004;
- Photogrammetric Mapping, by U.S. Army Corps of Engineers, July 2002;
- Imagery and Elevation Acquisition Guidelines, by Mapcon Mapping Ltd., November 2009;
- Data Capture Standards, Appendix M, Guidelines and Standards for Flood Risk Analysis and Mapping by FEMA, January 2008;
- Guidance for Aerial Mapping and Surveying, Appendix A, Guidelines and Specifications for Flood Hazard Mapping Partners by FEMA, April 2003;
- Supporting Sustainable Water Management in Ontario through Innovation, by Ganaraska Region Conservation Authority, March 2009;
- Surveying Principles and Applications, 6th Edition, Barry F. Kavanagh, 2003;
- ASPRS Positional Accuracy Standards for Digital Geospatial Data, American Society for Photogrammetry & Remote Sensing, Revision 7 Version 1, Final Draft for Board Approval, November 14, 2014;
- LAS Specification Version 1.4 - R13, American Society for Photogrammetry & Remote Sensing, July 15, 2013;
- LiDAR Base Specification, By Hans Karl Heidemann, Chapter 4 of Section B, U.S. Geological Survey Standards Book 11, Collection and Delineation of Spatial Data, Version 1.2, November 2014;
- LiDAR Specifications for Flood Hazard Mapping, Appendix 4B: Airborne Light Detection and Ranging Systems, Federal Emergency Management Agency; and
- National Floodplain Mapping Assessment, MMM Group Limited in association with JFSA and Matrix Solutions Inc. for Public Safety Canada June 2014.

### 3.0 HYDROLOGIC ANALYSIS

#### 3.1 General

Hydrologic analyses are undertaken to develop a comprehensive assessment and understanding of precipitation runoff characteristics and to provide input data to hydraulic analysis procedures. Hydrologic analyses must be conducted using established procedures, and must be easily reproducible. Professional engineers are to be able to recognize and understand all methods, approaches, basic data and rationale and any assumptions used in the analysis. Professional engineers are to be able to recreate the entire work without referring to other documents. Documentation must include the following:

- What analysis was done including purpose, alternative methods, and the rationale for the chosen method;
- How the analysis was conducted including input data, data sources, measurements of data, verification, collaboration, uncertainty analysis, calibration, validation, and sensitivity analysis;
- The results of the analysis;
- How the results were checked; and
- What are the limitations of the analyses.

A hydrologic analysis can be undertaken using the following steps (Figure 3-1):

1. Determine the information that is required, and to what level of accuracy;
2. Conceptualize and characterize the watershed including historical meteorological drivers of flooding;
3. Determine what data is available and to what level of accuracy;
4. Select the hydrologic computation procedure;
5. Conduct the hydrologic computations;
6. Determine the acceptability of the results and
7. Document the study process and results.

Standard Hydrologic Parameters (Section 3.9) should be used in all hydrologic computations. If the engineer feels that the Standard Parameters should be modified, the engineer should provide documentation to the Conservation Authority providing justification that can include the results of calibration/validation analyses.

Hydrologic computations for hazard limit delineation are usually conducted through either a frequency analysis of recorded streamflow rates, or by simulating streamflow rates using a computer program or by field measurements of maximum flood elevations.

Section 3 refers to two (2) types of data or series of data. Historical data refers to floods that have occurred. Design data or series of data refers to simulated streamflow using standard input such as design storms. For example, a historical flood frequency curve refers to return

period values developed using recorded streamflow data. A design flood frequency curve refers to return period values developed from computer simulation model data.

Section 3 is divided into the following subsections:

- 3.2 Information Requirements
- 3.3 Watershed Conceptualization and Characterization
- 3.4 Data Availability: Climatic, Precipitation, Streamflow
- 3.5 Selecting a Computational Procedure
- 3.6 Technical Reviews
- 3.7 Frequency Analysis: Streamflow
- 3.8 Computer Modelling
- 3.9 Hydrologic Standard Parameters
- 3.10 References

The hydrologic study report must be sealed, signed, and dated by a professional engineer. All computer program input and output data must be sealed, signed, and dated by the professional engineer who prepared or supervised the preparation of the input data and who checked the output data. The computer model description boxes must include the professional engineers name, PEO number, and the completion date.

### 3.2 Information Requirements

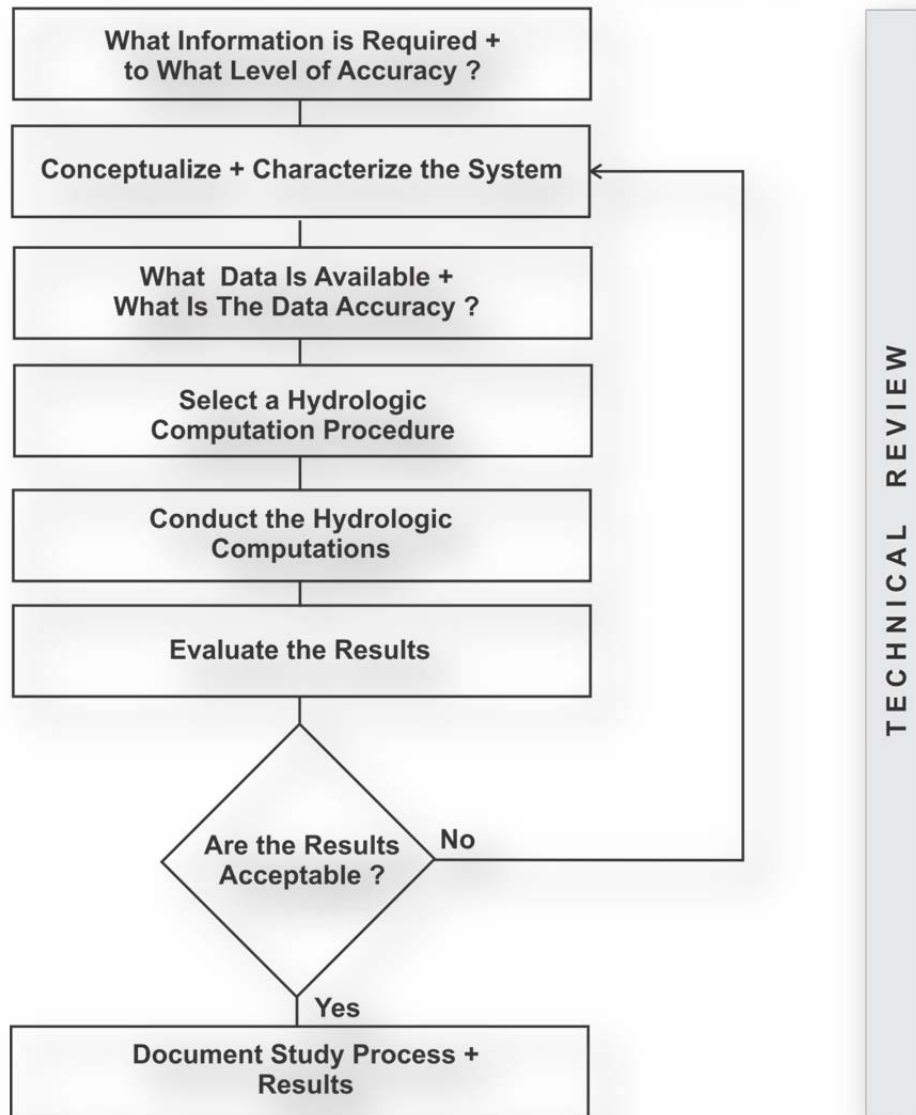
- The study report must discuss the hydrologic information required for input to the hydraulic model, and the methodology used to obtain that information. Information includes the characteristics of streamflow, and where the information is required. The report must discuss what scenarios are to be calculated, and what level of accuracy is required.
- It is the engineer's responsibility to review the accuracy of the input parameters and the computation methods to ensure the flood hazard maps are produced at a reasonable cost. The accuracy of the hydrologic results is a function of the accuracy of the input values and the computation methods. Generally, the greater the level of accuracy required in the hydrologic results, the greater the level of effort and resources needed to produce the hydrologic results. Each input value and computation method has an associated level of accuracy. Increasing the level of accuracy in one of the inputs does not necessarily increase the level of accuracy to the same extent in the hydrologic results. Increasing the level of accuracy in one of the inputs or selecting a computation method with a higher level of complexity may result in higher costs.
- Specification of the information requirements combined with characterization of the watershed, and determination of available data will allow a computation procedure to be selected.

### 3.3 Watershed Conceptualization and Characterization

- The report must discuss the conceptualization and characterization of the watershed under study. Conceptualization and characterization aids in determining the computation methods to be used in the hydrologic calculations including which computer programs may be applicable.
- Conceptualization will determine the salient components of the watershed, the relationships between the components, the upstream and downstream boundary conditions, and the temporal computation requirements. Also, the size of the time step to be used in the computations must be determined. Conceptualization will determine how lumped or detailed the hydrologic processes will be modelled. Assumptions must be fully discussed and justified.
- Characterization of the watershed will aid in determining which computation methods are selected. It includes the size and location of storage and conveyance elements within the watershed.

Figure 3-1

### Hydrologic Computation Selection Procedure



### 3.4 Data Availability: Climatic, Precipitation, Streamflow

The study report should contain a discussion on the data used to derive parameters for the model, and the data used to evaluate the model. The accuracy of the model will depend on the accuracy of the data used to develop and calibrate the model. The discussion should include the following:

- Where can the data be sourced;
- How and by whom was the data measured;
- Period of record that was used in the model; and
- What is the level of accuracy of the data.

Error and uncertainty creeps into data through a number of ways. Included are errors due to the procedures used to acquire the data, errors due to natural spatial and temporal variability, transcription errors, data storage errors, and errors due to data manipulation.

An example is streamflow data. Accuracy of streamflow rates can vary from plus or minus 2% to as high as 40%. The process entails observations of flow depth, periodic measurements of streamflow, and development of a rating curve to convert flow depth to flow rate. Error is dependent on the following:

- Accuracy and precision of the instruments used for making the flow depth measurements;
- Methods used to average the depth measurements;
- Skill of the hydrographer measuring streamflow rates;
- Open channel flow conditions such as backwater and non- steady flow conditions;
- Climatic and environmental factors that affect the quality of streamflow measurements; and
- The validity of the method used to develop the rating curve and the stability of the channel section.

Some agencies have considered measurements of daily streamflow to be excellent if measured within 5% of the true value, good if measured within 10% and fair if measured within 15%. For individual storm events, the accuracy of measurements could be greater than 15%.

### Data Filling and Modification

- The study report must contain a discussion on data filling and modification of data used in the study. Generally, missing data needs to be filled. Also, suspect data needs to be modified.
- Discussion should include the following:
  - What data was filled or modified; and
  - What techniques were used to fill the data including the statistical characteristics of the modified data. Statistics include data means, standard deviation, skewness, event frequency, and high/low spell lengths.

### Data Stationarity

- The study report must contain a discussion regarding data stationarity. Changes to data sets may be gradual, or may be abrupt or may be in a more complex form.
- Data sets may not be stationary for a variety of reasons including the following:
  - Changes in measurement techniques or instrumentation or relocation of the gauge;
  - Changes in land use or land use management;
  - Changes in stream channel geometry;
  - Changes in streamflow regulation and deregulation;
  - Changes in groundwater; and
  - Changes in climate.

### 3.5 Selecting A Computational Procedure

There are several procedures that may be conducted to calculate the hydrologic requirements for flood hazard mapping projects. Included are single station frequency analysis, regional frequency analysis, and hydrologic modelling. The choice is based on the need for a hydrograph as opposed to peak discharge rate, the size and characteristics of the watershed, the availability of data, input requirements of the hydraulic procedures, previous studies, and future land use change.

Single station frequency analysis that includes the use of recorded data in the vicinity of the study area is the preferred choice for developing the return periods of peak streamflow rates. The use of single station frequency analysis is limited to a significant period of record, stable upstream land use, unchanging future upstream land use, the lack of a need for a full hydrograph in the drainage system analysis, and the lack of a need for the analysis of a historical storm event. Many stations within southern Ontario cannot meet these criteria.

Regional frequency analysis is an extension of single station analysis to a region where data from several gauges is utilized to develop equations for the prediction of peak streamflow rates. Regional frequency analyses have limitations similar to single station frequency analyses.

Precipitation-runoff modelling or hydrologic modelling is the typical method used to develop the input data for the development of flood hazard maps. Data recorded at streamflow gauges and single station frequency analysis should be used in the development of precipitation-runoff models.

The Conservation Authority must approve the computation procedure prior to the analysis.



Brock St, in Stayner, ON



### 3.6 Technical Reviews

Hydrologic studies should be reviewed to determine the correctness, completeness or appropriateness of procedures used to develop information for the intended purpose and for adherence to these Technical Guidelines. Included are input data, initial conditions, conceptual model, mathematical model and parameters, model limitations, and documentation.

Reviews can be undertaken near the end of a study, or throughout the study. Both approaches have limitations. For example, there may not be sufficient budget to correct any deficiencies found in a review if the review is conducted near the end of a study. Also, a reviewer's independence may become jeopardized if reviews are conducted throughout the study, as the reviewer may act as an advisor rather than a reviewer. The preference is to have the reviewer involved throughout the study.

A formal process should be followed to review hydrologic studies, and each review should be documented. Reviews may be performed by the client organization soliciting the work, or can be undertaken by third parties.

Reviewers must have sufficient expertise in the area of practice to properly assess the hydrologic analysis. Reviewers must be capable of conducting the study, and reviewers must have a thorough understanding of methodologies and knowledge of accepted hydrologic engineering practice. A reviewer should have access to the computer program being used in the study. A reviewer should be a Professional Engineer licensed in the Province of Ontario.

The reviewers report should identify the following:

- The individual who authorized the review,
- The author;
- The purpose of the review;
- The basis under which the review was conducted;
- A brief description of the study report under review;
- A summary of documentation provided to the reviewer;
- Communications made during the review;
- A description of the reviewer's methodology for conducting the review; and
- The reviewer's findings that include information upon which the opinions are base.

### 3.7 Frequency Analysis: Streamflow

#### 3.7.1 General

Single station frequency analysis or regional frequency analysis may be used to determine peak streamflow rates required for the hydraulic analysis. Frequency analysis does not provide a full streamflow hydrograph and is not applicable to changing land use conditions.

As a result, frequency analysis cannot provide the input required for 2-D hydraulic modelling, or for unsteady flow modelling or for catchments where the existing land use is substantially different than future anticipated conditions.



Yonge/York Mills Channel, Toronto, ON

### 3.7.2 Single Station Frequency Analysis

- Frequency analysis can be undertaken where suitable streamflow records exist for the study watershed;
- The suitability of the records for frequency analysis will be evaluated through discussion with the Conservation Authority, the operating agency, field inspection and review of the records;
- Single station analysis should be carried out when the length of record is equal to or greater than 20 years;
- For record lengths between 10 years and 19 years, single station analysis shall be substantiated through comparison with regional frequency analysis. If the length of record is less than 10 years, only regional frequency analysis shall be undertaken;
- The 95% confidence limits on peak streamflow estimates and expected probability adjustments must be provided;
- Frequency analysis of streamflow data should only be performed for data that is random, independent, homogeneous and stationary;
- Factors that must be considered in using existing streamflow records are the conversion and reconversion of regulated and natural flows; non-stationary records; the extension of the streamflow records; single site versus regional flood frequency analysis; and transfer of location of record;
- Any modifications to streamflow data or the results of the frequency analysis must be documented in the study report. Documentation must include reasons for the modifications, and any limitations caused by the modifications;
- Frequency analysis may be performed using the Consolidated Frequency Analysis computer program (CFA88), developed by Environment Canada. Programs and spreadsheets may be used when prior approval has been granted by the Conservation Authority; and
- Computer programs, that are used to perform the frequency analysis must be selected by the engineer and approved by the Conservation Authority. Reasons for selecting the program must be documented in the study report.

### 3.7.3 Regional Frequency Analysis

- All parameter values must fall within the range of basin and climatic characteristics used to derive the equations; and
- Several regional frequency analyses have been prepared for Ontario applications. Included are the following:
  - Index Flood Method, Environment Canada 1985;
  - Multiple Regression Method, Environment Canada, 1986;
  - Regionalization by Multiple Regression Analysis, Ontario Ministry of Natural Resources, 1984; and
  - Modified Flood Index Method, by Ontario Ministry of Transportation, 1986.

### 3.7.4 Corroboration

- Where results from a single station or a regional frequency analysis are used as input to hydraulic procedures, the results must be corroborated using an independent method.

Regional frequency analysis results may be used to corroborate the results from a single station frequency analysis.

Regional frequency analysis results may be used to corroborate the results from a different regional frequency analysis methodology; and
- The results from the corroboration must be documented in the study report. If the results cannot be corroborated then the Conservation Authority must be contacted before hydraulic analyses are initiated.

### 3.7.5 Documentation and Deliverables

- All model input and output files and geo-referenced spatial files showing hydrologic features used for the analysis must be submitted;
- All data and reports must be submitted in electronic format as specified by the Conservation Authority;
- Discussion on streamflow gauging stations including equipment, site rating curve, vulnerability to backwater, ice influence or flanking with conclusions regarding its reliability shall be prepared as part of the study report;
- Discussion on the criteria used in the flood frequency analysis and reasons for choosing a particular frequency distribution shall be included in the study report;

## TECHNICAL GUIDELINES FOR FLOOD HAZARD MAPPING

- Table - results of the regional frequency analysis for 2 through 100 year peak flow rates at various points of interest;
- Table - input parameters used in the regional frequency analysis;
- Table - summary of streamflow gauges, including location, period of record, etc.;
- Table - summary of streamflow data used in the frequency analysis; and
- Graphs of flood frequency curves with 90% confidence limits.

## 3.8 Computer Modelling

### 3.8.1 General

Computer models are a simplification of reality. Computer models are simply tools that can be used to better understand how watersheds function. Computer models can range from complex, geographically explicit computer models, to simple lumped models. Modelling to a higher resolution or level of accuracy than is necessary will not always produce superior results and may ultimately waste time and resources.

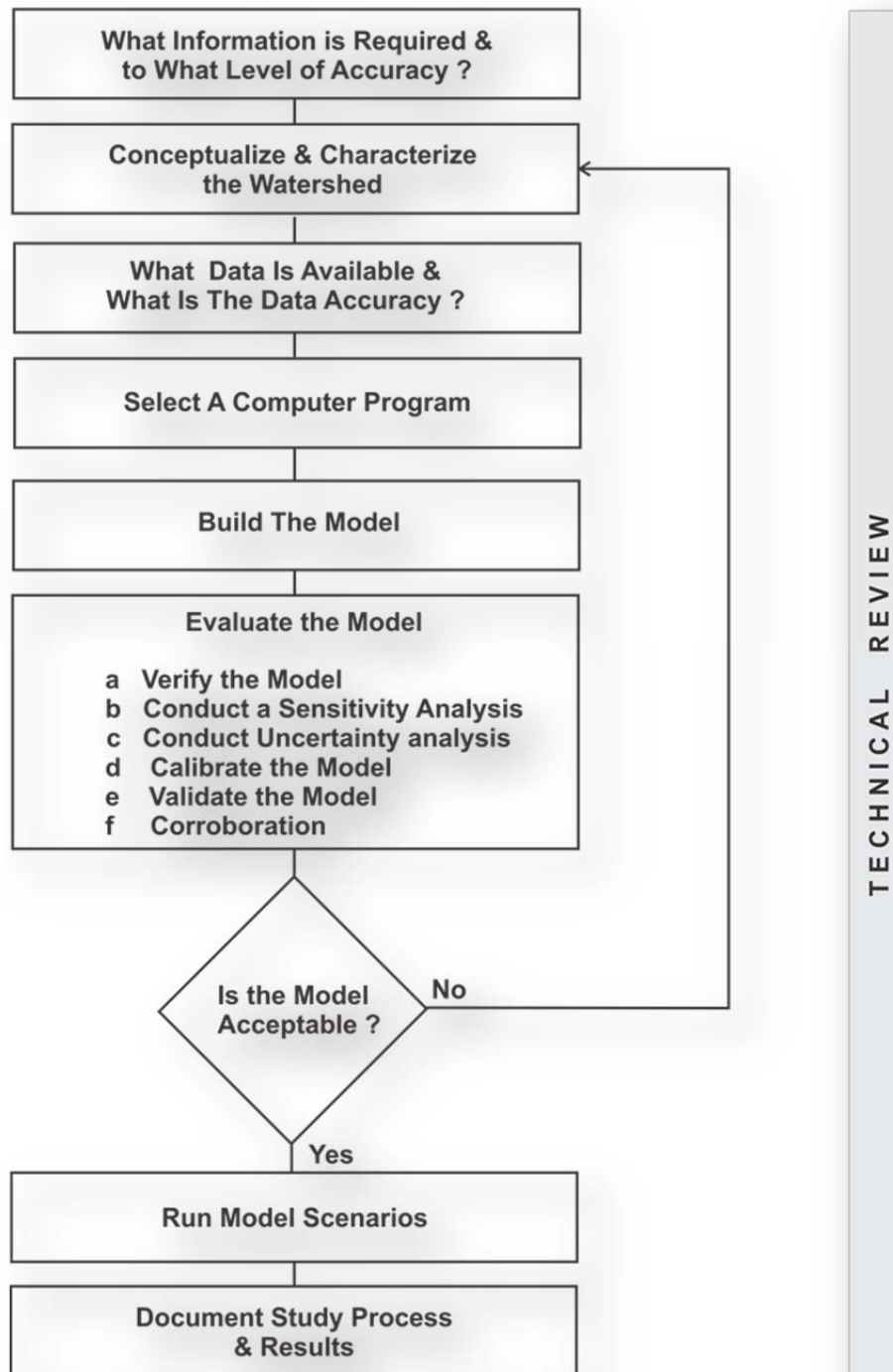
Figure 3-2 is a methodology or process that may be followed to undertake computer modelling. The process is similar to the hydrologic selection process shown in Figure 3-1.

Section 3.8 is divided into the following sections:

- 3.8.2 Program/Software Selection
- 3.8.3 Model Building
  - 3.8.3.1 Precipitation
  - 3.8.3.2 Discretization
  - 3.8.3.3 Land Use
  - 3.8.3.4 Time Steps
  - 3.8.3.5 Hydrologic Abstractions
  - 3.8.3.6 Hydrograph Convolution
  - 3.8.3.7 Channel Routing
  - 3.8.3.8 Reservoir Routing
  - 3.8.3.9 Diversions
  - 3.8.3.10 Input Hydrographs
- 3.8.4 Model Evaluation
  - 3.8.4.1 Model Verification
  - 3.8.4.2 Sensitivity Analysis
  - 3.8.4.3 Uncertainty Analysis
  - 3.8.4.4 Calibration/Validation
  - 3.8.4.5 Corroboration
  - 3.8.4.6 Error and Warning Messages
- 3.8.5 Model Acceptability
- 3.8.6 Modelling Scenarios and Results
- 3.8.7 Study Report and Deliverables

Figure 3-2

Hydrologic Modelling Methodology



### 3.8.2 Program/Software Selection

- An engineer must select the computer program to be used in the hydrologic analysis. Reasons for selecting a computer program must be documented by the engineer and approved by the Conservation Authority. The documentation must include alternate programs, and reasons why the alternate programs were not selected. The documentation for the program selection must be sealed, signed and dated by a professional engineer;
- Computer programs used in the hydrologic analyses must be the most recent version. The engineer should follow the procedures and guidance given in the program User's Manual;
- Computer programs used in the hydrologic analyses should not be modified by anyone except the programs author; and
- If the engineer proposes any modifications to the computer program or proposes to use an existing modified program, the consultant must submit to the Authority input test data, output, and complete listing of the modified computer program, user's manual and an explanation in detail as to the nature of and reasons for modifications for review and approval prior to its use. The Conservation Authority and its agents should be granted a royalty free license to use the program for flood plain modifications.

#### Program/Software Selection Notes

- A computer program is a system or algorithm with mathematical equations, parameters and data structures. Programs may be developed in-house, may be external open source or may be an external proprietary program where the source code is not shared. Open source programs that are actively managed are recommended;
- There may be more than one suitable program to conduct the computations and more than one computer program may be required;
- The engineer should be familiar with the principles, equations, algorithms, and assumptions used in the program; be aware of the programs limitations; and know when the program is providing the appropriate answers;
- Table 3.1 identifies some of the steps required by the engineer to demonstrate due diligence when selecting and using hydrologic and hydraulic software. The



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engineer selecting the software is responsible for conducting due diligence whether it is Conservation Authority staff or a consultant;

- The engineer should select a program (algorithms and equations) with the available data that reflects the dominant and sensitive processes described in the conceptual model; and

- The engineer should select a program that is no more complicated than necessary to compute the required information. Models tend to increase uncertainty in their results as they become too simple or too complex. The complexity of a model should be sufficient to minimize uncertainty, and that any more or less complexity will increase uncertainty.



Old Mill, Hamilton, ON

**Table 3.1 - Software Due Diligence**

1. The engineer should accept or reject software based on their own assessment of the compatibility and viability of the software to the task at hand.
2. The engineer should be able to justify and document the selection of each software tool.
3. The engineer should keep records of input data, and check output data from newer software versions with that obtained from earlier, verified versions.
4. The engineer should test all problematic situations that arose in the past.
5. Logs should be kept that report software performance and observations of past problems and limitations.
6. The engineer should establish and conduct suitable tests to determine that the software performs as it was intended to do.
7. Software is verified by comparing output data with actual results from real-life situations or thoroughly checked manual calculations.
8. The engineer should check output data after each run to be assured the data is correct and reliable for use in design.

The data can be checked by comparing output from manual calculations with software output. Also, output data can be checked through comparison of output data from past projects of a similar nature.

Notes:

One or more engineers may be required to comply with the above statements.

"Due diligence is the effort expected to be made by an ordinarily prudent or reasonable party to avoid harm to another party."

"Professional engineers are responsible for all aspects of the design or analysis they incorporate into their work, whether it is done by an engineering intern, a technologist or a computer program."

page 4, Professional Engineers Using Software-Based Engineering Tools *April 2011*, by Professional Engineers Ontario.

### 3.8.3 Model Building

Model building is the development of a mathematical model from a conceptual model. Conceptual models describe how a system behaves, the system components, and the functional relationships between these components. Model building requires both a spatial and temporal discretization of the physical watershed into a mathematical model. The construction of the mathematical model is a function of the computer program. The model building phase determines parameter values that are fixed, and parameter values before calibration. Parameters before calibration or standard parameters can be found in Section 3.9 Hydrologic Standard Parameters.

The development of flood hazard maps specifically refers to models that simulate extreme streamflow rates and streamflow hydrographs. Separate models may have to be developed for low flow events.

#### 3.8.3.1 *Precipitation*

##### Historical Storms

- Observed storms can be transposed from their location of occurrence to the basin in question and their orientation changed to maximize the flooding effects on the watershed; and
- For historical storms, the spatial distribution of rainfall must be discussed in the report. It is important to note that historic storms move across a catchment while design storms are assumed to be stationary over the catchment and evenly distributed across the catchment.

##### IDF Curves

- The model shall be based on rainfall frequency or, where snowmelt floods are significant, a combination of snowmelt and rainfall; and
- Municipal intensity-duration-frequency (IDF) values can be used when undertaking hydrologic simulations for urban watersheds. If municipal IDF values are not available, then the values shown in Section 3.9 Hydrologic Standard Parameters may be used.

### Long Duration Climate/Precipitation

- Continuous simulation programs may be used to simulate the runoff response required as input to hydraulic models. The continuous model should be capable of simulating high flow events. Time steps used for computation should be short enough to simulate high flow events. Typically, time steps should be equal to roughly 1/5th of the time to streamflow peak for a catchment. The study report must justify the selection of continuous simulation to develop flood flows and document the area where the flood flows are not appropriate. Continuous simulation programs and input data must be approved by the Conservation Authority before the analysis is initiated.

### Design Storms

- The engineer must document the characteristics of the design storm, the methodology used to develop the design storm, and where the data was sourced. Typically, design storms will represent either a snowmelt/rainfall (spring) event or an intense thunderstorm (summer) event. The design storm will be characterized by duration, time step, a temporal pattern, areal reduction factors, and antecedent precipitation.

The use of a snowmelt/rainfall event or an intense thunderstorm event will be dependent on when the majority of annual maximum peak flow rates occur, spring or summer. Generally, floods on rural basins are generated by spring snowmelt/rainfall events while floods on urban basins are generated by intense summer events. In some instances, both a snowmelt/rainfall event and an intense thunderstorm event will be required.

The design storm duration must exceed the time of concentration of the catchment upstream of the point of interest. The time of concentration should include the residence time in ponds and reservoirs. The time step of the design storm should be less than the minimum time of concentration of any subcatchment.

There are several design storm patterns available for intense summer events. Included are the Keifer & Chu or Bandyopadhyay storm, the SCS Type II storm, the AES storm, and the Hydrotek storm. The Keifer & Chu or Bandyopadhyay storm is recommended for use on urban or urbanizing basins. The storm has a variable duration, a variable time step, and all intensities within the storm conform to all durations within the Intensity-Duration-Frequency curve from which it is developed. The Conservation Authority should approve the design storm before the analysis is initiated.

A "critical design storm" approach should not be used for hydrologic modelling. A critical design approach involves simulating runoff from all design storms and then selecting the design storm that yields the highest flow rate. This approach does not preserve risk or return period intensities for all points of interest within a watershed. Intensities may be over estimated for some points of interest and under estimated for other points of interest. Intensity-duration curves can be developed for historical storms and design storms. These intensity-duration curves can be compared to intensity-duration-frequency curves (MSC) developed from recorded rainfall. For a given point of interest or a time of concentration, the intensities from the two curves should be equal or similar. Design storm distributions such as the SCS type II storm, the AES storm, and the Hydrotek storm do not preserve risk or return period intensities for all durations within the storm.

- The engineer must develop a design storm for snowmelt/rainfall events and have it approved by the Conservation Authority before use. There are no accepted design storms for snowmelt/rainfall (spring) events. A frequency analysis of snow-course data and meteorological conditions will have to be conducted to develop a design storm. The analyses will include the amount of snow (water) on the ground, the temperature pattern, and the volume of rainfall to be utilized in the design storm.
- Sensitivity analyses should be conducted when modelling snowmelt-rainfall events. Engineering experience with snowmelt-rainfall modelling is required when data is limited.

## Climate Change

It is recommended that an adaptive approach be utilized when accounting for climate change in the development of flood hazard maps. The recommended approach is based on the use of the last 50 years of recorded data when developing intensity-duration-frequency curves (IDF) and the last 50 years of recorded streamflow data when developing return period streamflow rates. This moving window approach should capture climate change that may be occurring and the 50 year period of record should be sufficient to develop 100 year return period values. There are other approaches to reflecting climate change in hazard limits. Maintaining up-to-date IDF curves and flood frequency curves of streamflow data is within the flood plain manager's area of control.

One of the key components of the hydrology that will change will be the local intensity-duration-frequency curve (IDF) that may result in a shift in how design storms are distributed or defined. While this component is often developed outside of the floodplain manager's area of control, utilizing the most recent IDF curve and understanding its vulnerabilities from a climate change perspective should be a component of any mapping update program. Maintaining a working understanding of IDF research related to climate change is recommended.

Climate change may also result in the key drivers of flood risk within the watershed to shift. An example may be a watershed that responds to snowmelt and rainfall as the key flood driver may shift to a thunderstorm driven watershed. Flow and weather data may change and will need to be understood to determine how sensitive the watershed may be to climate change, and therefore the need to reassess flood hazard mapping needs. It is anticipated that climate driven changes will be subtle and may need to be viewed over a longer duration. Understanding the potential changes and creating a component within the watershed management program that allows for their recognition and assessment in terms of defining a need to update mapping should be incorporated, if not already in place.

There may also be an impact to the riverine system and therefore hydraulic component of flood hazard mapping as a result of climate change. Increased erosion and flood events can lead to major changes within the channel. This may or may not be a major trigger for a flood hazard mapping update. Changes to the low flow channel may result in a shift in terms of the frequency of flooding experienced within the floodplain area, and impacts to local servicing infrastructure and transportation features.

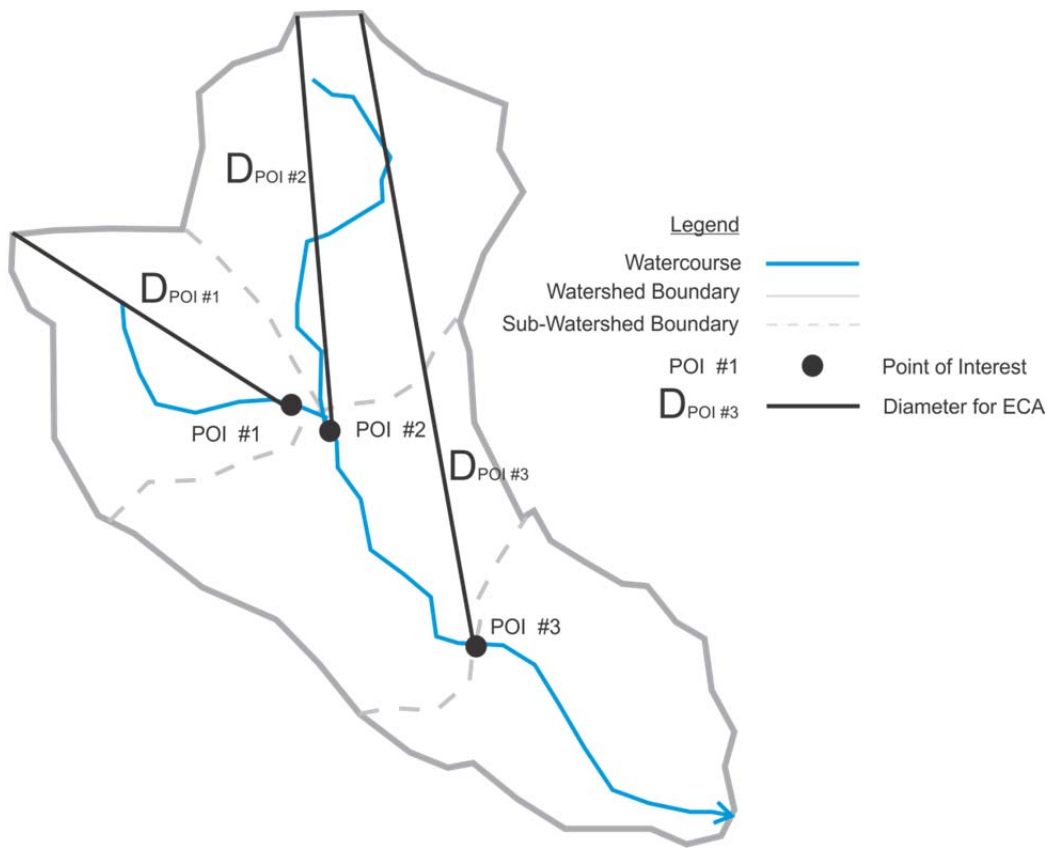
Determining the need to update a map or series of maps or even an entire watershed based upon impacts related to climate change alone, while possible is operationally unlikely. Understanding the impacts that the effects of a changing climate can create such as those noted above is important. It is also important to understand and incorporate all stressors that may create changes that result in a need to update flood hazard mapping. A sensitivity analysis can be conducted to gain insight on how changing precipitation patterns impact runoff.

Areal Reduction Factors

- Areal reduction factors should be used for all design storms including 2 through 100 year events. Areal reduction factors (or lack thereof) for return period storms must be documented in the study report and approved by the Conservation Authority. If areal reduction factors are not used, reasons must be documented in the report.
- The areal reduction factors must be calculated using the equivalent circular area method (ECA).

The equivalent circle area (ECA) will be calculated by using the distance, as the diameter, from the point of interest to the furthest upstream watershed boundary.

For the Regional Storm, extremely elongated shaped watersheds can use the isohyetal method where the Regional Storm rainfall isohyets are transposed to the upstream watershed.



**3.8.3.2**      ***Discretization***

- Watershed points of interest will be included in the discretization scheme;
- Future proposals for culvert replacement shall also be considered. For points downstream of such structures, the design flows shall not exhibit the retardation provided by the structures; i.e., only non-routed flows should be used;
- Drainage Boundaries - determine the watershed contributing drainage area through the use of topographic maps, DEMs, shapefiles, air photo interpretation, and field reconnaissance. Ineffective runoff areas, (e.g. pits and quarries) shall be included in the model and the parameters affecting runoff should be adjusted accordingly. Ineffective runoff areas will be discussed in the report and with the Conservation Authority prior to finalizing the hydrologic calculations;
- Sub-catchments used for modelling should have similar times of concentration, have fairly homogeneous land use, fairly homogeneous soils, fairly homogeneous vegetation, and similar geographic characteristics. Sub-catchments should be delineated at confluences of major tributaries;
- Data sources and datum must be provided for all topographic information used in the analysis. Information should include map title, author, publisher, scale, surveyor name, survey date, and date flown. If multiple sources are used then the datum must be modified to be congruent; and
- Generally, the change in flow rate between points of interest should be limited through discretization to 10%. There may be exceptions in headwater areas, and where tributaries confluence with the main branch. An iterative approach in discretization is required to achieve the 10% change in flow rate.

**3.8.3.3**      ***Land Use***

- All hydrologic analysis for the development of flood hazard maps must be based on anticipated future land use conditions as defined in Official Plans and other municipal land use planning documents. An assessment of the impact of the future land use on the return period flows must be conducted using an existing condition calibrated hydrologic model as the base and fully documented in the study report. Land use at the time of the calibration/validation events maybe different than the when the Study is being undertaken; and
- Existing Land Use Impervious Areas - shall be computed for existing areas from topographic maps, aerial photographs, and shapefiles. For large basins,



impervious areas can be determined by sampling a representative area in each sub-catchment. An accurate estimate of the impervious area is very important, as models are sensitive to this parameter. The method of determining impervious areas must be documented and justified in the study report.

#### **3.8.3.4**      ***Time Steps***

- The study report must document the time steps used within the computer model, and the reasons for choosing the time steps. There may be up to several time steps required in a computer model. Included are a time step for precipitation, a time step for hydrograph computation, a time step for sewer routing, a time step for reservoir routing, and a time step for channel routing. Some programs allow only a single time step value.

If a more accurate hydrograph peak flow rate is required, the hydrograph computation time step must be based on the shortest catchment time of concentration and shortest routing time step. The rainfall time step should be at approximately 1/5 the shortest catchment time of concentration.

For example, the use of a design storm that uses a 15 minute time step, would dictate the shortest basin time of concentration of approximately 1.25 hours (5 x 0.25 hours). A channel reach of say 200 m would dictate routing time step in the order of a few minutes. The conceptualization and subsequent discretization of the model must ensure that time step criteria are met. If the criteria are not met then simulated peak flow rates for some points of interest may not be accurate.

#### **3.8.3.5**      ***Hydrologic Abstractions***

- The study report must include a discussion on the methods used to compute rainfall losses, the reasoning for using those methods, the sources of data and methods used to measure parameters. Also, the report should include a discussion on the antecedent precipitation condition modelled for each frequency; and
- The method used for simulating infiltration should account for all the flows entering, moving within, and leaving soil-water storage. As an example, perched groundwater tables should be included in soil-water storage. The amount of infiltration may be low even though the soil matrix is capable of higher infiltration rates.

**3.8.3.6 Hydrograph Convolution**

- The study report must document the rationale for using a particular option and the sources and methods used for measuring data and determining the input parameters;
- If a unit hydrograph is input as a table, documentation must include its derivation, including the sources of rainfall and runoff data; and
- There are many methods to calculate hydrograph time to peak or time of concentration for rural areas. Two (2) methods commonly used include the Airport Method, and the Bransby-Williams method. The methods are described in the Hydrologic Standard Parameters Section 3.9 of this report.

**3.8.3.7 Channel Routing**

- Appropriate channel/sewer routing method should be incorporated into the hydrologic model. Sewer routing may be necessary where runoff from upstream rural areas is piped through a development area;
- Dynamic wave routing shall be undertaken for channel reaches with mild slope where the diffusive wave model criterion cannot be satisfied;
- Cross Section Points - cross section points required for the hydrologic model routing procedure must be obtained from contours, TINs, DTMs or from field surveys. Cross sections shall be extended sufficiently to ensure that the flows shall not exceed the range of the travel timetable.
- Rating curves and travel times used in channel routing shall be determined by preliminary hydraulic calculations of the backwater profile or by procedures available in the approved hydrologic model;
- The study report will contain graphs of all cross sections utilized in the hydrologic model. In addition, the cross section locations will be shown in the shapefiles.
- Manning Roughness Parameters - refer to Section 3.9 Hydrologic Standard Parameters;
- The study report must document the routing methods used, including the values of input parameters, the derivation of those parameters, and the methods of measurements and sources from which those parameters were obtained or measured; and

- Two or more hydrographs will be combined before being routed through channel reaches. It is not acceptable to route the hydrographs separately.



### **3.8.3.8 Reservoir Routing**

- Reservoir routing shall be undertaken for in-stream lakes and swamps, dam and embankments, such as railway embankments and road fills that have significant storage effects. e.g. A minimum volume assessment for road and railway embankments where 10-15% of the flood is available for routing can be used as a trigger to determine if routing should be investigated further. The 10-15% trigger can also be used to investigate whether storage behind embankments should be used in the calibration/validation events;
- Storage upstream of road embankments, dams, and in reservoirs should not be used in the development of peak flow rates unless it can be demonstrated that the structure will not fail under extreme events. A geotechnical analysis may be required to confirm stability. Failure includes the exceedance of design flow rates;

- The Conservation Authority shall be consulted where this storage upstream of road and railway embankments, or alternatively, failure of the dam or embankment, will have a significant effect on downstream flows and upstream flood levels. If failure may occur under flood conditions, consideration will be given to the effect on increasing the downstream peak flows or requesting a dam break analysis;
- Elevation-storage-outflow relations used in the model must be documented in the study report. Documentation must include sources of data regarding reservoir operation, the outlet structure, and the methods, sources, and measurements of data used to define the relation; and
- The study report should discuss the method used and assumptions made in the calculating the effect of storage on flows.

**3.8.3.9**      ***Diversions***

- All calculations and results used to divert flow in the hydrologic model must be included in the study report. Often hydraulic analysis must be completed before the hydrologic analysis is conducted.

**3.8.3.10**     ***Input Hydrographs***

- Any inflow hydrographs used in the hydrologic model must be documented in the study report. Details should include synchronization of rainfall and the input hydrographs.

### 3.8.4 Model Evaluation

- The study report must discuss the results of the model evaluation, and the model evaluation process. Model evaluation is the process used to determine whether a model and its results are sufficient to simulate the inputs required for the hydraulic analysis. Model evaluation includes the following:

3.8.4.1	Model Verification
3.8.4.2	Sensitivity Analysis
3.8.4.3	Uncertainty Analysis
3.8.4.4	Calibration/Validation
3.8.4.5	Corroboration
3.8.4.6	Error and Warning Messages

The engineer must consider what degree of uncertainty is acceptable within the context of model application. If the engineer does not accept the model for its intended purpose, then the process must be re-started by re-visiting the conceptualization of the study watershed and the drainage system.

#### 3.8.4.1 *Model Verification*

- The computer model will be verified and documented in the study report. Model verification is the examination of the model to prove that it truly represents the conceptual model.

Model verification checks the proper implementation of the model on the computer. The model should be computationally stable and provide credible results.

#### 3.8.4.2 *Sensitivity Analysis*

- Sensitivity analyses should be performed to determine the impact of changing model input parameters and initial conditions on simulated flows. Model input parameters to be varied for the sensitivity analysis may include impervious area, time to peak, recession constants, storage coefficients, overland flow lengths, slopes, Curve Numbers, initial abstraction, and roughness coefficients. Typical ranges would be 75% to 125% of the estimated parameter values; and
- Documentation of the results of the sensitivity analyses shall be provided in the study report. The results will identify the importance of model parameters that will have to be adjusted during calibration.

**3.8.4.3**      ***Uncertainty Analysis***

- An uncertainty analysis will be conducted and discussed in the study report.
- The uncertainty analysis will investigate the effects of the lack of knowledge and other potential sources of error of model inputs (e.g., the “uncertainty” associated with parameter values, constants, data and beliefs). Models cannot be expected to be more accurate than the errors in the input and observed data. Sources include the science underlying the model, assumptions, and simplifications of what the model is representing. Uncertainty analysis is performed with numerical modelling.

**3.8.4.4**      ***Calibration/Validation***

- Calibration/validation must be conducted for any hydrologic computer simulation model. Calibration/validation improves the confidence in the hydrologic model results;
- Calibration - consists of a model test with known input and output information that is used to adjust or estimate model coefficients or parameters within physically defensible ranges until the resulting predictions give the best possible fit to the observed data;
- Validation - the model results are compared with an independent set of observations (not used in the calibration) of the real system to verify whether the model describes system behaviour correctly;
- If there are no suitable records within the study watershed, parameters used in the model must be supported by calibration/validation on a similar adjacent watershed. Selection of the appropriate adjacent watersheds or sub-watersheds must be documented and agreed upon by the Conservation Authority;
- Both calibration and validation should be conducted. Validation is as important as calibration. Validation is used to determine the accuracy of the hydrologic model. Validation is used, in part, to determine if the model is good enough to simulate the required information;
- Calibration/validation of the hydrologic model shall be undertaken using all available streamflow records

## TECHNICAL GUIDELINES FOR FLOOD HAZARD MAPPING

- Calibrated watershed parameters shall not be adjusted beyond ranges shown in Section 3.9 Hydrologic Standard Parameters. Parameters outside the range must be revised;
- The flows generated by the calibrated model must be substantiated through comparison with other analyses such as regional frequency analysis;
- Documentation must include dates, measurements, and locations of measurements of historical storms; parameters revised and rationale for revising; and input and output data for the calibrated model;
- All hydrologic data must be submitted in electronic format;
- Size of Events - events greater than the capacity of the natural low flow channel or in the case of channelization the events should be greater than the 2 year flow rate. The model has been developed to simulate flood flows. Flood flows are conveyed in the left and right overbanks. Therefore the model should be calibrated and validated with flow rates greater than the capacity of the natural low flow channel. If no such events exist, the model should use Hydrologic Standard Parameters shown in Section 3.9. The selected events for calibration/validation must be approved by the Conservation Authority;
- Duration of Events - should exceed the time of concentration of the watershed upstream of the streamflow gauge;
- Number of Events - At a minimum, two (2) events should be used for each calibrated parameter. One event should be used for calibration and one event for validation. Usually there are more model parameters for calibration than there are observed precipitation/streamflow data sets. Alternatively stated: there are fewer equations than there are unknowns. As a result there is more than one combination of parameter values that can yield good results. A set of parameters that yields good results for one storm event may not yield equally good results for another event. Generally, the number of parameters required for calibration needs to be reduced. Usually, sensitivity analysis is used to reduce the number of parameters to be calibrated. The parameters that have considerable influence on the model results should be used in the calibration process. A sensitivity analysis can be undertaken to determine the parameters that have considerable influence; and

- Antecedent Moisture Conditions - soil moisture conditions should match as closely as possible to actual soil moisture conditions for the historical storm event. Soil moisture conditions have a significant impact on runoff and peak flow rates for rural catchments. The most accurate calibration and validation results will occur when model soil moisture conditions match actual soil moisture conditions. Soil moisture conditions for historic storms must be discussed and approved by the Conservation Authority.

### Calibration/Validation Notes

No calibration/validation procedure is perfect.

- There are always deviations due to modelling and measurement errors. There are conceptual errors due to model definition such as the simplification of complex structures, neglect of sub-processes, and errors in the mathematical description or in the numerical method applied. There are errors when measuring field observations such as precipitation and streamflow. There are also errors when selecting model parameters that are not known with certainty.

No model can be truly validated, but can only be invalidated for a specific application. After a sufficient number of successful tests the model is not valid or good but good enough. The model can then be regarded as having been validated.

There are no universally accepted "goodness-of-fit" criteria that will apply in all cases.

- Model performance is evaluated by a series of graphical and statistical tests. Model performance is the ability to reproduce field observations. Graphical tests include the following:
  - Time series plots of observed and simulated values;
  - Observed vs. simulated scatter plots with a 45° linear regression line; and
  - Cumulative frequency distributions of observed and simulated variables.
- Statistical tests include the following:
  - Error statistics; e.g., mean error, absolute mean error, relative error, relative bias, standard error of estimate;
  - Nash-Sutcliffe Efficiency;
  - Correlation tests e.g. linear correlation coefficient, coefficient of model fit efficiency; and
  - Cumulative distribution tests.



### Manual vs. Automatic Calibration:

- Involves adjusting parameters until a good fit is achieved between measured and simulated values. Manual trial-and-error adjustments can be successful for a simple set of parameters. Manual trial-and-error is usually not reproducible, and the minimum difference between measured and simulated values may not be found. Automatic calibration finds the minimum difference between measured and simulated values using iterations of many parameter values. The engineer is usually limited to the automation procedures found within the program.
- Either manual or automatic calibration will involve (i) selecting the parameters to be calibrated; (ii) determining the range of values for the calibration parameters; (iii) selecting an objective function to determine the goodness of fit; and (iv) determining the criteria to stop the calibration process.

### Non-stationarity Data Sets:

- Care must be taken when using data sets that are non-stationary; e.g., streamflow has been measured while the upstream watershed is undergoing urbanization.

### Example of the Steps in a Single Event Manual Calibration/Validation Process -

1. Select Cutoff Points for Calibration and Validation
2. Conduct a Sensitivity Analysis
3. Select Recorded Events for Calibration/Validation
4. Conduct Calibration Simulations for Hydrograph Volume of Runoff
5. Conduct Calibration Simulations for Hydrograph Time to Peak
6. Conduct Calibration Simulations for Hydrograph Shape and Peak
7. Accept or Reject the Calibration Results
8. Conduct the Validation Simulations
9. Accept the Validation Simulations
10. Accept the Calibration/Validation Process

**3.8.4.5 Corroboration**

- Results from computer simulation models must be corroborated using other methods that include previous studies, single station frequency analysis, and regional frequency analysis. The comparison must be documented in the study report. If the results are significantly different reasons must be stated to explain the differences.

**3.8.4.6 Error and Warning Messages**

- All error and warning messages generated by hydrologic programs must be corrected. Any messages that cannot be corrected must be discussed in the study report.

**3.8.5 Model Acceptability**

- The study report must include a statement regarding the acceptability of the model to simulate the information required for the hydraulic model. The statement should summarize the results of the model verification, the calibration/validation analysis, the sensitivity analysis, and the uncertainty analysis. Also, the discretization in time and space, and the correctness of the conceptual model will be addressed. The statement will need to answer the question of whether the correct program, and model have been chosen; and
- The Conservation Authority must approve the acceptability of the model in writing before the modelling scenarios are conducted.

**3.8.6 Modelling Scenarios and Results**

- The study report must contain the results of the scenario runs. Once the model has been accepted or the model is sufficient to conduct the simulations, the scenario runs may be undertaken.

### 3.8.7 Study Report and Deliverables

#### Study Report

The Study Report should allow third parties to reproduce the model study including its results. The Study Report must include the following:

- List of technical persons with qualifications that worked on the project;
- The hydrologic study report must be sealed, signed, and dated by a professional engineer. Any computer program input and output data must be sealed, signed, and dated by the professional engineer who prepared or supervised the preparation of the input data and who checked the output data. Where the input data and the output data cannot be sealed, the computer model description box must include the professional engineers name, PEO number, and the completion date;
- A statement on the appropriateness of the model to provide the information required for the hydraulic program;
- A section on model limitations;
- An explanation of differences between observations and model predictions;
- The location of the watershed and study area, study limits, locations where the flood discharges were estimated, associated streamflow gauges, climatic data, hydrologic features;
- The rainfall-runoff model used and all the assumptions and supporting computations associated with the model;
- All data, and assumptions used for rainfall analyses, including the antecedent moisture conditions modeled for each frequency, the methods used to compute the rainfall losses, and areal reduction factors;
- The reasoning for selecting and the methods for determining the hydrograph parameters;
- The routing methods used, including the values of input parameters, the derivation of those parameters, and methods of measurements and sources of data;
- The methods and data used for modelling any diversions;
- The process for model calibration/validation, including dates, measurements, and locations of measurements of historical storms; parameters revised and rationale for revising; and input and output data for the calibrated model; and
- A comparison of modelled flow rates with regional frequency analysis, previous studies, and single station frequency analysis.

Typical Report Figures and Maps

- All Figures and maps to be provided in electronic format acceptable to the Conservation Authority;
- Figure - watershed location plan;
- Figure - watershed modelling schematic that reflects the model input data and the sub-catchment map;
- Figure - precipitation, and observed and simulated hydrographs in the calibration and validation analysis;
- Figure - cross section plot of all routing cross sections with Manning roughness coefficient values, and channel slope;
- Watercourse Profile Graph - through all sub-catchments with the location of the routing cross sections;
- Map - showing sub-catchment location, hydrometric stations, and meteorological stations. Use of an aerial photograph is recommended;
- Map - showing sub-catchments and soil types;
- Map - showing hydrologic model input parameters by catchment.;
- Map - showing sub-catchments and existing and anticipated future land use;
- Map - showing the location of the routing cross sections and the watershed sub-catchments; and
- Map - showing key nodes described in the modelling report.

Typical Report Tables

- Table - model input parameters for existing and anticipated future land use;
- Table - listing the percentage of each soil type in each sub-catchment;
- Table - storage and associated discharge rates used in the reservoir routing;
- Table - discharge storage values, or number of inlets and inlet capacities for diversion structures;
- Table - calibration and validation results;
- Tables - data (observed hydrographs, rainfall amounts, spatial and temporal distributions of rainfall, antecedent moisture conditions, etc.) used in calibration;
- Table - calculated and calibrated watershed parameters for existing and anticipated future conditions;
- Table - comparison of modelled and regional frequency analysis peak flow rates at various points of interest for 2- through 100-year return periods;
- Table - comparison of modelled peak flow rates developed in the present study with values generated in past studies;
- Table - comparison of 100 year peak flow rates generated by varying model input parameters such as impervious area, infiltration rates, and hydrograph shape parameters;

- Table - Regional 100-, 50-, 25-, 10-, 5-, and 2-year peak flow rates for various points of interest within the Study watershed for existing and future land use conditions;
- Table - identifying potential spill areas;
- Table - available hydrometric and meteorological data;
- Table - listing the intensity-duration-frequency values for the 2 through 100 year return periods;
- Table - listing input design storm values; and
- Table - listing the equivalent circular drainage areas and rainfall reduction factors for the various points of interest for the Regional Storm and 2- through 100-year return period events.

### Deliverables

- Electronic copies of model input data and output files used in the sensitivity analysis;
- Electronic copies of input and output files used in the computer modelling including Regional, and 2- through 100-year return period events for existing and future land uses;
- Electronic copies of the model input data and output of the calibration and validation analysis;
- Electronic copies of the Study Report that contains at the minimum the Submission Requirements;
- Deliverables - geo-referenced shapefiles showing the sub-basins, locations of estimated flood discharges, flood control structures, such as reservoirs, soil types, creek centreline, road network, and diversions within the reach system that affect flood flow; and
- Electronic copies of all model input and output files and geo-referenced spatial files showing hydrologic features used in the modelling must be submitted.

### 3.9 Hydrologic Standard Parameters

Standard parameters are shown in Table 3.2. The parameters should be used for un-calibrated models. If the engineer feels that the Standard Parameters should be modified, the engineer should provide documentation to the Conservation Authority providing justification. Area weighted calculations based on land use and soil types are required for Curve Numbers, initial abstraction and runoff coefficients.

An analysis should be conducted for each computer program to determine the sensitive input parameters.



Burlington, ON, on August 5, 2014.

**Table 3.2 - Hydrologic Standard Parameters**

**Table 3.2.1 - Rainfall**

Summer Rainfall or Intense Rainfall Storms

- Pattern - Keifer & Chu (Chicago)
- Duration - 24 hours, 5 min time step
- Time of Peak - 0.4 of Storm Duration
- IDF Curves - as below

MSC Toronto Gauge 6158350  
1940 - 2003 55 years

Rainfall Intensity Duration Frequency Values

Duration min	2 year mm/hr	5 year mm/hr	10 year mm/hr	25 year mm/hr	50 year mm/hr	100 year mm/hr
5	111	154	183	220	247	274
10	76.8	103	120	142	158	174
15	61.8	85.5	101	121	136	150
30	39.1	54.6	64.9	77.8	87.5	97.0
60	23.8	32.0	38.5	45.9	51.4	56.9
120	14.1	18.8	21.9	25.9	28.8	31.7
360	5.8	7.7	9.0	10.6	11.8	12.9
720	3.4	4.5	5.1	6.0	6.6	7.3
1440	1.9	2.5	2.8	3.3	3.6	4.0

**Recommended Areal Reduction Factors - U.S. Weather Bureau**

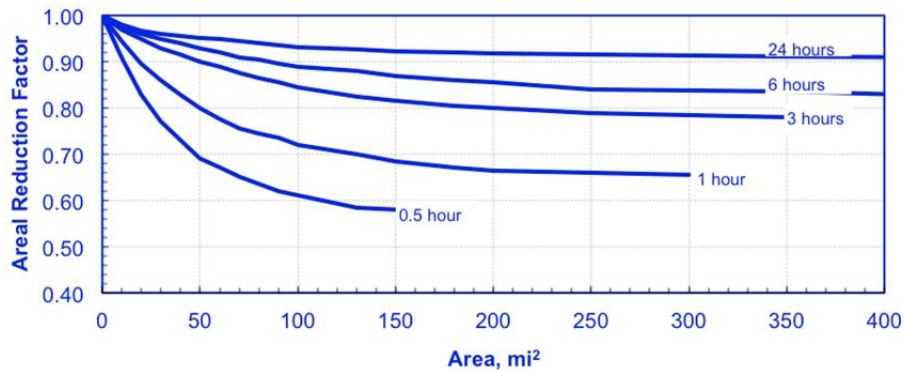


Table 3.2 - Hydrologic Standard Parameters...continued

Table 3.2.2 - Depression Storage Parameters

Depression Storage	d <sub>s</sub> Standard mm	Calibration Range	
		Minimum mm	Maximum mm
Impervious	2.0	1.0	3.0
Lawns	5.0	3.0	10.0
Cultivated	7.0	3.0	10.0
Meadows	8.0	3.0	10.0
Woods	10.0	5.0	15.0
Wetland	15.0	15.0	45.0

Table 3.2.3 - Subcatchment Width

Overland Flow Length - SWMM/PCSWMM			
Width = Area/OFL, m <sup>2</sup> /m		OFL Should not include channelized flow.	
Overland Flow Length	OFL Standard m	Calibration Range	
		Minimum m	Maximum m
Rural	100	20	150
Urban	40	20	50

**Note:** The sub-catchment width represents overland sheet flow and not rill or channel flow.



Table 3.2 - Hydrologic Standard Parameters...continued

Table 3.2.4 - Horton Infiltration Parameters

<b>Horton Equation - Minimum Infiltration Rate</b>			
<b>SCS Hydrologic Soil Group</b>	<b>f<sub>c</sub> Standard mm/hr.</b>	<b>Calibration Range</b>	
		<b>Minimum mm/hr.</b>	<b>Maximum mm/hr.</b>
A	10.0	8.0	12.0
B	6.0	4.0	8.0
C	3.0	2.0	4.0
D	1.0	0.0	2.0

<b>Horton Equation - Maximum Infiltration Rate</b>			
<b>SCS Hydrologic Soil Group</b>	<b>f<sub>o</sub> Standard mm/hr.</b>	<b>Calibration Range</b>	
		<b>Minimum mm/hr.</b>	<b>Maximum mm/hr.</b>
A	250.0	150.0	300.0
B	80.0	60.0	150.0
C	50.0	35.0	60.0
D	25.0	15.0	35.0

<b>Horton Equation - Decay Parameter</b>			
	<b>k Standard hr<sup>-1</sup></b>	<b>Calibration Range</b>	
		<b>Minimum hr<sup>-1</sup></b>	<b>Maximum hr<sup>-1</sup></b>
Decay Parameter	4	1	5

**Note:** Table is not applicable to frozen soils or to a period where snowmelt contributes to runoff.

**Table 3.2 - Hydrologic Standard Parameters...continued**

Approval is required from the Conservation Authority to modify any of the following Green-Ampt parameters:

**Table 3.2.5 – Green – Ampt Method Parameters**

Soil Texture Class	Hydrologic Soil Group	Porosity	Wetting Front Soil Suction Head cm	Saturated Hydraulic Conductivity cm/h
Sand	A	0.435	4.95	23.56
Loamy Sand	A	0.440	6.13	5.98
Sandy Loam	A	0.450	11.01	2.18
Loam	B	0.465	8.89	1.32
Silt Loam	B	0.500	16.68	0.68
Sandy	C	0.400	21.85	0.30
Clay Loam	D	0.465	20.88	0.20
Silty Clay	D	0.470	27.3	0.20
Sandy Clay	D	0.430	23.90	0.12
Silty Clay	D	0.480	29.22	0.10
Clay	D	0.475	31.63	0.06

**Table 3.2.6 - SCS Curve Numbers**

Curve Numbers - AMC II							
Cover	Hydrologic Soil Group						
	A	AB	B	BC	C	CD	D
Woods	32	46	60	67	73	76	79
Meadows	38	51	65	71	76	79	81
Cultivated	62	68	74	78	82	84	86
Lawns	49	59	69	74	79	82	84
Impervious Areas	100	100	100	100	100	100	100

**Note:** AMC II conditions are used where the Timmins Storm is applicable and AMC III conditions are used for the Hurricane Hazel Storm. Converting from an AMC II Curve Number can be accomplished using Table 3.2.7.

Hydrologic classification of soils types can be found in the MTO Drainage Manual, Design Flood Estimations, Chapter H, Chart H2-5, Hydrologic Soil Groups for Soil Associations in Southern Ontario.

Table 3.2 - Hydrologic Standard Parameters...continued

**Table 3.2.7 - Variation In Curve Number Based On Antecedent Condition**

Condition			Condition			Condition		
I	II	III	I	II	III	I	II	III
100	100	100	48	68	84	19	36	56
97	99	100	47	67	83	18	35	55
94	98	99	46	66	82	18	34	54
91	97	99	45	65	82	17	33	53
89	96	99	44	64	81	16	32	52
87	95	98	43	63	80	16	31	51
85	94	98	42	62	79	15	30	50
83	93	98	41	61	78	12	25	43
81	92	97	40	60	78	9	20	37
80	91	97	39	59	77	6	15	30
78	90	96	38	58	76	4	10	22
76	89	96	37	57	75	2	5	13
75	88	95	36	56	75	0	0	0
73	87	95	35	55	74			
72	86	94	34	54	73			
70	85	94	33	53	72			
68	84	93	32	52	71			
67	83	93	31	51	70			
66	82	92	31	50	70			
64	81	92	30	49	69			
63	80	91	29	48	68			
62	79	91	28	47	67			
60	78	90	27	46	66			
59	77	89	26	45	65			
58	76	89	25	44	64			
57	75	88	25	43	63			
55	74	88	24	42	62			
54	73	87	23	41	61			
53	72	86	22	40	60			
52	71	86	21	39	59			
51	70	85	21	38	58			
51	69	85	20	37	57			

I dry antecedent precipitation conditions  
 II average antecedent precipitation conditions  
 III wet antecedent precipitation conditions

**Table 3.2 - Hydrologic Standard Parameters...continued**

**Table 3.2.8 - Entrance/Exit, and Transition Loss Coefficients**

Weir Flow Coefficients	'C' Standard	Calibration Range	
		Minimum	Maximum
Broad Crested i.e. Road Embankment	1.5	1.40	1.70
Sharp Crested	1.6	1.40	1.80

A sharp crested weir coefficient should be used when there is air underneath the nappe. Such conditions would exist for a stormwater management pond weir outlet. A broad crested weir assumes the nappe is supported. An example of a broad crested weir would be a road crossing. Generally, when the ratio of flow depth divided by the weir thickness is greater than 0.5 a sharp crested weir coefficient should be used. When the ratio is less than 0.5 the broad crested weir coefficient should be used.

Orifice Coefficient	'C' Standard	Calibration Range	
		Minimum	Maximum
Orifice Coefficient	0.66	0.62	0.78

Expansion/Contraction Coefficients	Contraction	Expansion
Gradual Transitions	0.1	0.3
Bridges	0.3	0.5
Culverts	0.5	0.8
Abrupt Transitions	0.6	0.8

Table 3.2 - Hydrologic Standard Parameters...continued

Table 3.2.9 - Manning Roughness Coefficients

Conduit	'n' Standard	Calibration Range	
		Minimum	Maximum
Concrete	0.013	0.011	0.015
Brick	0.015	0.013	0.017
Plastic	0.013	0.011	0.015
Iron	0.013	0.011	0.015
Corrugated Steel Pipe - 3"x1"	0.024	0.021	0.027
Structural Plate Corrugated Steel Pipe - 6"x2"	0.032	0.026	0.036

Open Channel	'n' Standard	Calibration Range	
		Minimum	Maximum
<u>Overbank</u>			
Woods	0.080	0.040	0.120
Meadows	0.055	0.035	0.070
Lawns	0.045	0.030	0.055
<u>Channel</u>			
Natural	0.035	0.025	0.045
Grass	0.030	0.025	0.035
Natural Rock	0.035	0.025	0.045
Armour Stone	0.025	0.017	0.030
Concrete	0.015	0.011	0.017
Articulated Block	0.020	0.019	0.032
Gabions	0.025	0.020	0.030
Wood	0.012	0.011	0.013

Overland	'n' Standard	Calibration Range	
		Minimum	Maximum
Impervious	0.013	0.011	0.015
Lawns	0.250	0.150	0.410
Cultivated	0.300	0.060	0.170
Meadows	0.350	0.025	0.400
Woods	0.600	0.400	0.800

**Table 3.2 - Hydrologic Standard Parameters...continued**

***Table 3.2.10 - Computation Time Steps***

**Hydrograph Computation Time Step**

Time step should be equal to 1/5 of smallest basin time to peak.

**Routing Computation Time Step**

DT = Length / Celerity

= Length \* (g \* Avg. Depth) 0.5 / Q

DT = time step, s

Length = routing length, m

g = gravitational constant, 9.8... m<sup>2</sup>/s

Depth = flow depth, m

Q = flow rate, m<sup>3</sup>/s

**Table 3.2 - Hydrologic Standard Parameters...continued**

**Table 3.2.11 - Time of Concentration**

Bransby-Williams Formula <sup>2</sup>

If runoff coefficient “C” value is greater than 0.4

$$t_c = 0.057 * L * S_w^{-0.2} * A^{-0.1}$$

Airport Equation <sup>2</sup>

If “C” value is less than 0.4

$$t_c = 3.26 * (1.1 - C) * L^{0.5} * S_w^{-0.33}$$

$t_c$  = time of concentration, minutes

C = runoff coefficient

L = watershed length, m

Sw = watershed slope, %

A = watershed area, ha

**Rational Method Runoff Coefficients**

Rational Method 'C' Values	'C' Standard	Calibration Range	
		Minimum	Maximum
Impervious	0.95	0.95	0.95
Lawns	0.15	0.05	0.35
Cultivated	0.45	0.22	0.70
Meadows	0.35	0.10	0.55
Woods	0.30	0.08	0.52
Wetlands	0.05	0.00	0.10
Business	0.70	0.50	0.95
Residential	0.50	0.25	0.75
Industrial	0.80	0.50	0.90
Parks	0.15	0.10	0.25
Apartments	0.60	0.50	0.70

**Table 3.2 - Hydrologic Standard Parameters...continued**

**Table 3.2.12 - Hurricane Hazel Storm**

In the first 36 hours the total rainfall recorded was 73 mm. The following 12 hour rainfall represents the Ontario Ministry of Natural Resources Storm:

<b>Timing</b>	<b>Depth (mm)</b>	<b>Percent of Total</b>
37th hour	6	3
38th hour	4	2
39th hour	6	3
40th hour	13	6
41st hour	17	8
42nd hour	13	6
43rd hour	23	11
44th hour	13	6
45th hour	13	6
46th hour	53	25
47th hour	38	18
48th hour	13	6
Total	212 mm	100

**Table 3.2.13 - Hurricane Hazel Areal Reduction Factors**

<b>Circular Drainage Area (km<sup>2</sup>)</b>	<b>Total Percentage of Rainfall</b>
0 to 25	100
26 to 45	99.2
46 to 65	98.2
66 to 90	97.1
91 to 115	96.3
116 to 140	95.4
141 to 165	94.8
166 to 195	94.2
196 to 220	93.5
221 to 245	92.7
246 to 270	92.0
271 to 450	89.4
451 to 575	86.7
576 to 700	84.0
701 to 850	82.4
851 to 1000	80.8
1001 to 1200	79.3
1201 to 1500	76.6



**Table 3.2 - Hydrologic Standard Parameters...continued**

**Table 3.2.14 - Timmins Storm**

The following 12 hour rainfall represents the Ontario Ministry of Natural Resources Storm:

<b>Timing</b>	<b>Depth (mm)</b>	<b>Percent of Total</b>
1st hour	15	8
2nd hour	20	10
3rd hour	10	6
4th hour	3	1
5th hour	5	3
6th hour	20	10
7th hour	43	23
8th hour	20	10
9h hour	23	12
10th hour	13	6
11th hour	13	7
12th hour	8	4
Total	193 mm	100

**Table 3.2.15 – Timmins Storm Areal Reduction Factors**

<b>Circular Drainage Area (km<sup>2</sup>)</b>	<b>Total Percentage of Rainfall</b>
0 to 25	100
26 to 50	97
51 to 75	94
76 to 100	90
101 to 150	87
151 to 200	84
201 to 250	82
251 to 375	79
376 to 500	76
501 to 750	74
751 to 1000	70
1001 to 1250	68
1251 to 1500	66
1501 to 1800	65
1801 to 2100	64
2101 to 2300	63
2301 to 2600	62
2601 to 3900	58
3901 to 5200	56
5201 to 6500	53
6501 to 8000	50

Figure 3-3 Flood Hazard Criteria Zones

Abstracted from Technical Guide, River & Stream Systems: Flooding Hazard Limit, page 12, Ontario Ministry of Natural Resources, 2002

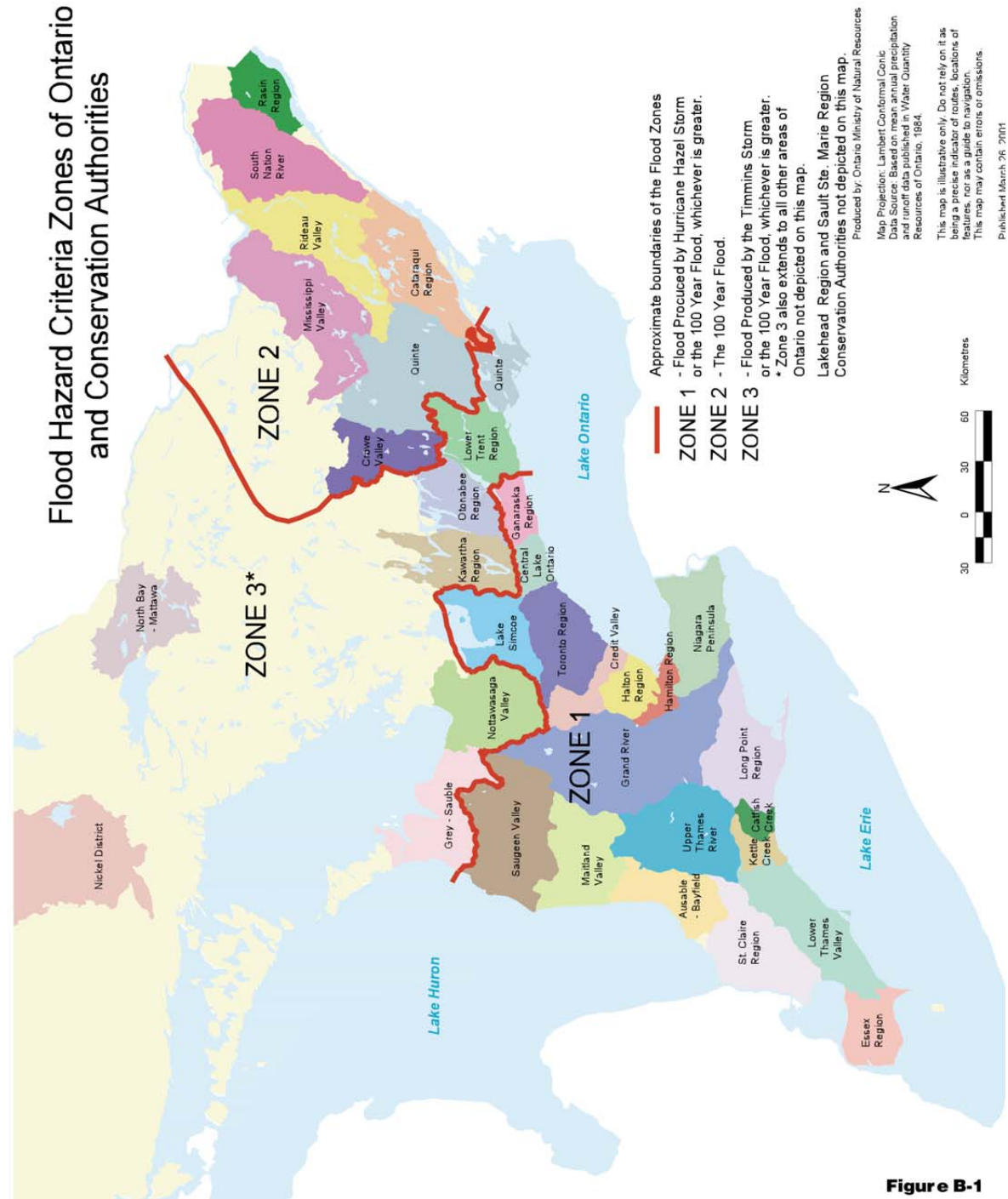


Figure B-1

### 3.10 References

Information used in Section 3 has been abstracted from the following documents:

- Guidelines for Water Management Modelling  
eWater CRC, Australia 2011
- Guidance on the Development, Evaluation, and Application of Environmental Models  
US EPA CREM (Council for Regulatory Environmental Modeling) March 2009
- Good Modelling Practice Handbook  
STOWA Report 99-05
- Appendix 2 Modelling  
Assessment Report: Draft Guidance Modules, Ontario Ministry of the Environment October 2006
- Flooding Hazard Limit, Technical Guide River & Stream Systems  
Ontario Ministry of Natural Resources 2002
- Appendix C: Guidance for Riverine Flooding Analyses and Mapping  
Guidelines and Specifications for Flood Hazard Mapping Partners US FEMA  
November 2009
- Selection, Calibration, and Testing of Hydrologic Models.  
D.L. James and S.J. Burges. In Hydrologic Modeling of Small Watersheds,  
Mono. No. 5, American Society of Agricultural Engineers. 1982

## 4.0 HYDRAULIC ANALYSIS

### 4.1 General

Hydraulic analyses are performed to determine water surface elevations at various locations along a watercourse for various streamflow return periods. The water surface elevations are used to delineate flood hazard limits and floodplains.

- The technical reports for hydraulic analyses are to be prepared in such a manner that the entire work can be recreated by professional engineers without the need to refer to any other material. Further, professional engineers are to be able to recognize and understand all methods, approaches, basic data, and rationale used for these methods;
- Hydraulic Standard Parameters (Section 4.9) should be used in all hydraulic computations. If the engineer feels that the standard parameters should be modified, the engineer should provide documentation to the Conservation Authority providing justification that can include the results of calibration/validation analyses;
- Hydraulic calculations must be approved by the Conservation Authority before the flood hazard limits are delineated. Hydraulic calculations to determine water surface elevations are usually conducted using a computer program;
- The study report documentation must include the following:
  - What analysis was done including purpose, alternative methods, and the rationale for the chosen method;
  - How the analysis was conducted including input data, data sources, measurements of data, verification, collaboration, uncertainty analysis, calibration, validation, and sensitivity analysis;
  - The results of the analysis;
  - How were the results checked; and
  - What are the limitations of the analyses.

The hydraulic analysis report must be sealed, signed, and dated by a professional engineer. Any computer program input and output data must be sealed, signed, and dated by the professional engineer who prepared or supervised the preparation of the input data and who checked the output data. The computer model description box must include the professional engineer's name, PEO registration number, and the completion date.

Section 4 is divided into the following subsections:

- 4.2 Information Requirements
- 4.3 Watercourse Conceptualization and Characterization
- 4.4 Data Availability
- 4.5 Technical Reviews
- 4.6 Selecting a Flow Analyses Procedure
- 4.7 Computer Modelling
- 4.8 Study Report and Deliverables
- 4.9 Hydraulic Standard Parameters
- 4.10 References

## **4.2 Information Requirements**

- The study report must discuss the objectives of the analysis, the information required for input to the hydraulic model, and the methodology used to obtain that information. The report must discuss the scenarios to be analyzed, and the level of accuracy required.

Specification of the information requirements combined with characterization of the watercourse, and determination of available data, will allow a computation flow analyses procedure to be selected.

## **4.3 Watercourse Conceptualization and Characterization**

- The report must discuss the conceptualization and characterization of the watercourse under study. Conceptualization and characterization aids in determining the computation methods to be used in the hydraulic analysis including which computer programs may be applicable.

Conceptualization will determine the salient components of the watercourse, the relationships between the components, the upstream and downstream boundary conditions, and the temporal computation requirements. Conceptualization will determine if computations should be undertaken at a 1-D or 2-D level. Conceptualization will also include the size of the time step if unsteady flow computations are conducted. Conceptualization will determine how lumped or detailed the hydraulic processes will be modelled. Assumptions must be fully discussed and justified in the study report.

#### 4.4 Data Availability:

- The study report should contain a discussion on the data used to derive parameters for the model, and the data used to evaluate the model. The accuracy of the model will depend on the accuracy of the data used to develop and calibrate the model. The discussion should include the following:
  - Where the data can be sourced;
  - How and by whom was the data measured;
  - Period of record that was used in the model; and
  - What is the level of accuracy of the data.

Error creeps into data through a number of ways. Included are errors due to the procedures used to acquire the data, errors due to natural spatial and temporal variability, transcription errors, data storage errors, and errors due to data manipulation.

#### Data Filling and Modification

- The study report must contain a discussion on any data filling and modification of data used in the study. Generally, missing data needs to be filled. Also, suspect data needs to be modified. Discussion should include the following:
  - What data was filled or modified, why; and
  - What techniques were used to fill the data.

#### Data Stationarity

- The study report must contain a discussion regarding data stationarity. Changes to data sets may be gradual, or may be abrupt or may be in a more complex form. Data sets may not be stationary for a variety of reasons. Included are the following:
  - Changes in measurement techniques or instrumentation or relocation of the gauge; and
  - Changes to stream channel geometry.

#### 4.5 Technical Reviews

Hydraulic studies should be reviewed to determine the correctness, completeness and appropriateness of procedures used to develop information for the intended purpose and for adherence to these Technical Guidelines. Included are input data, boundary conditions, conceptual model, mathematical model and parameters, model limitations, and model documentation.

Reviews can be undertaken near the end of a study, or throughout the study. Both approaches have limitations. Both approaches have limitations. For example, there may not be sufficient budget to correct any deficiencies found in a review if the review is conducted near the end of a study. Also, a reviewer's independence may become jeopardized if reviews are conducted throughout the study, as the reviewer may act as an advisor rather than a reviewer. It is recommended that the technical review be undertaken throughout the study to minimize the potential for wasted efforts.

A formal process should be followed to review hydraulic studies, and each review should be documented. Reviewers can be from the Conservation Authority undertaking the work, or can be undertaken by third parties.

Reviewers must have sufficient expertise in the area of practice to properly assess the hydraulic analysis. Reviewers must be capable of conducting the study, and reviewers must have a thorough understanding of methodologies and knowledge of accepted hydraulic engineering practice. A reviewer must have access to the computer program being used in the study. A reviewer must be a Professional Engineer licensed in the Province of Ontario.

The reviewer's report should identify the following:

- The individual who authorized the review,
- The author;
- The purpose of the review;
- The basis under which the review was conducted;
- A brief description of the study report under review;
- A summary of documentation provided to the reviewer;
- Communications made during the review;
- A description of the methodology for conducting the review; and
- The reviewer's findings that include information upon which the reviewer's opinions are based.

The reviewer shall check the following:

- Results of the hydraulic model should match the maps, including the distances between cross sections, water-surface elevations, flood widths;
- All hydraulic structures in the model are reflected on the maps and vice versa;
- Water-surface and energy grade line profiles of different flood frequencies do not cross one another;
- Water-surface profiles do not show water-surface elevations at an upstream cross section lower than a water-surface elevation at a downstream cross section;
- Flood discharges used as inputs correlate with the hydrologic analysis;
- Cross section location and alignment;

## TECHNICAL GUIDELINES FOR FLOOD HAZARD MAPPING

- Ineffective flow areas;
- Absence of buildings from cross sections;
- Floodline map accuracy and appearance;
- Starting water-surface elevations are correct;
- Distribution of flood flows or changes to the distribution between left overbank, channel, and right overbank;
- Cross sections, Manning's roughness coefficients, transition loss coefficients, and loss coefficients at structures are modeled in accordance with the Technical Guidelines;
- Water-surface elevations at bridges or culvert sections are correct;
- Hydraulic models are calibrated with high-water marks or measured flow rates and water surface elevations where available;
- Hydraulic model results that are compared with aerial photographs of historic flooding where flood elevations can be determined;
- Appropriateness of the program used in the analysis; and
- Water surface elevations on the main branch must equal the water surface elevations of tributaries that confluence with the main branch for those tributaries not being studied.

**Figure 4-1 – Sample Flood Plain Mapping Product for Public Discussion.**





#### 4.6 Selecting A Flow Analyses Procedure

- Generally, the type of flow analysis will be requested in a study's Terms of Reference. The engineer should confirm and discuss in the study report the type of flow analyses that is appropriate for the development of floodlines in the study area.

Four (4) types of flow analyses can be analyzed for the development of floodlines. The types of flow analysis include the following:

- One-dimensional steady flow;
- One-dimensional unsteady flow;
- Two-dimensional steady flow; and
- Two-dimensional unsteady flow.

One-dimensional (1-D) steady flow models are applicable where flow peaks are not significantly affected by storage, where the channel storage-discharge relationship is represented by a single-valued rating curve, and where water-surface profiles are not affected by reverse flow conditions. Typical reaches are well-defined open channels with gradually varied flow.

One-dimensional (1-D) unsteady flow models are applicable to reaches with significant storage, reverse flow, or are subject to rapidly varied flow and waves.

Two-dimensional (2-D) steady and unsteady flow models are most applicable to streams on flat terrain with broad floodplains where flow is moving in two or more directions, or flow is hydraulically disconnected between the main channel and the floodplain (spills and split flow). Two-dimensional (2-D) modelling may be appropriate for Special Policy Areas, Two-Zone mapping, risk assessment, emergency response and flood remediation measures.

## 4.7 Computer Modelling

### 4.7.1 General

Computer models, despite their complexity, are a simplification of reality. Computer models are simply tools that can be used to better understand how watercourses function. Modelling to a higher resolution or level of accuracy than is necessary may not guarantee better results and may ultimately waste time and resources.

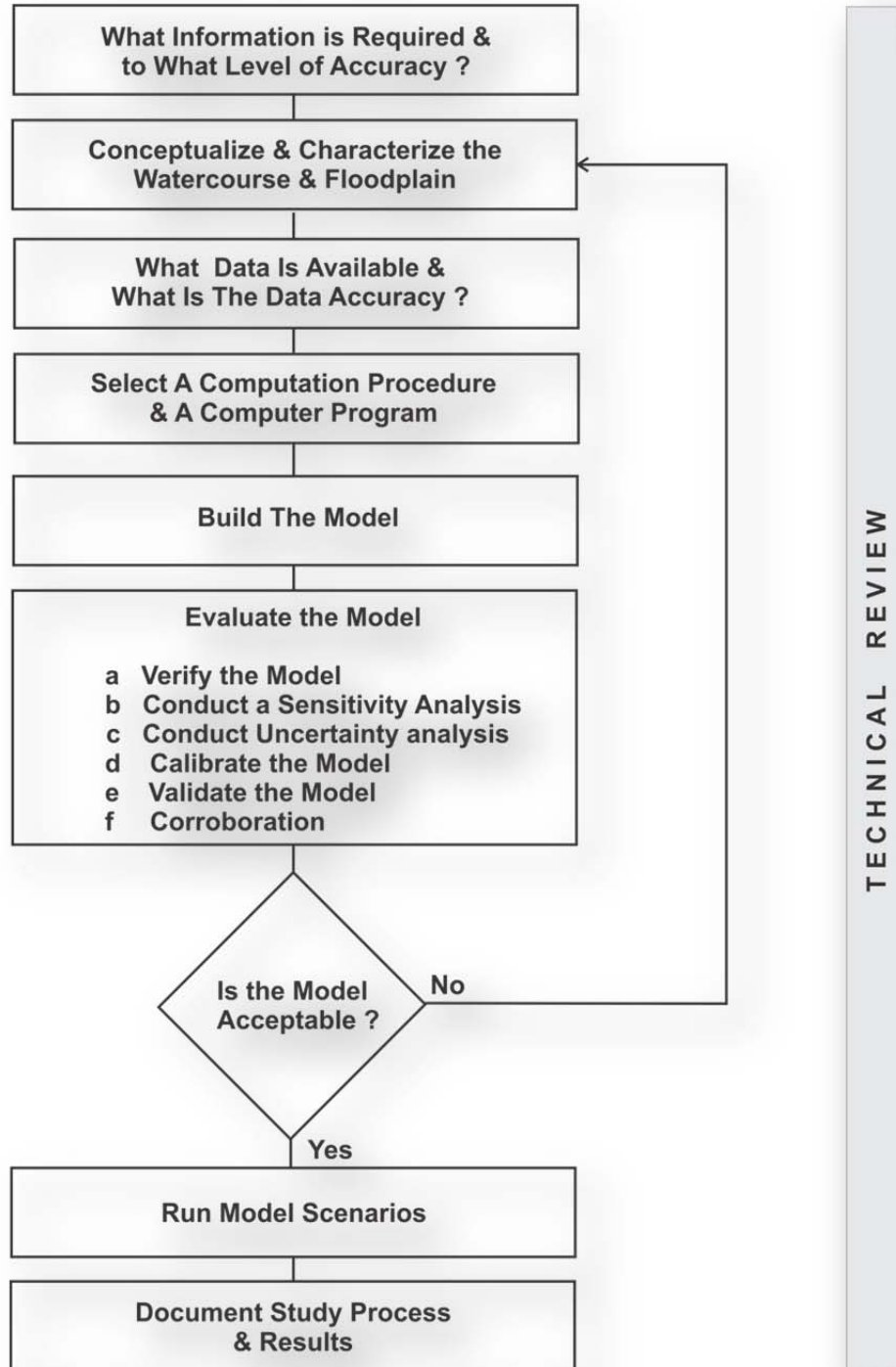
The hydraulic modelling methodology is shown in Figure 4-2.

Section 4.7 is divided into the following subsections:

- 4.7.2 Program/Software Selection
- 4.7.3 Model Building
  - 4.7.3.1 One Dimensional - Steady Flow Models
  - 4.7.3.2 One Dimensional - Unsteady Flow Models
  - 4.7.3.3 Two Dimensional - Steady and Unsteady Flow Models
- 4.7.4 Model Evaluation
  - 4.7.4.1 Model Verification
  - 4.7.4.2 Sensitivity Analysis
  - 4.7.4.3 Uncertainty Analysis
  - 4.7.4.4 Calibration/Validation
  - 4.7.4.5 Corroboration
  - 4.7.4.6 Error/Warning Messages
- 4.7.5 Model Acceptability
- 4.7.6 Modelling Scenarios and Results

Figure 4-2

Hydraulic Modelling Methodology



#### 4.7.2 Program/Software Selection

- The engineer must select the computer program to be used in the hydraulic analysis. Reasons for selecting a computer program or a suite of programs must be documented in the study report and must be approved by the Conservation Authority prior to model building;
- The documentation must include an assessment of alternate programs, and reasons why the alternate programs were not selected;
- The most recent version of the computer programs must be used. The engineer should follow the procedures and guidance given in the program's User Manual and Technical Reference;
- Computer programs used in the hydraulic analyses should not be modified by anyone except the program author; and
- If the engineer proposes any modifications to a computer program or proposes to use an existing modified program, the engineer must submit to the Authority input test data, output, and complete listing of the modified computer program, user's manual and an explanation in detail as to the nature of and reasons for modifications for review and approval prior to its use. The Conservation Authority and its agents should be granted a royalty free license to use the program for floodline modifications.

#### Program/Software Selection Notes

- A computer program is a system or algorithm with mathematical equations, parameters and data structures. Programs may be developed in-house, may be external open-source or may be an external proprietary program where the source code is not shared. Open source programs are preferred;
- There may be more than one suitable program to conduct the computations and more than one computer program may be required;
- The engineer should be familiar with the principles, equations, algorithms, and assumptions used in the program; be aware of the programs limitations; and know when the program is providing the appropriate answers;

- Table 3.1 identifies some of the steps required by the engineer to show demonstrate due diligence when selecting and using hydrologic and hydraulic software. The engineer who selects the software is responsible for conducting due diligence whether it is Conservation Authority staff or a consultant;
- The engineer should select a program (algorithms and equations) with the available data that reflects the dominant and sensitive processes described in the conceptual model; and
- The engineer should select a program that is no more complicated than necessary to compute the required information. Models tend to increase uncertainty as they become too simple or too complex. The complexity of a model should be sufficient to minimize uncertainty, and that more or less complexity will increase uncertainty.

### 4.7.3 Model Building

Model building is the development of a mathematical model based on a conceptual model. Model building requires both a spatial and temporal discretization of the physical watercourse into a mathematical model. The construction of the mathematical model is a function of the computer program used. The model building phase determines parameter values that are fixed, and initial estimates of calibration parameters are made. Hydraulic standard parameters are shown in Section 4.9.

Section 4.7.3.1 should be read first as it contains information common to Section 4.7.3.2 and Section 4.7.3.3.

Some general notes include the following:

- The hydraulic model should be continuous from the upstream study limit to the downstream study limit. Only one hydraulic model should be used; and
- The study report must include a discussion of the assumptions made and methods used, with respect to parameter estimation, and effective flow areas of the cross section at various stages of the hydraulic analysis.

Effective flow areas are portions of cross sections through which floodwaters are conveyed. Ineffective flow areas are portions of the flood plain where water ponds.

**4.7.3.1 One-Dimensional Steady Flow Models**

- One-dimensional (1-D) steady flow backwater models must be applied to channels with mild to moderate slopes without significant storage and with gradually varied flow. One dimensional steady flow models should not be applied to channels with reverse flow conditions;
- Documentation of one-dimensional models must include shapefiles showing the location and alignment of each cross section, location of each hydraulic structure, river centreline, and show water surface elevations; and
- One-dimensional models usually require the following information:
  - Cross Sections;
  - Hydraulic Structures;
  - Ineffective Flow Areas;
  - Expansion and Contraction Coefficients;
  - Weir Coefficients;
  - Manning 'n' Values;
  - Starting Water-Surface Elevations;
  - Flow Interpolation Between Points of Interest;
  - Spills and Split Flows; and
  - Mixed Flow Calculations.

Cross Sections

- Documentation must include the sources of cross-section data points and methods of measurement; and
- Each cross section must have a unique identifier that is used on the maps, in the hydraulic model, in the field survey notes, and on the cross section plots.

Cross Sections - Location

- Cross sections should be located in accordance with a program's user manual;
- Maximum spacing between successive cross sections shall be dictated by the analytical requirements of the program. The length between cross sections should be based on river geometry and the assumption that gradually varied flow within a reach is valid;

## TECHNICAL GUIDELINES FOR FLOOD HAZARD MAPPING

- Cross sections should be representative of the reaches adjacent to them, and located close enough together to ensure accurate computation of the energy losses;
- Cross sections should be located such that the energy gradient, water-surface slope, and bed slope are all as parallel to each other between cross sections as is pragmatic. If any channel feature causes one of these three profiles to curve, break, or not be parallel to the others, the reach should be further subdivided with more sections;

Discussion shall be contained within the report on the criteria used in locating and defining the cross-sections;

- Cross sections shall be located where changes occur in longitudinal slope, cross-sectional area, channel roughness, bridges and other channel constrictions. Several cross sections at short intervals maybe required to model abrupt changes where the conveyance changes greatly as a result of changes in width, depth, or roughness, and where the lateral distribution of conveyance changes radically with distance. Abrupt changes occur at bridges, culverts, weirs, dams, ponds, levees, bends, and expanding and contracting reaches;
- Tributaries - cross sections should be located immediately upstream and downstream from the confluence on the main stream and immediately upstream on the tributary to account for changes in flow rates in the hydraulic model;
- Locate cross-sections immediately upstream and downstream of any culvert or bridge. The cross sections should be just outside the toe of the fill and the side ditch; and
- Locate cross-sections at the same cross sections used in previous floodplain studies, where high water marks are available, at county, city, and town and other corporate boundaries, and at future development sites.

### Cross Sections - Alignment

- Cross sections must be placed perpendicular to flood flow. Cross section alignment should be a straight line if possible. Cross sections with more than two or more segments are likely to occur;
- Cross sections should never cross or intersect each other. Care must be taken at river bends and tributary junctions to avoid overlap of sections;

## TECHNICAL GUIDELINES FOR FLOOD HAZARD MAPPING

- Cross sections shall be extended across the entire anticipated floodplain, should be perpendicular to the anticipated flow lines (approximately perpendicular to contour lines) and only positive distances are to be utilized. Computer generated vertically extended and interpolated cross-sections are not acceptable; and
- Buildings shall be included (coded or obstructions) in the flood plain portion of cross sections.

### Cross Sections - Points

- All cross sections should be coded left to right looking downstream. Existing models and detail design drawings for crossings may contain cross sections looking upstream. Updates to existing models should be coded consistently looking upstream or downstream;
- Cross sections should include points at changes in grade across the cross section;
- Cross section data points can be abstracted from mass points, DEMs, TINS, contours, geodetic field surveys, and measured low flow sections. Cross section data points must have the accuracy specified in Section 2. Typical low flow sections shall be field measured for each reach between hydraulic structures;
- Left and right bank channel stations shall be representative of actual channel low flow banks;
- Ineffective flow areas shall be noted and excluded from the conveyance portion of the cross section;
- The maximum elevation of each end of a cross section should be higher than the anticipated maximum water surface elevation. The maximum water surface elevation must be contained within the input cross section. Some computer programs will modify input cross sections to contain the flow; and
- Local irregularities in the ground surface such as depressions or rises that are not typical of the reach or do not allow conveyance of flow should not be included in the cross sectional data.



### Hydraulic Structures

- For each stream crossing modeled, the engineer must document the dimensions of the crossing, values of energy loss coefficients, and the justification of those values;
- The sources of data and means of measurement must be fully documented. Documentation must include an explanation for any structures that were not surveyed;
- Discussion of the method used and assumptions made in the calculation of water surface elevations at watercourse crossings;
- Dimensions of hydraulic structures may be taken from as-built drawings where access to the structure cannot be obtained and the as-built drawings can be visually verified in the field;
- Survey information of dimensions and elevations must be referenced to geodetic datum;
- The top of road profile should be obtained by field survey and extend across the entire width of the flood plain;
- A dam break analysis shall be considered to determine flood levels downstream of high (greater than 5 m) embankments that are associated with large upstream storage volumes and where failure under flood conditions may occur. The Conservation Authority should be contacted to confirm dam break modelling. Inundation lines may be plotted on maps for information purposes.
- Hydraulic model coding should reflect the bridge data sheets;
- Equivalent culverts may be required where culverts are composed of two or more segments with different shapes, sizes, and constructed of different materials. Also, equivalent culverts may be required where there are bends in the culvert alignment. The upstream culvert should be modified to equate to the combined head losses of the two or more segments;
- Horizontal stationing at a bridge or culvert section must be consistent with the downstream and upstream channel-floodplain cross-sections. The centerline station of a culvert should be provided and be consistent with the upstream and downstream cross-section stationing;
- Bridge/culvert cross sections will include parapets and railings;

## TECHNICAL GUIDELINES FOR FLOOD HAZARD MAPPING

- Bridge/culvert losses should be checked by a method other than the hydraulic program used to develop water surface profiles. In addition the results of the bridge/culvert loss check should be documented in the study report;
- The study report must document for each profile the amount of flow through bridges/culverts and the amount of weir flow. For the HEC-RAS program an option under the profile output table report lists the amount of pressure and weir flow; and
- Skewed cross sections must be corrected for the hydraulic calculations. The corrections can be made using program parameters or corrected manually.

### Ineffective Flow Areas

- Ineffective flow elevations at a bridge/culvert represent weir flow over the bridge/culvert. For the upstream cross section the elevations are set equal to the elevation (minimum top of road) at which weir flow occurs in the left and right overbanks. For the downstream cross section the elevation at which weir flow occurs is not known for the initial run. An initial estimate is the half way between the low chord and the minimum top of road. The final downstream ineffective flow elevation must be determined through trial runs with different flow rates to determine the flow at which weir flow occurs and then setting the ineffective elevation equal to the downstream water level; and
- The study report must fully document the location and the technique used to exclude ineffective flow areas from the conveyance portion of the watercourse.

### Contraction and Expansion Coefficients

- Expansion and contraction coefficients - refer to Hydraulic Standard Parameters Section 4.9. Typical values are 0.1 and 0.3 for gradual contractions and expansions respectively and 0.3 and 0.5 at abrupt contractions and expansions such as bridges and culverts.

The engineer may use other values when approved by the Conservation Authority. The engineer must document the reasons for using other values and provide documentation to support those reasons.

### Weir Coefficients

- Weir coefficients - refer to Hydraulic Standard Parameters Section 4.9. The engineer may use other values when approved by the Conservation Authority. The engineer must document the reasons for using other values and provide documentation to support those reasons.

### Manning 'n' Values

- Manning's roughness coefficients - refer to Hydraulic Standard Parameters Section 4.9;

The engineer may use other values when approved by the Conservation Authority. The engineer must document the reasons for using other values and provide documentation to support those reasons. Other values may be suggested after a site visit. Documentation of on-site observations must include photographs; and

- If “n” values are adjusted based on calibration, the documentation must include a summary of the values before and after the adjustments.

### Starting Water-Surface Elevations

- Where a control starting elevation, such as a weir that creates a critical depth, is not possible, the starting section shall be located sufficiently downstream that the reach under consideration is not significantly affected by starting water surface elevations. A sensitivity analysis can be used to demonstrate that the starting water surface elevation is located sufficiently downstream not to affect the study reach.

A control is a cross section at which the computed water-surface elevation is unaffected by changes in the downstream flood elevation, and the upstream reach is hydraulically independent;

- Starting water surface elevations for tributaries will assume coincident peaks with the main branch unless it can be justified otherwise;
- Where a lake is the control point, the starting water surface elevation shall be based on the long-term mean lake level;
- Discussion on the methods used and assumptions made in the determination of the starting water surface elevations for backwater computations shall be included in the study report; and

- 100-year lake levels are to be superimposed on the resultant water surface profile to establish the Regulatory level.

#### Flow Interpolation Between Points of Interest

- The study report must contain a discussion on how flow rates were interpolated for locations between points of interest in the hydrologic model. Generally, flow rates should not change more than 10% between points of interest and less between cross sections.

Two methods are acceptable. The first method uses the flow rate from a downstream point of interest in all cross sections to the upstream point of interest. The flow rate does not vary.

The second method interpolates the flow rate between two points of interest based on drainage area. A linear interpolation of drainage area is used in the calculations.

#### Spills and Split Flows

- The study report must document the location of a spill, the estimated maximum depth of the spill, the estimated maximum flow rate of the spill, the estimated volume of the spill, and the receiving watercourse of the spill. The lack of mapping is not considered a spill location.

Spills are floodwaters that leave a defined watercourse and spill overland. Spills can re-enter the watercourse at a downstream point or flow overland to another watercourse;

- The study report must discuss whether a spill is natural or as a result of artificial structures. In case of a significant natural spill, downstream flood levels may be based upon reduced peak flow rates. The Conservation Authority should be contacted for approval prior to the use of reduced peak flow rates.

The hydrologic model may need to be modified to include the natural spill;

- The study report must discuss the methods used and assumptions made in the determination of the estimated spill flows, effects on downstream flows and flood plains, and areas affected due to the spill shall be included in the study report.

At crossings, spill characteristics may be estimated using the lateral weir option in HEC-RAS or by using a top of road or weir cross section that accounts for flow moving over the crossing and moving along the path of the diverted flow. Both these methods provide estimates only, as the methods assume that flow passes through critical depth.

A more accurate estimate may be made using split flow analysis or a 2-D model. Split flow analysis refers to flow that is separated from the main channel for some distance and then merges back with the main channel. Split flow analysis requires at a minimum a common upstream headwater level. HEC-RAS contains an option to conduct a split flow analysis. Split flow analysis can be conducted manually as described in *Open Channel Hydraulics* by Ven Te Chow.

### Mixed Flow Calculations

- Subcritical flow calculations shall be assumed for natural reaches. Mixed flow (subcritical and supercritical) calculations will be considered for artificial watercourses such as concrete lined channels. The Conservation Authority should be contacted for approval prior to the use of mixed flow calculations;
- The study report must document the reaches where subcritical and mixed flow calculations were used to delineate the Regulatory Floodlines. The study report should document where there are large differences in water surface elevations between subcritical and mixed flow calculations; and
- The engineer must investigate and report on natural reaches where the computer program indicated that flow was critical at a cross section. Some hydraulic programs use critical depth as a default water surface elevation. If critical depth is calculated, then the engineer should check the number of iterations used to calculate critical depth. If the number is equal to the maximum allowed number of iterations, then more cross sections may be required. Where there are numerous or continuous critical depth values, mixed flow calculations may be required. The Conservation Authority should be contacted for approval prior to the use of mixed flow calculations.

### **4.7.3.2 One-Dimensional Unsteady Flow Models**

- Generally, 1-D unsteady flow models are not used to develop Regulatory Floodlines. 1-D unsteady flow modelling maybe used to delineate Two Zone areas and may be used to develop inundation areas for dam break analysis;

- The Conservation Authority should be consulted and must approve the use of 1-D unsteady flow modelling to delineate Regulatory Floodlines;
- The study report must document data sources used to develop the hydraulic model, including inflow hydrographs, geometry data for channel cross sections or other conduits, junctions and/or other storage areas, energy loss coefficients, and downstream boundary conditions. Some one-dimensional unsteady state models describe the drainage system as a nodal network, consisting of nodes (junctions) and links (conduits). Other programs use channel network features described by cross sections. All data and sources must be described in the study report; and
- Steady flow models may not be easily converted into unsteady flow models.

### Cross Sections for 1-D Unsteady Flow

- Cross section end points should have the same elevations. Uneven end points may cause numerical instabilities during simulation;
- Interpolated cross sections should not be used;
- Hydraulic properties such as top width, hydraulic radius, etc. of a cross section should not change abruptly; and
- In-line weirs should be used for severe drops in bed profile.

### Boundary Conditions for Unsteady Flow Computations

- The study report must document the upstream boundary conditions (hydrographs), downstream boundary conditions (stage-discharge relationship), tributary hydrographs, and lateral inflows. The documentation should include the source of the data, and the reasoning used to assign frequencies to the hydrographs.

### Non-Conveyance Areas for Unsteady Flow Computations

- The study report must document any non-conveyance or storage portions of cross sections used in the unsteady flow computations. Many 1-D unsteady flow programs can model off-channel storage area connected to the channel. Documentation must include elevation-storage relationships, used in the

analysis, including the methods, sources, and measurements of data used to define the relationships; and

- These storage areas are usually defined by elevation-volume or elevation-surface area relations or modeled by user-defined flow allocation ratios. Such areas should be clearly labeled with a unique identifier corresponding to the storage area used in the model.

#### **4.7.3.3 *Two-Dimensional Steady and Unsteady Flow Models***

- Generally, 2-D steady or unsteady flow models are not used to develop flood hazard limits. 2-D modelling may be required in areas where flow is moving in two different directions at the same time or where flow paths may not be well defined or difficult to visualize. 2-D models provide a better estimation of local variations of velocity and water depths. 2-D models will only be required for reaches where 1-D modelling is inappropriate;
- 2-D models are applicable to bi-furcated flow patterns, rigid boundaries, overland flow, and complex hydrodynamics. For flood hazard maps, 2-D models should only be used when flow depths are greater than 0.3 m;
- It is expected that full 2-D models will be rarely required to develop flood hazard maps. Rather a 1-D model coupled with a 2-D model will be used after consultation with and approved by the Conservation Authority; and
- The study report must document the reasons for utilizing a 1-D/2-D steady or unsteady state model for delineating hazard limits.

1-D analysis may be appropriate to represent the channel flow for wide floodplains with defined channels where conveyances, velocities, and associated physical forces are only significant in the downstream direction. Hydraulic parameters can be computed using cross sections placed perpendicular to the flow direction. 1-D modelling is well suited to hydraulic structures and has short computation times when compared to 2-D modelling.

The 2-D analysis has the ability to accurately model steady or unsteady, unconfined flows caused by flat terrain. Flow in this scenario is moving in two or more directions. The 1-D flow analysis may not accurately model water surface elevations. For 2-D modelling grid elevations are presumed to vary gradually. For 2-D analysis a grid is required instead of cross sections and rating curves maybe used to model crossing losses. The 2-D model accounts for lateral variations in

water surface elevations. The 2-D analysis has significant computation times and may not accurately account for head losses at structures.

A coupled 1-D/2-D model is often the most efficient model given the advantages and disadvantages of 1-D models and 2-D models. A coupled 1-D/2-D model has short computation times, accounts for bifurcated flow, and accurately accounts for head losses at hydraulic structures.

### Model Domain

- The model domain defined by bathymetry should cover the river network and its floodplain. In urbanized areas the slope of the road network may carry the shallow flooding well beyond the area of interest. A boundary should be chosen sufficiently far from the area of interest and located where the surface is sloping down away from the model domain;
- In places where the 2-D model domain crosses the 1-D channel model the location of the 2-D model boundary should be chosen such that flow is expected to be generally confined to the 1-D channel;
- The model domain must be sufficiently extended laterally from the channel to ensure that overland flow moving away from the channel does not encounter the boundaries of the 2-D domain and become artificially constrained within the domain; and
- The model domain should be adjusted in such a way that the 1-D model network should ideally extend upstream and downstream such that the start point and end point are outside of the 2-D model area of interest.

### Boundary Conditions for 1-D/2-D Models

- The study report must document the upstream boundary conditions (hydrographs), downstream boundary conditions (stage-discharge relationship), tributary hydrographs, and lateral inflows. The documentation should include the sources of the data, and the reasoning used to assign frequencies to the hydrographs;
- Downstream boundary conditions for the 2-D model will be extracted from the 1-D model at the domain limits;
- The 2-D domain must be of sufficient lateral extent to ensure that flow moving away from the channel does not encounter the boundaries of the 2-D domain and



become artificially constrained within the domain. The lateral flow should be allowed to reach a shallow depth of flow under hydraulic influence only 0.05 m; and

- The 2-D model must provide for lateral inflows or changes in flow over the 2-D domain, where the domain is large enough that there is a distinct hydrologic transition to higher flows (e.g. domain encompasses an area where upstream catchments are connected via downstream reaches to additional catchments providing inflows into the river network).

### Cross Section in coupled 1-D/2-D model

- Cross sections should be spaced to adequately represent the bank elevations along the lateral link for smooth transfer of flows from 1-D to 2-D and vice versa.

### Links in coupled 1-D/2-D model

- The study report must document linkages (lateral and standard/structure link) types, locations and lengths of the 1-D and 2-D model components and why the linkages were selected.

### Initial Conditions in Coupled 1-D/2-D Models

- The study report must justify the initial conditions used for 2-D analysis. The documentation should include the source of inflow hydrographs and downstream water surface elevations; and
- If inflow hydrographs are modified, for example to reduce computation time, then justification should be provided in the study report.

### Computational Grids in Coupled 1-D/2-D Models

- The study deliverables must include a geo-referenced spatial data file (i.e. DEM, DTM) showing the locations of the stream under study, major flow paths emanating from and adjacent to the study stream, hydraulic structures adjacent to and crossing the stream, and the grid of cells. The location of each cell must be readily ascertained from the spatial data file. The grid cells should cover the entire project area and consider buildings.
- The study report should document the grid cell size, and the reasoning for the selection of the cell size. The cell size will be dependent on the accuracy of the

topographic data, the computational efficiency of the program, and the mapping and floodplain management requirements. The engineer must ensure gradual changes in elevation from one cell to adjacent cells.

The grid spacing should be sufficiently resolved such that it can capture the topographic features (e.g. curbs, berms, ditches, etc.) that will act as hydraulic controls to influence the direction and depth of overland flow. In order to capture appropriately the flood waters in the floodplain, review of noticeable land features should be conducted to determine if there will be any high or low ground topography that required a finer resolution in the grid spacing. Some sensitivity analysis may be required to develop reasonable grid spacing.

### Hydraulic Structures in Coupled 1-D/2-D Models

- The study report must document the modeling of each hydraulic structure. The documentation must include a list of each cell associated with the structure and a description of the rating table including its derivation and its sources of data. Typically, hydraulic structures are input as rating tables at specific grid cells;
- A long crossing with significant overtopping that does not flow back to the stream should be coded in the 2-D model. In a coupled 1-D/2-D model, the majority of crossings should be coded as part of the 1-D model;
- Q-h relations should be calculated for all weirs and culverts to verify the model hydraulics are representative of the defined geometries.

### Non-Conveyance Areas (Buildings) in Coupled 1-D/2-D Models

- The study report must document the reasoning for, location of, and technique used to model non-conveyance areas through input data and include a discussion where artificial data have been used.

The engineer must ensure that non-conveyance areas be modelled to reflect natural conditions (topography and roughness) as closely as practical. Removing cells from computation should not be used when performing hydraulic computations.

### Energy Loss Coefficients in Coupled 1-D/2-D Models

- The study report must document roughness coefficients or Manning's 'n' values for each of the grid cells. Roughness coefficients are one of the parameters to be considered in model calibration.
- Bed roughness within the 2-D domain should provide equivalent representation of the frictional characteristics of the 2-D domain as the Manning 'n' roughness coefficients for the corresponding 1-D model.

### Coupled 1-D/2-D Models Modelling Notes

- Deliverables must include geo-referenced shapefiles showing the locations of the stream, major flow paths, hydraulic structures crossing the stream, and the grid of cells. For models using a grid of cells, the location of each cell must be readily ascertained from the geo-referenced shapefiles;
- The study report must include a list of each grid or element associated with the crossings, and a description of the rating table including the derivation, sources of data;
- The study report must document initial conditions and why the initial conditions were selected;
- The study report must document a discussion of the sensitivity analysis and the results;
- The study report should summarize mathematical formulations integrated in the proposed 2-D model to simulate the physical processes, numerical method to solve the mathematical formulation, numerical grid type to discretize the study area in order to apply the numerical method, representation of boundary condition to the model domain and method of linking with other models; and
- The study report should show separate flood profiles for significant flow paths including the main channel that can be identified by velocity, flow rate, flow depth, and flow volume.

#### 4.7.4 Model Evaluation

- The study report must discuss the results of the model evaluation, and the model evaluation process. Model evaluation is the process used to determine whether a model and its results are sufficient to simulate the inputs required for the hydraulic analysis. Model evaluation includes the following:

4.7.4.1	Model Verification
4.7.4.2	Sensitivity Analysis
4.7.4.3	Uncertainty Analysis
4.7.4.4	Calibration/Validation
4.7.4.5	Corroboration
4.7.4.6	Error/Warning Messages

The engineer must consider what degree of uncertainty is acceptable within the context of model application. If the engineer does not accept the model for its intended purpose, then the process must be re-started by re-visiting the conceptualization of the study watershed and the drainage system.

##### 4.7.4.1 *Model Verification*

- The computer model will be verified and documented in the study report. Model verification is the examination of the model to prove that it truly represents the conceptual model.

Model verification checks the proper implementation of the model on the computer. The model should be computationally stable over the entire range of flow rates being analyzed and provide credible results; and

- FEMA's Check-RAS program can be utilized to check HEC-RAS models for errors and reasonableness. The Check-RAS program offers comments on Manning's roughness coefficients and transition loss coefficients, cross-sections, bridges and culverts, floodways, and computed profiles. Engineering judgement must be utilized to interpret the Check-RAS results.

**4.7.4.2 Sensitivity Analysis**

- Sensitivity analyses shall be performed to determine the impact of changing model input parameters and initial conditions on calculated flows;
- Sensitivity analysis will involve varying Manning roughness coefficients by plus/minus 20%, expansion/contraction parameters by plus/minus 100%, bridge area by plus/minus 20%;
- An assessment of the sensitivity of culvert blockages on upstream flood levels must also be carried out for high embankments that have a history of debris blockages. The Conservation Authority should be contacted before undertaking sensitivity analyses; and
- Documentation of the results of the sensitivity analyses shall be provided in the study report. The results will identify the importance of model parameters that will have to be adjusted during calibration.

**4.7.4.3 Uncertainty Analysis**

- An uncertainty analysis will be conducted and discussed in the study report.

The uncertainty analysis will investigate the effects of the lack of knowledge and other potential sources of error. Sources include data collection, model inputs, constants, and recorded data, numerical simulation, post processing, and theoretical assumptions.

**4.7.4.4 Calibration/Validation**

- The model should be calibrated where sufficient data exists. The study report must document the process, including dates, measurements, and locations of measurements of historic floods; parameters revised and rationale for revising; and the calibration model input and output data.

Generally, calibration of hydraulic model parameters is performed by adjusting energy loss coefficients and comparing model results with values from historic floods.

Data for calibration/validation includes the following:

- Highwater marks;
- Rating curves at streamflow gauges;

- Measured water surface elevations and flow rates along a reach;
- Photographs showing flood plains with measured flow rates and water surface elevations;
- Calibrated parameters shall not be adjusted beyond the ranges shown in Section 4.9. Model parameters must be within the range of engineering practice. Parameters outside the range must be revised;
- All hydraulic data must be submitted in electronic format; and
- Discussion of the data used in calibration work including the reasons for the choice of data used in the work shall be included in the study report.

### Calibration/Validation Notes

#### *Calibration*

- Consists of a model test with known input and output information that is used to adjust or estimate model coefficients or parameters within physically defensible ranges until the resulting predictions give the best possible fit to the observed data.

#### *Validation*

- The model results are compared with an independent set of observations (not used in the calibration) to verify whether the model describes system behaviour correctly.

#### *No calibration/validation procedure is perfect*

- There are always deviations due to modelling and measurement errors. There are conceptual errors due to model definition such as the simplification of complex structures, neglect of sub-processes, and errors in the mathematical description or in the numerical method applied. There are errors when measuring field observations such as high water marks, precipitation and streamflow. There are also errors when selecting model parameters that are not known with certainty.

#### *No model can be truly validated*

- But can only be invalidated for a specific application. After a sufficient number of successful tests the model is not valid or good but good enough. The model can then be regarded as having been validated.

*There are no universally accepted "goodness-of-fit" criteria that will apply in all cases*

- Model performance is evaluated by a series of graphical tests. Model performance is the ability to reproduce field observations. Graphical tests include the following:
  - Observed vs. simulated profile plots of water surface elevations; and
  - Observed vs. simulated plots stage vs. water surface elevations at a specific location (e.g., streamflow gauge).

*Manual vs. Automatic Calibration*

- Calibration for hydraulic simulation models typically involves energy loss coefficients. Examples include expansion/contraction coefficients and Manning 'n' roughness coefficients. Manual trial-and-error adjustments can be very successful for a few parameters. The engineer must determine whether automatic calibration is required.

*Data Set Trends*

- Care must be taken when using data sets where changes in measurement locations, changes in equipment, and changes in personnel can negatively impact measurements.

*Number of Parameters To Be Calibrated*

- Generally, there are fewer parameters to be calibrated in hydraulic models than in hydrologic models. Calibration usually entails the matching water surface elevations to measured streamflow rates at gauges.

#### **4.7.4.5 Corroboration**

- Results from computer simulation models must be corroborated using other methods. For hydraulic programs these methods include hand calculations, MTO inlet and outlet charts, and results from previous studies. The comparison must be documented in the study report. If the results are significantly different, then reasons must be stated in the study report to explain the differences.

#### **4.7.4.6 Error/Warning Messages**

- All error and warning messages generated by hydraulic programs should be corrected. Any messages that cannot be corrected must be discussed and explained in the study report; and
- Critical depth locations in the HEC-RAS model output must be carefully reviewed. HEC-RAS defaults to critical depth when the flow changes from

subcritical to supercritical flow and when the program cannot reach a solution in a specified number of iterations.

Engineering judgement is required to ensure that the location of critical depth is correct when the flow is changing from sub- to super-critical. When the program cannot reach a solution this is an indication of errors in the modelling procedure. The engineer should review whether additional cross sections are required or cross sections have to be modified.

### **4.7.5 Model Acceptability**

- The study report must include a statement regarding the acceptability of the model to simulate the information required from the hydraulic analysis. The statement should summarize the results of the model verification, the calibration/validation analysis, the sensitivity analysis, and the uncertainty analysis. Also, the discretization in time and space, and the correctness of the conceptual model will be addressed. The statement is required to answer the question of whether the correct program, and model have been chosen; and
- The Conservation Authority must approve the acceptability of the model before the modelling scenarios are conducted.



## 4.7.6 Modelling Scenarios and Results

### 4.7.6.1 *General*

- The study report must discuss the methods used and assumptions made in the determination of spill flows; effects on downstream flows and flood plains, and areas affected due to the spill shall be included in the Hydraulic Report; and
- The study report must contain the results of the scenario runs. Once the model has been accepted or the model is sufficient to conduct the simulations, the scenario runs may be undertaken.

### 4.7.6.2 *Ice Jams*

The study report must document instances or lack of instances of ice jam flooding through the study reach. Ice jams can reduce watercourse flow area and increase upstream water surface elevations that result in flooding. Flood hazard limits must consider ice jams whenever ice jams have historically been indicated within the study reach. There are several methods to predict ice jam water levels. Most have not been widely tested in Ontario.

#### Ice Jam Characteristics

- Ice jams have been categorized as freeze-up jams or break-up jams;
- Several freeze-up and break-up jams may occur each year;
- Freeze-up and break-up jams do not necessarily denote fall and spring events;
- Ice accumulation may remain until the next thaw;
- Ice jams may occur in some reaches but not in others;
- Ice jam data in one reach may not be transposed to other reaches;
- Ice jams cannot be predicted with certainty in any given year;
- Ice jams often re-occur at the same locations;
- Ice jams may not be sustainable beyond a given flow rate;
- Ice jams occur over small areas (e.g., a few kilometres), and for short durations (e.g., a few hours to a few days);
- Ice jams often occur when flow rates are low and increasing;
- Ice usually flows downstream and accumulates at an obstruction or a sudden change in channel flow direction, slope, alignment, or cross sectional shape or depth;
- Ice jam growth depends on the river discharge, the quantity of ice delivered from upstream, and meteorological conditions; and
- Ice jams can only be removed by either thermal melt or a sudden dynamic collapse created by an increase in upstream hydraulic head or from internal ice

erosion caused by flows moving through the ice jam. Ice jams may re-form downstream.

The maximum stage-frequency distribution through a reach is the combination of a stage-frequency distribution for ice jam conditions with the stage-frequency distribution for open water conditions. Stage-frequency distributions are developed rather than discharge-frequency distributions, as ice jams tend to occur at periods other than very high flow rates.

The stage-frequency distribution analysis will consist of ranking stages, assigning plotting positions, plotting the ranked stages on probability paper, and curve fitting the stages. The stage-frequency analysis can use historical stages or can use synthetic (computer simulated) stages.

Figure 4-3 presents the procedure for undertaking an ice jam analysis. It is based upon information presented in the Technical Guide - River and Stream System: Flooding Hazard Limit, Ontario Ministry of Natural Resources, 2002. The following text gives a short description of that procedure:

#### Are High Water Levels the Result of Ice Jams ?

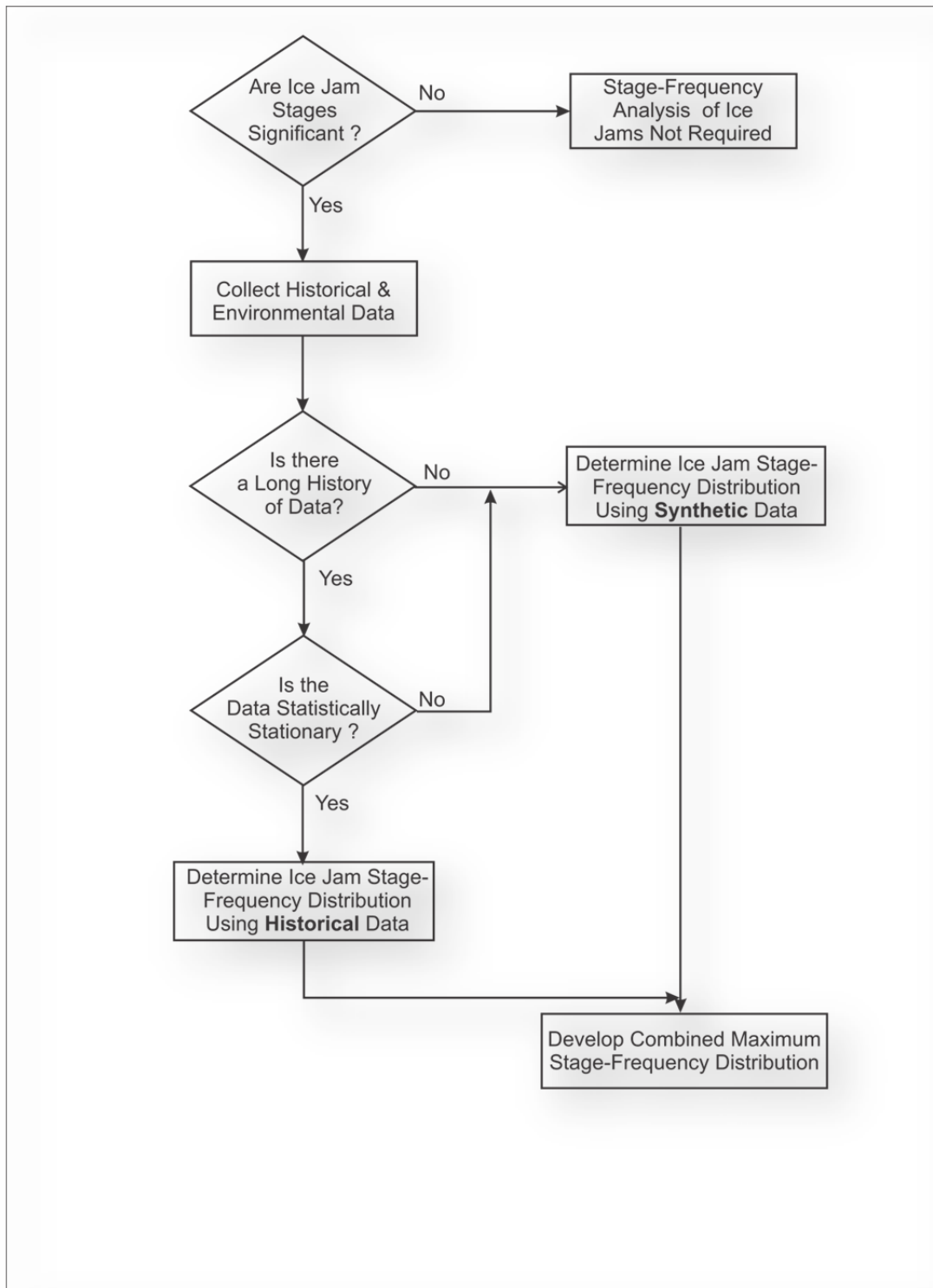
The study report must document whether high water levels or stages within the study reach are the result of ice jams. Conservation Authorities, municipalities, and local residents should be contacted to determine if high water levels are the result of ice jams. Also, the study report should document who was contacted and when.

If high water levels are not the result of ice jams, then the frequency analysis of ice jam stages does not have to be performed.

If high water levels are the result of ice jams, then historical and environmental data relating to ice jams must be collected.

A detailed review of the ice jam documents listed in Section 4.10 should be conducted before ice jam calculations are conducted.

Figure 4-3 - Ice Jam Stage-Frequency Analysis Procedure



### Collection of Historical and Environmental Data

The study report must document all of the historical and environmental data relating to ice jams and the source of that data collected during the study. Data is collected during on-site investigations, surveys, and through discussions with local authorities and residents. Data include the following:

- Tree damage and scars;
- Vegetation trim lines;
- Disturbed bank material;
- Gravel pavement;
- Ridges of bank material;
- Societal - resident recollections, archives, newspapers, books, photographs, hydrometric gauges;
- Location of ice jams;
- Dimensions of ice jams;
- Volume of ice jams;
- Causes of ice jams;
- Associated river stages and discharges;
- Frequency of occurrence;
- Detailed river geometry;
- Lateral and upstream extent of flooding;
- Historical flood level data;
- Discharge measurement data;
- Duration of ice jam event;
- Season of occurrence; and
- Damage to structures.

### Is There A Long History of Data? and Is the Data Statistically Stationary?

The study report must document whether there is a long history of data and if that data is statistically stationary.

If there is a long history of data and the data is statistically stationary, then a frequency analysis of historical stages may be undertaken. A long history is considered to be three or more events in a 25 year period of record. Data may not be statistically stationary if there have been modifications to the watercourse or streamflow. Modifications may include channelization, reservoirs, dyking, etc.

If there isn't a long history of data or the data is not statistically stationary then a frequency analysis of synthetic (computer simulated) and historical data is required.

The results from the use of historical information or synthetic information should always be checked using an alternate method.

### Determining a Stage-Frequency Distribution Using Historic Ice Jam Stages

The study report should document the stage-frequency distribution analysis and the historical data used in the analysis. Separate stage-frequency distribution curves will be developed for ice jam events and for open water events. The peak ice jam stage can occur at a different time than the maximum discharge rate. Graphical frequency analysis may be used to develop the stage-frequency distribution.

A frequency analysis of historical data requires the following:

- Many years of observed levels at an ice jam site;
- An ice regime that has been statistically stationary;
- An examination of ice jam flood stages and the flood prone area; and
- On-site investigations and interviews.

A methodology is presented in the paper entitled "Probability Analysis of Historical Flood Data" by Gerard and Karpuk to determine a stage-frequency distribution using historical ice jam stages. The Gerard and Karpuk methodology is presented in the MNR Flooding Hazard Limit document (2002).

### Determining a Stage-Frequency Distribution Using Synthetic Ice Jam Stages

The study report should document the stage-frequency distribution analysis and the synthetic data used in the analysis. A stage-frequency distribution for ice jams must be developed using synthetic data when there is insufficient historical data or the historical data is not statistically stationary. A methodology presented in "Ice Related Flood Frequency Analysis: Application of Analytical Estimates" by Gerard and Calkins may be used for determining a stage-frequency distribution for ice jams.

The study report will document the development of a stage-frequency distribution for open water, for a solid ice cover, and for an ice jam cover in equilibrium. The stage-frequency distribution curve would represent a minimum ice-affected stage while the stage-frequency curve for an ice jam in equilibrium would represent the maximum stage possible for a given discharge.

Discharge data used in the analysis may have to be transposed from gauge data elsewhere along the river course or from computer simulation models. Ice jam stages may have to be developed using computer simulation modeling (HEC-RAS, RIVJAM, etc.) and confirmed with observed ice jam stages. Considerable judgement is required when estimating stages for ice

cover conditions and for ice jam conditions. Information required includes estimates of ice thickness, ice cover or ice jam roughness, position of the jam's toe and head, and the upstream length contributing ice to a jam.

The final ice jam stage-frequency distribution is the highest stage resulting from a combination of the solid cover distribution curve and the ice jam distribution curve. The final distribution is largely a matter of engineering judgement.

### Develop A Maximum Stage-Frequency Distribution

Once the ice jam stage-frequency distribution has been determined, it must be combined with the open water stage-frequency distribution. The combined maximum stage-frequency distribution will allow the abstraction of flood stages for various return periods.

## 4.8 Study Report and Deliverables

### Study Report

- The study report should allow third parties to reproduce the model study including its results; and
- The study report must document the program utilized to conduct the computations, the source and method of measuring cross-section data; the source and method of measuring hydraulic structures; and the method of estimating loss parameters and starting water-surface elevations.

The study report must include the following:

- List of technical persons with qualifications that worked on the project;
- PEO seal, signature, and date of the professional engineers who prepared or supervised the preparation of the input data and checked the output data;
- A statement on the appropriateness of the model to provide the information required for the hydraulic program; and
- A section on model limitations.

### Tables

- Table - Design flows and water surface elevations for the Regional, 100, 50, 25, 10, 5 and 2-year return period floods. Design flows and water surface elevations must be determined for existing and future land use conditions;
- Table - starting water surface elevations;
- Table - results of calibration;
- Table - of initial hydraulic parameters and calibrated hydraulic parameters;
- Table - observed flow hydrographs and water level profiles used in the calibration;
- Table summarizing spill locations and associated details;
- Table - results of the sensitivity analysis; and
- Table - comparing the immediate previous study water surface elevations with the current study water surface elevations.

### Figures

- Figure - a topographic map showing the watershed and sub-watershed boundaries, flood plain mapping study limits and flood plain map sheet location;
- Figure - water surface profiles of all design floods;
- Plots of field measured representative low flow sections of each reach;

## TECHNICAL GUIDELINES FOR FLOOD HAZARD MAPPING

- Plots of all cross-sections and road profiles with crossings;
- Photographs of channel and floodplain at several representative locations;
- Plots of surveyed profiles across each hydraulic structure (road/rail crossing, dam, etc.);
- Copies of all bridge/culvert drawings used to develop the hydraulic model;
- Photographs of all hydraulic structures including bridges, dams, weirs, etc.; and
- Schematic plot with names of the main branch and tributaries in the HEC-RAS model.

### Deliverables

- Electronic copies of model input and output data;
- Electronic copies of all calibration input and output data;
- Electronic copies of all sensitivity input and output data; and
- Electronic copies of all Check-RAS output files.



#### 4.9 Hydraulic Standard Parameters

Standard parameters are shown in Table 4.1. The parameters should be used for un-calibrated models. If the engineer feels that the Standard Parameters should be modified, the engineer should provide documentation to the Conservation Authority providing justification. For calibrated models, the parameters must be within the range shown in each of the tables.

A sensitivity analysis should be conducted for each computer program to determine the sensitive input parameters.

**Table 4.1 - Hydraulic Standard Parameters**

**Table 4.1.1 – Loss Coefficients**

Weir Flow Coefficients	'C' Standard	Calibration Range	
		Minimum	Maximum
Broad Crested i.e. Road Embankment	1.5	1.4	1.7
Sharp Crested	1.6	1.4	1.8

A sharp crested weir coefficient should be used when there is air underneath the nappe. Such conditions would exist for a stormwater management pond weir outlet. A broad crested weir assumes the nappe is supported. An example of a broad crested weir would be a road crossing. Generally, when the ratio of flow depth divided by the weir thickness is greater than 0.5 a sharp crested weir coefficient should be used. When the ratio is less than 0.5 the broad crested weir coefficient should be used.

Orifice Coefficient	'C' Standard	Calibration Range	
		Minimum	Maximum
Orifice Coefficient	0.66	0.62	0.78
Expansion/Contraction Coefficients	Standard Parameters		
	Contraction	Expansion	
Gradual Transitions	0.1	0.3	
Bridges/Culverts	0.3	0.5	
Abrupt Transitions	0.6	0.8	

Table 4.1 - Hydraulic Standard Parameters...continued

**Table 4.1.2 - Manning Roughness Coefficients**

Conduit	'n' Standard	Calibration Range	
		Minimum	Maximum
Concrete	0.013	0.011	0.015
Brick	0.015	0.013	0.017
Plastic	0.013	0.011	0.015
Iron	0.013	0.011	0.015
Corrugated Steel Pipe - 3"x1"	0.024	0.021	0.027
Structural Plate Corrugated Steel Pipe - 6"x2"	0.032	0.026	0.036
<b>Open Channel</b>			
	'n' Standard	Calibration Range	
		Minimum	Maximum
<b>Overbank</b>			
Woods	0.080	0.040	0.120
Meadows	0.055	0.035	0.070
Lawns	0.045	0.030	0.055
<b>Channel</b>			
Natural	0.035	0.025	0.045
Grass	0.030	0.025	0.035
Natural Rock	0.035	0.025	0.045
Armour Stone	0.025	0.017	0.030
Concrete	0.015	0.011	0.017
Articulated Block	0.020	0.019	0.032
Gabions	0.025	0.020	0.030
Wood	0.012	0.011	0.013

## 4.10 References

Information used in Section 4 has been abstracted from the following documents:

- Appendix C: Guidance for Riverine Flooding Analyses and Mapping, Guidelines and Specifications for Flood Hazard Mapping Partners, US FEMA, November 2009
- Open Channel Hydraulics  
by Ven Te Chow, McGraw-Hill Book Company, 1959
- Chapter 10 Ice Jam Floods  
Hydrology of Floods in Canada, A Guide to Planning and Design, W.E. Watt, et. al. National Research Council of Canada, 1989
- Technical Guide, River & Stream Systems: Flooding Hazard Limit  
Ontario Ministry of Natural Resources,  
2002
- Guidance for Ice-Jam Flooding Analyses and Mapping  
Guidelines and Specifications for Flood Hazard Mapping Partners, Federal Emergency Management Agency (FEMA)  
April 2003
- Probability Analysis of Historical Flood Data  
R. Gerard and E.W. Karpuk, Journal of the Hydraulics Division, A.S.C.E., pp. 1153-1165.  
1979
- Ice Related Flood Frequency Analysis: Application of Analytical Estimates  
R. Gerard and D.J. Calkins  
Proceedings Cold Regions Engineering Specialty Conference, CSCE, Montreal.  
1984
- River Ice Jams: Theory, Case Studies, and Applications  
S. Beltaos, Journal of Hydraulic Engineering, American Society of Civil Engineers,  
Vol. 109, No. 10, pp. 1338-1359.  
1983

## 5.0 FLOOD HAZARD MAPS

### 5.1 General

Section 5 provides guidance for displaying and communicating flood risk information including flood hazard limits, water surface elevations, flood depths, flood velocities, and the product of flood depth times flood velocity.

Flood hazard maps identify cultural information, topographic information, and flood risk information. Traditionally, flood hazard maps show cultural information that can be shown on ortho-photographs or line drawings. Topographic information is added to the cultural information along with the flood risk information.

Flood hazard maps can be composed of ortho-photographs combined with a grid of cells representing flood characteristics. Gridded information can be categorized with colours to more easily communicate flood risk information.

Section 5 is comprised of the following sections:

Map Sheet Layout and Contents	Section 5.2
Flood Risk Information	Section 5.3
References	Section 5.4

## 5.2 Map Sheet Layout and Contents

A sample map sheet layout is shown on Figure 5-1. For this sample, the trimmed map sheet size is 1067 mm x 762 mm (42 inches by 30 inches) although other sizes are acceptable. The map border size is 1025 mm X 710 mm. The map sheet is composed of a series of information blocks. The map sheet includes the following blocks:

- Base Map/Photo & Flood Risk Information Block
- Base Map Author & Stamp Block
- Flood Risk Author & Stamp Block
- Legend Block
- North Arrow & Datum Block
- Scale & Contour Interval Block
- Map Sheet Index Block
- Client Logo Block
- Title Block
- Sheet Number Block

The following describes each of the information blocks:

Base Map/Photo & Flood Risk Information Block - will contain an ortho-photograph or a line drawing showing cultural information, flood risk information, and topographic information. If gridded information is presented, topographic information may be omitted. The base map block (Figure 5-1) will show the location of the following:

- Location of all benchmarks and monuments;
- Location of all streamflow gauges and climate stations;
- Street names, park names, cultural information, etc.;
- Political boundaries; i.e., cities, municipalities, townships, counties, etc.;
- Watercourse name and flow arrow;
- Name of major water control structures;
- Cross section and cross section labels;
- Water surface elevation at each cross section;
- Gridded flood characteristic name and colour ramp categories;
- Upstream and downstream study limits and mapping limits;
- Match lines for overlapping map sheets; and
- Topographic information.

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Base Map Author & Stamp Block - will identify the author or organization that developed the base map showing the cultural and topographic information. If appropriate the block will contain an author's stamp. The block will contain the date of the data used to derive the mapping.

Flood Risk Author & Stamp Block - will identify the author or organization conducting the flood risk map study and the PEO seal, signature, and date of the professional engineers who prepared or supervised the preparation of the flood risk map.

Legend Block - will contain all annotations used on the base map.

North Arrow & Datum Block - will contain a north arrow and the horizontal and vertical datum used to develop the base map and the flood risk information.

Scale & Contour Interval Block - will contain a scale for metric units. In addition, the block will contain the contour interval used for the topographic information along with the interpolated contour interval. A 1:2000 scale is commonly used.

Map Sheet Index Block - will identify the location and number of all map sheets for the study area, and will show the location of the current sheet. In addition, the index will identify the major transportation features to aid in identifying the location of the current sheet.

Client Logo Block - the clients name, address information, and logo will be contained within this block.

Title Block - The title block will contain the watercourse name and a brief description of the study limits or the limit of the hydraulic profiles.

Sheet Number Block - will contain the sheet number and the total number of sheets for the Study area.

## 5.3 Flood Risk Information

### 5.3.1 Flood Hazard Information

The following information will be added to each flood hazard map:

- Flood hazard limit (Hurricane Hazel or Timmins);
- 100-year floodline;
- Cross sections used in the hydraulic model;
- Water surface elevations (Hurricane Hazel or Timmins and 100 year Storms) at each cross section; and
- Notes on annotating flood hazard limits, cross sections, and text are shown on Figure 5-2 and on the following pages.

Floodlines should be used to define flood hazard limits. Gridded flood risk maps can be used to present flood risk information (water surface elevations, flood depths, flood velocities, etc.) to the general public.

If hydraulic characteristics of a flood plain require a 2-D model, then the results of the 2-D model should be used to develop floodlines for the flood hazard limit. A gridded map can be used to convey flood risk information to the public.

In some situations the results of the hydraulic modelling may not be appropriate to define flood hazard areas. For instance, most hydraulic programs do not model rapidly varied flow. In those situations, flood elevations should not be shown on the flood risk maps and floodlines should be shown as dashed lines. A note should be added to the maps indicating more detailed analysis is required to define the flood hazard areas. Other situations are where the results of the hydraulic modelling may not be appropriate is where the watercourse is under active and significant erosion.

### Floodline Notes

- All cross sections in the hydraulic model must be shown on the Flood Hazard Maps. Two types of cross sections can be shown: major and minor;
- Major cross sections are shown with a large circle with water surface elevations, and a cross section label;
- Minor cross sections are shown with a small circle;
- The flood hazard limit (Hurricane Hazel or Timmins Storm or the 100 year floodlines) must be plotted on all maps and ;
- The flood hazard limits or floodlines that intersect a building must be drawn to include the entire building and not drawn along the side of the building facing the watercourse;
- Two floodlines must not intersect;
- Flood hazard limits or floodlines must join at the edge of sheets and match on adjacent sheets. Do not overlap information on different sheets;
- Flood hazard limits or floodlines must be continuous across the sheet;
- Flood hazard limits or floodlines must only cross a contour line once. Flood hazard limits or floodlines must parallel contour lines in all other locations;
- Flood hazard limits or floodlines at the cross section must have the same label as in the hydraulic model;
- Flood hazard limits or floodlines at the cross section must have the same elevation as the label; and
- Flood hazard limits or floodlines, cross section labels, water surface elevations must be identical to the legend.

### Cross Section Notes

- Crossings are represented by two small circles with a line over the road profile;
- 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;
- All cross section endpoints must be outside the flood plain. All cross section map lengths must match the lengths in the hydraulic model;
- A white background must be used on cross section labels to improve readability;
- The flood hazard limits or floodlines or cross sections must not be shown beyond mapping sheet match lines or study limits;
- Cross sections that overlap two sheets must have a label on both sheets;
- Hurricane Hazel or Timmins Storm and the 100 year flood elevation must be shown in circles at the end of the cross section labels;
- Each cross section will be labelled with the cross section number in the hydraulic model;



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- Labels must be placed on one side of the map in an ascending order; and
- Tic marks must be located at both ends of the cross section to denote the start and end of each cross section.

### Text Notes

- Study Limits at upstream and downstream boundaries of the flood profiles;
- Mark minor watercourses with a Study Limit;
- Starting and ending chainage should be located where the watercourse enters and leaves the mapping sheet;
- Notes where topographic mapping does not match surveyed data;
- Street names adjacent to watercourse; and
- Spills - open floodline with a large arrow and marked SPILL. Spill locations must be approved by the Conservation Authority.

### 5.3.2 Gridded Flood Risk Information

Floodlines should be used to define flood hazard limits. A grid of cells can be used to communicate flood risk information to the public. Each cell can represent a magnitude of a flooding characteristic. Only one characteristic would be shown on a single map sheet. Each cell can have geographic coordinates. The grid would define geographic space with an array of square cells arranged in rows and columns. A grid of cells can more easily communicate flood risk information to the public than traditional floodline maps.

Typical flood characteristics for a gridded map include the following:

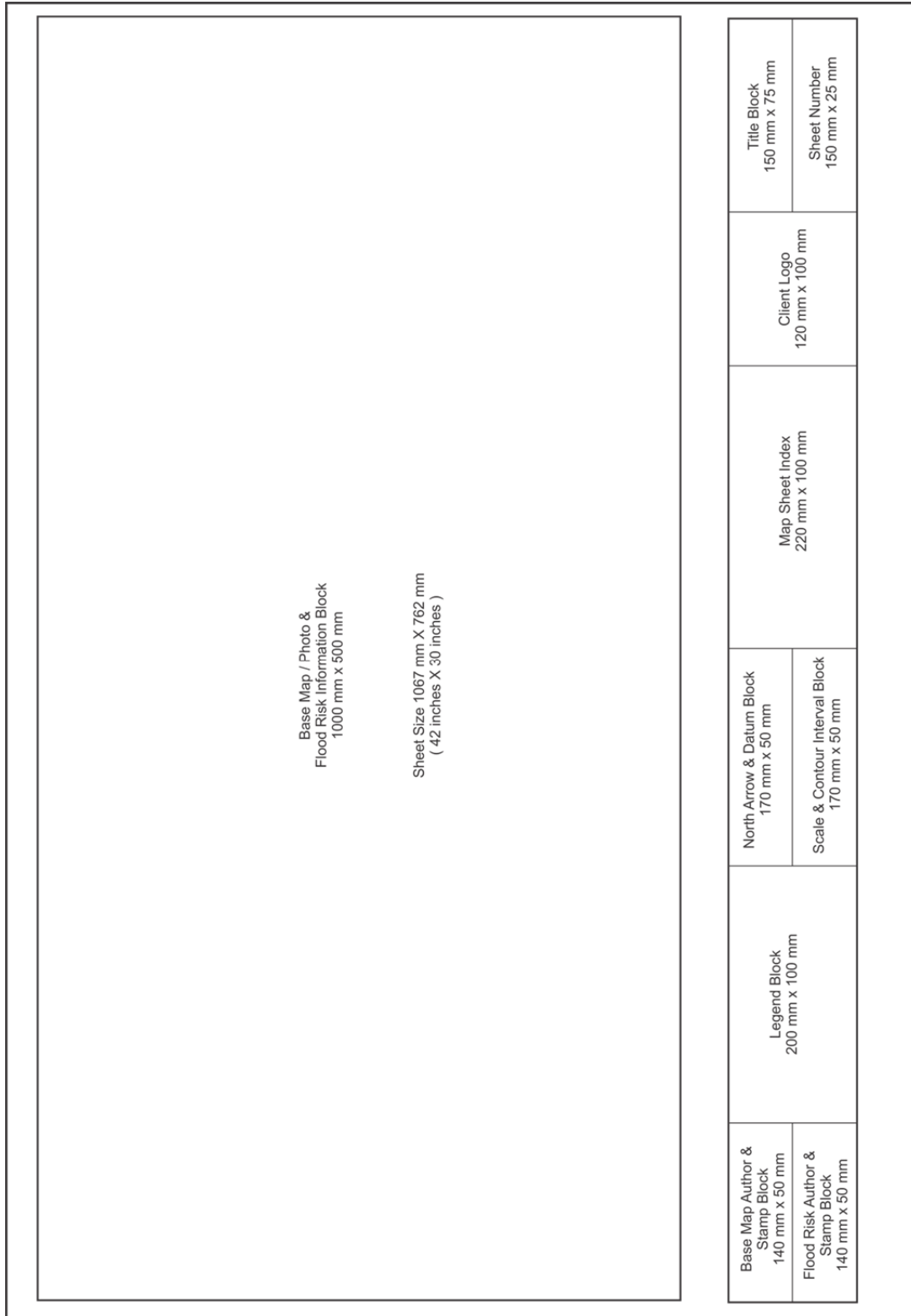
- Water Surface Elevation;
- Flood Depth;
- Velocity and Direction; and
- Flood Severity - the product of depth and velocity.

Cell Size - each flood characteristic cell size should be based on the cell size of the ground elevation data.

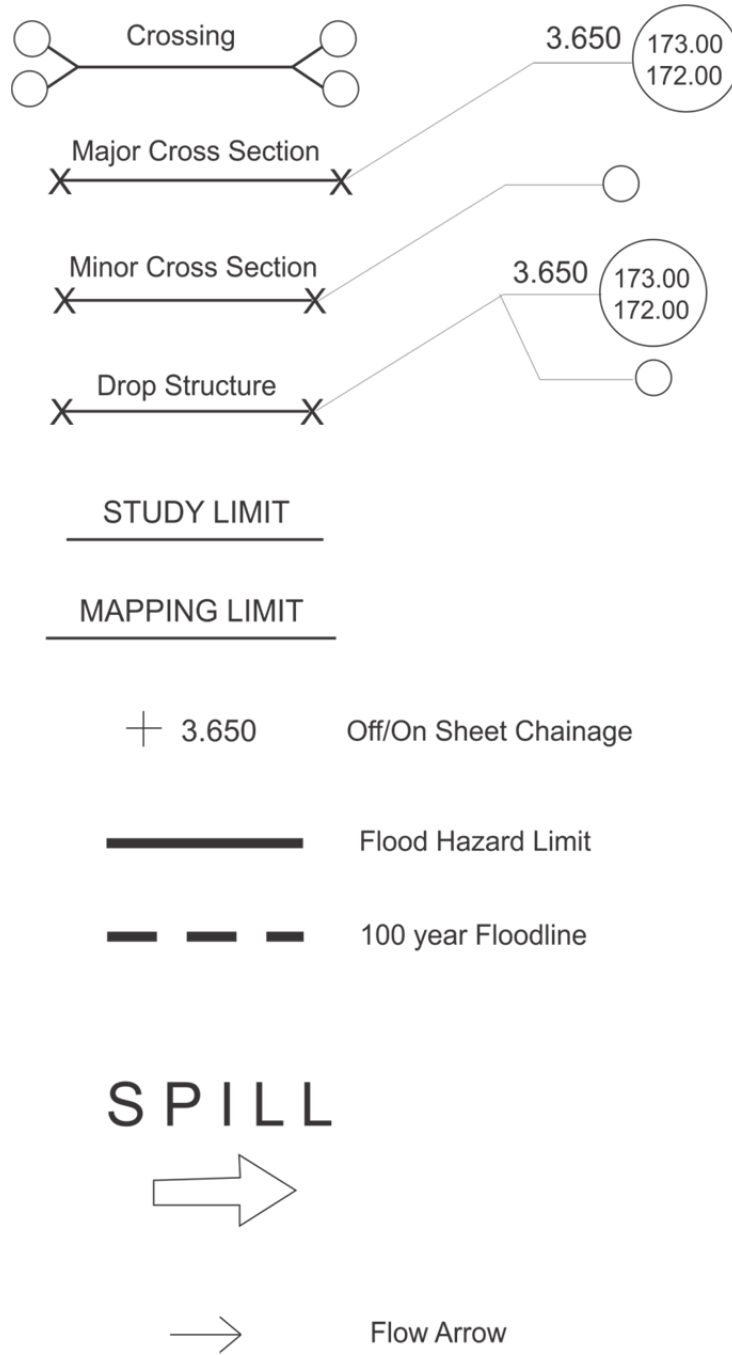
Grid Origin - all flood characteristic grids should have the same origin, extent, and coordinate system. This allows for comparison and manipulation of cell values for characteristics of flood depth and flood velocity.

Results from both 1-D and 2-D hydraulic models can be displayed as gridded values. 2-D models are developed using DEMs or gridded elevation data. Results from 1-D models, such as HEC-RAS, can be displayed in a grid using a GIS program, a TIN (Triangulated Irregular Network) and water surface elevations at each cross section.

Figure 5-1 Sample Flood Hazard Map Sheet Layout



**Figure 5-2 Typical Flood Hazard Map Sheet Annotations**



**Note:** Spills are floodwaters that leave a defined watercourse and spill overland. Spills can re-enter the watercourse at a downstream point or flow overland to another watercourse.

## 5.4 References

Information used in Section 5 has been abstracted from the following documents:

- Appendix K: Format and Specifications for Flood Insurance Rates Maps, Guidelines and Specifications for Flood Hazard Mapping Partners  
FEMA (Federal Emergency Management Agency)  
April 2003
- Flood Depth and Analysis Grids,  
Guidance for Flood Risk Analysis and Mapping  
FEMA (Federal Emergency Management Agency)  
May 2014

## 6.0 FLOOD HAZARD MAP UPDATES

### 6.1 General

Flood hazard maps may need to be updated for many reasons including the following:

- More accurate terrain information is available;
- If a frequency analysis was used to determine flow rates, then the frequency analysis may need to be updated when there are additional streamflow data;
- If a hydrologic model is used to determine flow rates, then the model may need to be updated when there are more flow events for the calibration/validation process;
- If there has been a significant change to the hydrologic and hydraulic flow regimes. Examples include encroachment, new dams, removal of flood control structures, stormwater ponds, new crossings, land use changes, stream rehabilitation, revised operating procedures, etc. Existing data files should be run with the model updates, and if necessary the flood risk maps should be updated;
- To correct errors in previous modelling; and
- Hydrologic and hydraulic computer programs used in the original flood hazard map study have been upgraded.

An investigation must be conducted in-conjunction with Official Plan reviews to determine if flood hazard maps need to be updated. Currently Official Plan reviews are conducted every five years. Flood hazard map updates should be conducted to inform the land use planning process rather than in reaction to the land use planning process.

For some Authorities there may be a need to replace a few maps, but not all maps in a series. In these cases, replacement flood hazard maps must be edge matched with existing flood hazard maps not being replaced.

A new study should be commissioned to update floodlines within a flood hazard map. The new flood hazard map sheet should incorporate the PEO seal, signature, and date of the professional engineers who prepared or supervised the preparation of the input data and checked the output data for the flood hazard map. It is not recommended to update the original flood hazard map unless the original authoring engineer is conducting the update.

Hydrologic and hydraulic analyses required to update flood hazard maps must, when feasible, be conducted with the methodology that was used to develop the original flood hazard maps. If the methodology is not available or it's use is inappropriate, the reasons why the methodology cannot be used must be documented along with the reasons why the proposed methodology is appropriate.

## 6.2 Estimated Flood Hazard Mapping

Estimated flood hazard mapping must be updated to engineered flood hazard mapping to support a development application that is within or near estimated flood hazard limits. Estimated flood hazard mapping has been developed by Conservation Authorities where engineered flood hazard mapping does not exist. Estimated flood hazard maps are not prepared to the same level of detail as engineered flood hazard maps that are described in this Technical Guideline document. The level of detail pertains to topographic information, hydrology, and hydraulics.

The Conservation Authority should be contacted before updating estimated flood hazard mapping.





