Preliminary Flood Hazard Assessment at the Ignace Study Area

NWMO-TR-2021-26 December 2021

Andres Rodriguez, Rikke Brown

AECOM Canada Ltd.

NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Nuclear Waste Management Organization
22 St. Clair Avenue East, 4th Floor
Toronto, Ontario
M4T 2S3
Canada

Tel: 416-934-9814
Web: www.nwmo.ca

Preliminary Flood Hazard Assessment for Ignace Study Area

NWMO-TR-2021-26

December 2021

Andres Rodriguez, Rikke Brown, AECOM Canada Ltd.

Document History

Title:	Preliminary Flood Hazard Assessment for Ignace Study Area		
Report Number:	NWMO-TR-2021-26 AECOM: 60645233-436-01		
Revision:	R000	Date:	December 2021
AECOM Canada Ltd.			
Authored by:	Andres Rodriguez, P.Eng., Rikke Brown, P.Eng.		
Verified by:	Brian Richert, P.Eng.		
Approved by:	Pippy Warburton, P.Eng. and Doug Bellomo P.E.		
Nuclear Waste Management Organization			
Reviewed by:	J. Chen, M. Ion, K, Birch		
Accepted by:	P. Gierszewski		

Revision Summary		
Revision Number	**Date**	**Description of Changes/Improvements**
R000	2021-12	Initial Issue

EXECUTIVE SUMMARY

Title: **Preliminary Flood Hazard Assessment for Ignace Study Area**

Report No.: **NWMO-TR-2021-26**
Author(s): Andres Rodriguez, P.Eng., Rikke Brown, P.Eng., Pippy Warburton, P.Eng., Doug Bellomo, P.E.
Company: AECOM Canada Ltd.
Date: December 2021

Abstract

A nuclear waste management facility is being considered near the Town of Ignace, for the long-term containment and isolation of used nuclear fuel. The proposed facility is an underground Deep Geological Repository (DGR) and includes access roads and various surface facilities.

The Revell Site is within the Ignace study area, located approximately 45 km west of the Town of Ignace, Ontario, and just south of Highway 17. The property is bounded to the north by Highway 17, to the west and south by Mennin River and Mennin Lake, and to the east by forested land and wetlands which extend towards Highway 622.

It was found that the Revell Site and surrounding area are included within four watershed or catchment areas, based on preliminary catchment delineations completed using the Ontario Flow Assessment Tool (OFAT) and then refined using GIS software with the available LiDAR data. Three of these catchments drain towards the south into Mennin Lake, while the remaining catchment drains north towards Highway 17.

A qualitative assessment was first completed as part of the preliminary assessment of flooding hazards for the Revell Site. This qualitative assessment is based on the guidelines provided in the IAEA Safety Standards entitled *Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations* (IAEA 2011).

The qualitative analysis indicated that flooding hazards due to extreme precipitation events required further consideration. However other hydrological hazards such as storm surges, wind generated waves, tsunamis, seiches, bores and mechanically induced waves, and high groundwater levels, were determined to have minimal effects with respect to surface flooding within the site.

Flooding was then quantitatively assessed for two conditions: direct rainfall on site, and rainfall on the upstream catchments. The qualitative analysis noted that due to the site topography, extreme precipitation events should be applied without reduction factors, and the catchment response to precipitation is expected to be fast with rainfall in the upper part of the catchment moving to the outfall point relatively quickly.

A hydrologic model of the Revell Site was developed for this assessment with the software HEC-HMS. The results of the hydrologic model indicated that the SCS-Type II rainfall distribution creates the highest peak flows for all catchments. The SCS Type II distribution with a duration of 24 hours was applied to the probable maximum precipitation (PMP) value reported by Ontario Ministry of Natural Resources (OMNR 2006) since this is the highest precipitation value (436 mm) for the Ignace study area, as reported in the report entitled *Climate Change Impacts on Climate Variables for a Deep Geological Repository (Ignace Study Area)* by Golder (2020).

A total of 14 scenarios were included in this preliminary flood hazard assessment. These scenarios are divided by period (current, mid-century, and end-of-century), climate change scenario (three PMP risk projections) and by type of flood (direct rainfall on-site and rainfall on upstream catchments).

A hydraulic model was created, with the software HEC-RAS, to transform assumed extreme precipitation amounts into surface runoff depth at the Revell Site. The results of the model for all 14 scenarios show areas where surface ponding occurs as well as the floodplain boundaries of streams within the site. This ponding is based on the current topography developed from the LiDAR data.

These preliminary results do not consider grading or ditches. As the detailed design progresses for the proposed facilities at the Revell Site, it is expected that site grading will modify the current floodplain delineations. In addition, it is also expected that site stormwater management (SWM) measures such as ditches will further mitigate surface flooding impacts within the site. In general, the proposed site is mostly located at the boundary of two catchment areas near their headwater areas, which makes it less sensitive to extreme precipitation. This is partly because of elevation differences between the upstream areas and the outlet of each catchment, and because there is limited area that contributes to runoff at these upstream areas, therefore minimizing the potential impacts of precipitation.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

1. INTRODUCTION

The Nuclear Waste Management Organization (NWMO) has retained AECOM Canada Ltd. (AECOM) to carry out preliminary flood hazard assessments at two study sites located in Ontario, near the Township of Ignace and the Municipality of South Bruce, respectively. Both locations are within the province of Ontario.

These sites are being considered for the development of a Deep Geological Repository (DGR) for the long-term containment and isolation of used nuclear fuel in Canada. The DGR facility would consist of various surface facilities and an underground repository. The repository would be located at an approximate depth of 500 m in the host rock.

The intent of this assignment is to carry out a preliminary flood hazard assessment at each study site.

A qualitative flood hazard assessment was first completed. This qualitative assessment is based on the guidelines provided in the IAEA Safety Standards entitled *Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations* (IAEA 2011).

Flooding was then quantitatively assessed for two conditions: direct rainfall on-site and upstream watershed flooding.

To support the preliminary flood hazard assessments, NWMO has previously commissioned independent studies to determine the probable maximum precipitation (PMP), Intensity-Duration-Frequency (IDF) curves, and snowpack accumulation projections for both sites considering current and future climate conditions. Results for the Ignace study area are presented in the report entitled *Climate Change Impacts on Climate Variables for a Deep Geological Repository (Ignace Study Area)* by Golder (2020).

The design of the DGR stormwater management system and the placement of the DGR surface facilities and shafts within potential siting areas must consider the range of credible storms for the watershed. The assessment will use the estimated PMP, IDF and snowpack accumulation values provided by the independent case studies and will be completed in two phases.

This report presents our results for the Revell Site within the Ignace study area. A separate report addresses the South Bruce Site.

1.1 Overview of Analysis Approach

The steps that were carried out to complete this preliminary flood hazard assessment at the Revell Site are summarized in Figure 1. A total of 12 steps were defined and they include, in logical order, the tasks that were completed to obtain floodplain boundaries for the proposed assessment scenarios.

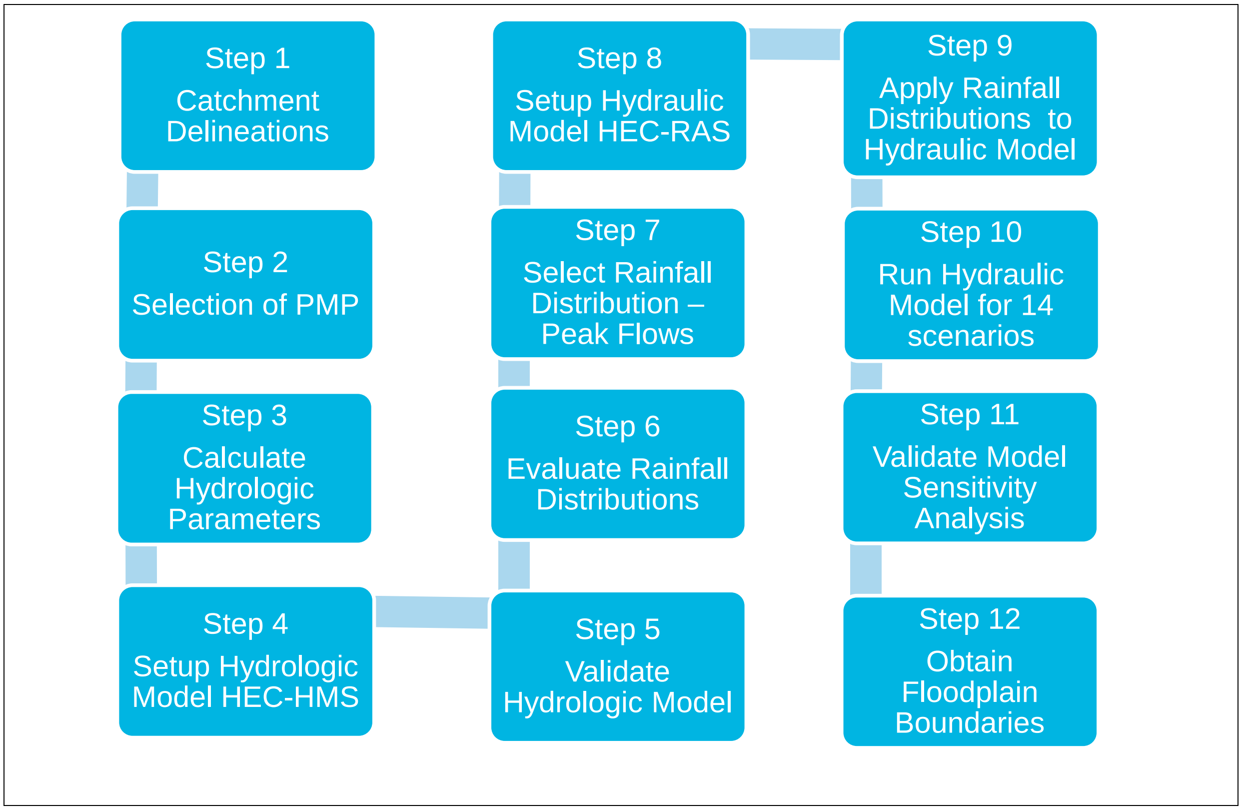

Figure 1. Steps for Flood Hazard Assessment Procedure

A brief explanation of each step is provided below, while further details for each step are provided in other sections of this report.

Step 1: Catchment Delineations

Catchment areas or watersheds are defined by surface topography. Catchment delineations were completed for the Revell Site to define the boundaries where rainfall is collected and flows towards each catchment outlet. This is the initial step to calculate peak flows which are needed to define floodplain boundaries.

Step 2: Selection of PMP

The selection of the probable maximum precipitation (PMP) was based on the results provided by Golder (2020) for the Revell Site. The PMP defines the maximum rainfall input that is feasible to occur at the Site for a given duration. A rainfall volume can be calculated for each catchment, where the PMP is defined as a total precipitation amount in mm for a given duration and each catchment has a surface area in square metres.

The distribution of rainfall over time is also important. The selection of the PMP is an iterative process where different rainfall distributions are applied to a hydrologic model, and the highest peak flow calculated by the model defines the most critical rainfall distribution.

Step 3: Calculate Hydrologic Parameters

A hydrologic model using the software HEC-HMS was used to calculate peak flow runoff values for each catchment for the selected PMP values. The hydrologic model requires the input of parameters such as time of concentration, surface infiltration coefficients, and impervious areas, to calculate excess precipitation that is transformed into runoff.

Step 4: Setup the Hydrologic Model in HEC-HMS

The hydrologic model was developed based on the previous steps to calculate peak flows, runoff volumes, and excess precipitation. The results of the hydrologic model were used in subsequent steps to define floodplain boundaries.

Step 5: Validate Hydrologic Model

Considering that long-term flow monitoring data at the Revell Site is not available, the validation of the HEC-HMS hydrologic model was completed by comparing the results with the Modified Index Flood Method (MIFM). This method relies on a regional frequency analysis of annually recorded maximum peak flow rates and provides values for a series of Annual Exceedance Probabilities (i.e., peak flows for different return periods).

Step 6: Evaluate Rainfall Distributions

Once it is considered that the hydrologic model is representative of site conditions, the PMP values (which define an amount of rainfall for a given duration) were applied to the hydrologic model using different rainfall distributions (which define how rainfall amounts are distributed over time).

Step 7: Select Rainfall Distribution – Peak Flows

The results of Step 6 were analyzed to select the rainfall distribution that creates the highest peak flow for each catchment. This rainfall distribution was carried forward for hydraulic analysis at the Revell Site.

Step 8: Setup Hydraulic Model in HEC-RAS

Once the selection of the critical rainfall distribution was completed, a hydraulic model of all catchments was developed with the software HEC-RAS. The model requires parameters to represent the characteristics of each catchment to create a geometry file that is used for hydraulic routing, as well as boundary conditions and control specifications that define each scenario.

Step 9: Apply Rainfall Distributions to Hydraulic Model

Once the hydraulic model setup is completed, the selected rainfall distributions from Step 7 were added to the hydraulic model. The excess rainfall amounts were applied to the HEC-RAS model which in turn calculates the runoff conveyance and flow accumulation for each catchment. The hydraulic model also calculated the floodplain boundaries for both rainfall on-site and rainfall on upstream areas.

Step 10: Run Hydraulic Model for 14 Scenarios

The hydraulic model was used to analyze the 14 scenarios that were defined for this preliminary flood hazard assessment.

Step 11: Validate Model and Sensitivity Analysis

The hydrologic and hydraulic models were further reviewed to determine the sensitivity of main parameters and the impact of changing them in the results. This task is completed to understand the numerical properties of the models and how different parameters may affect model results.

Step 12: Obtain Floodplain Boundaries

The last step is to export the results that show the floodplain boundaries from the hydraulic model for all 14 scenarios. The model boundaries were mapped and presented in this report.

2. PHYSICAL SETTING

The physical setting of the Revell Site includes relevant characteristics that can affect regional and local drainage. In turn, these characteristics can influence the hydrologic cycle and processes which define the amount and distribution of excess runoff over time, and therefore have an impact on the resultant overland flood events. Further details of the physical setting of the site and the watersheds where it is located are presented in the following sections.

2.1 Site Location and Features

The Revell Site approximate location is 45 km west of the Town of Ignace and just south of Highway 17. The property has a total area of 1925 hectares and is located within a catchment that drains south into Mennin Lake and Mennin River. The property is bounded to the north by Highway 17, to the west and south by Mennin River and Mennin Lake, and to the east by forested land and wetlands which extend towards Highway 622. The property boundary is shown in Figure 2. The relative location of the Site within the Province of Ontario is also shown in this figure.

The design of the facility is in progress; and therefore Figure 2 shows a possible location for the surface facilities and the excavated rock management area.

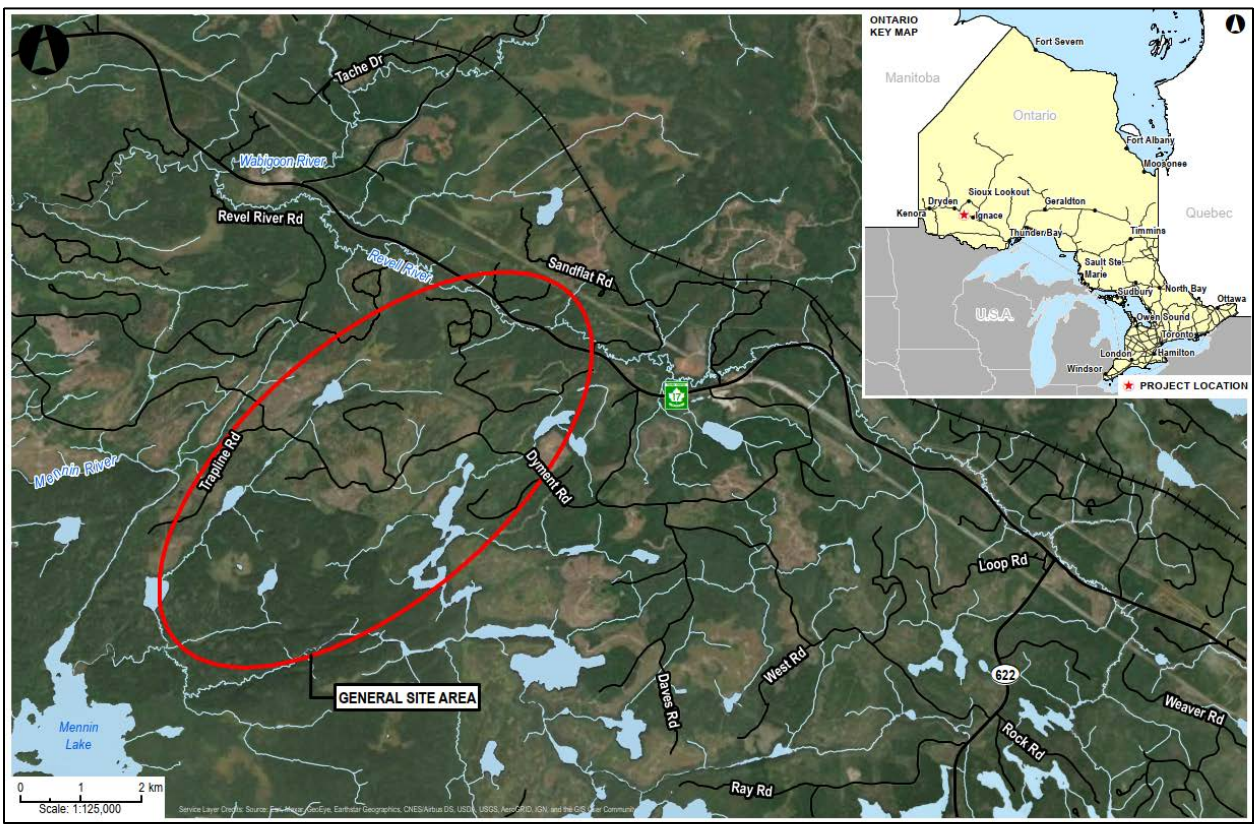

Figure 2: Revell Site Location

The available aerial imagery (ESRI 2020) shows clear evidence of extensive logging activities and a network of access roads in the area where the Site is located; however, no further development or infrastructure has been identified.

A large portion of the property towards the north has been cleared and only small patches of forested land remain. The logging operations will ultimately change the response of the land to hydrologic inputs, mainly due to a change in land cover which affects the retention of rainfall (i.e., infiltration and evapotranspiration amounts) as well as times of concentration due to an increase in overland sheet flow velocities.

In contrast, the south portion of the property is mostly covered by forested and wetland areas and include catchment outlets towards Mennin Lake.

2.2 Catchment Areas

Preliminary catchment delineations were completed using the Ontario Flow Assessment Tool (OFAT). OFAT provides an online automated portal based on the Ontario Hydro Network and the provincial Digital Elevation model to delineate catchments with a horizontal resolution of 30 m by 30 m. OFAT can also calculate catchment parameters including the percentage of land cover from the Ontario Land Cover Compilation (OLCC ver. 2.0) raster dataset and surface area, slope, terrain elevations, and mean temperature and precipitation amounts.

The preliminary catchment delineations were then refined using GIS software with the LiDAR data provided by NWMO for the streams that are located within the Ignace study site. Four catchments cover most of the study site, these were labeled CA1 to CA4 and arranged by surface area from larger to smaller. The total area of these catchments and other relevant parameters are included in Table 1**,** while the catchment boundaries are shown in Figure 3.

The general site area predominately covers catchments CA1 and CA2. Catchments CA3 and CA4 were included in the analysis mainly for consistency given that they cover a portion of the site, however, for the purposes of this preliminary assessment, the focus was on catchments CA1 and CA2.

Table 1: Delineated Catchment Areas

Catchment ID	Surface Area (ha)	Drainage Direction	Max/Min Elevation*	Receiving Stream
CA1	1632	East	468/404	Tributary/Mennin Lake
CA2	1198	South	452/390	Mennin River
CA3	110	North	443/410	Revell River
CA4	87	South	448/401	Tributary/Mennin Lake

*Indicated in metres above sea level.

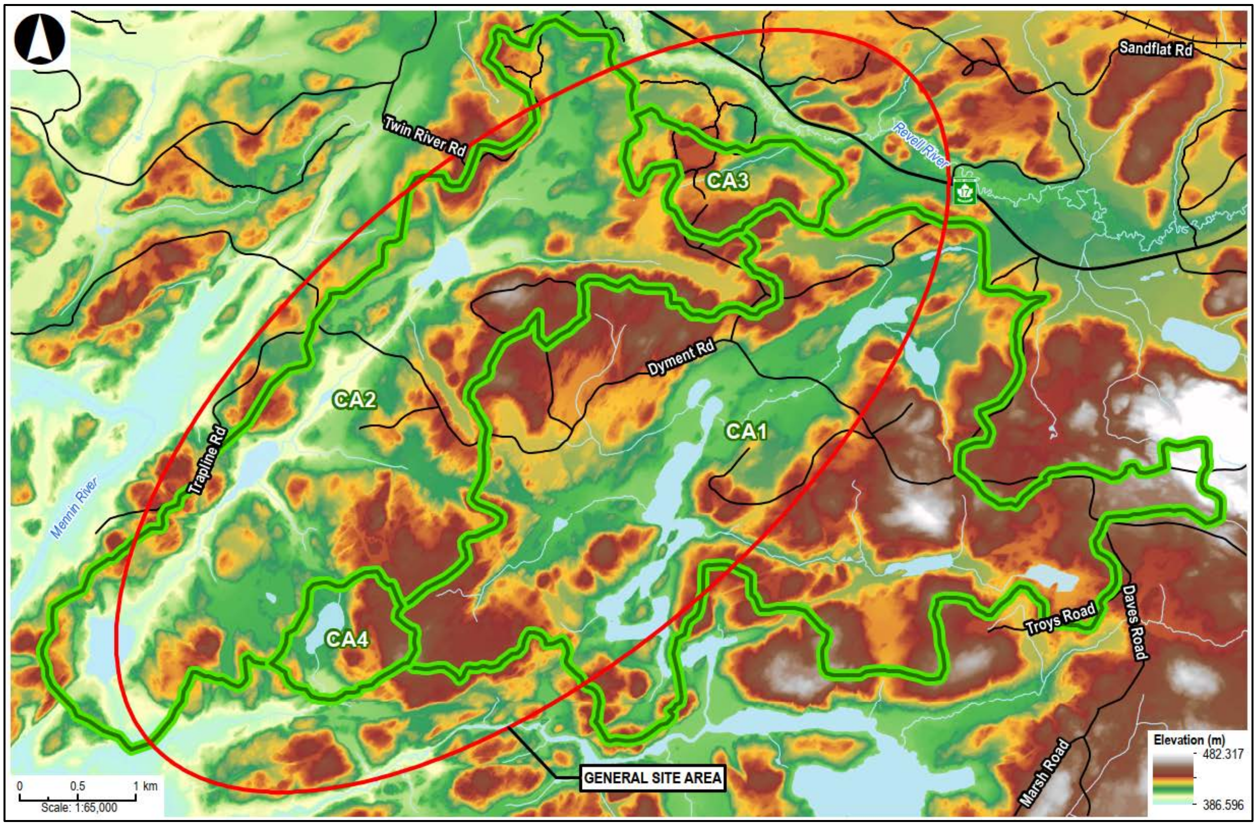

Figure 3: Catchment Areas and DEM at the Revell Site

2.3 Topography

A digital elevation model (DEM) which covers all catchments was generated with the available LiDAR data provided by NWMO. The DEM has a horizontal resolution of 2 m by 2 m and is georeferenced using the plane coordinate grid projection Universal Transverse Mercator NAD1983 - Zone15 North. The LiDAR derived DEM is presented in Figure 3 and was used as the base terrain raster for this assessment.

The topography of the site is dominated by long linear depressions and two predominant hill formations aligned from north to south. These are typical of the area and are characterized as bedrock knobs. Terrain elevations range from 390 m to 450 m above sea level within the Site, where the lowest point can be found in catchment CA2 in the channel that drains towards Mennin Lake at its southern boundary.

The topographic conditions also define the drainage characteristics of the catchments, where sheet flow accumulation becomes concentrated into drainage swales which eventually form watercourses and lakes. From the point of view of potential surface flooding, the location of watercourses, lakes, wetlands, and surface depressions provide the baseline condition where flood hazards are most likely to be identified.

2.4 Drainage Patterns

Overall drainage patterns for all catchments were inferred based on the topography and location of streams, wetlands, and waterbodies. A drainage mosaic has been developed and is shown in Figure 4, with three out of four catchments draining towards Mennin Lake (CA1, CA2, CA4) while catchment CA3 drains north towards Highway 17 and discharges into Revell River.

Furthermore, each catchment area contains a series of mapped streams and lakes with hydrological stream orders that range from 1 to 3. The hydrological stream order is used as an indicator to describe the density of a stream network by increasing the order at confluence points. The simplest stream network is therefore a single stream with order 1, however, its confluence with another tributary stream of order 1 means an increase to order 2, this process is repeated until the outlet is reached. The most complex stream network is found in CA1, followed by CA2, while the remaining catchments are small and only contain a tributary each and have therefore a stream order value of 1.

The available data shows that catchments CA1, CA2 and CA4 have natural flow regimes without regulation from hydraulic structures or other factors such as natural obstructions. This condition will likely change with the construction of an access road to the Site within catchment CA2. Catchment CA3 drains north and its tributary crosses Highway 17 under a hydraulic structure which affects its flow regime. Stream obstructions can cause backwater effects which can extend inside the study area.

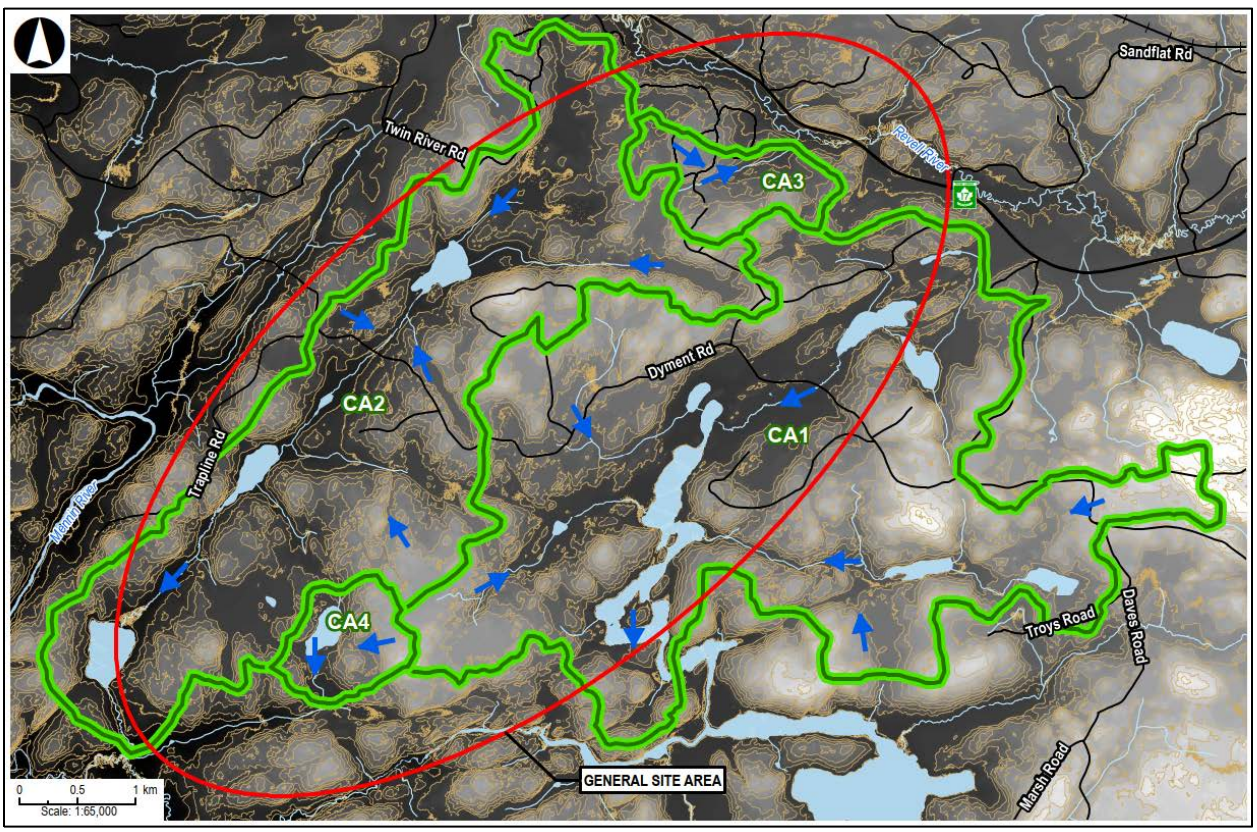

Figure 4: Drainage Mosaic for the Study Site

2.5 Land Cover

Land cover classifications for all catchments were obtained from the Ontario Land Cover Compilation layer (version 2) from the Ministry of Natural Resources and Forestry and are shown in Table 2 as percentages of total area.

The predominant land cover type in all catchment areas is forested land, formed by coniferous, sparse, and mixed trees. Catchments CA1 and CA2 also present smaller percentages of disturbance (i.e., cleared land), open water and wetlands. Disturbance can be inferred as gravel roads and logging activities since there is no other development present. Land cover types are also shown in Figure 5.

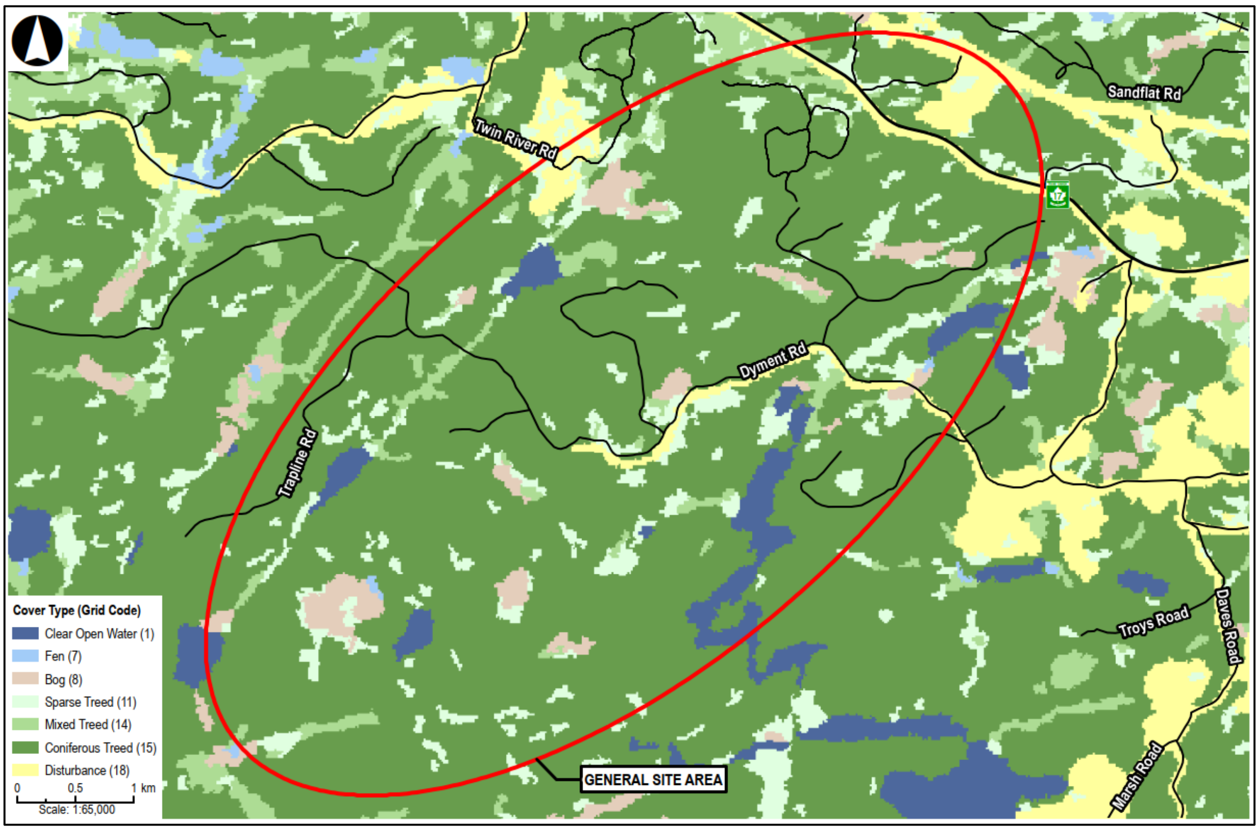

Figure 5: Land Cover Types

Additionally, any present and future logging activities can change land cover types and modify the response of the catchment to precipitation inputs. The calculated land cover percentages in Table 2 were reviewed based on recent aerial imagery that was available to reflect recent changes in land cover (if any).

Table 2: Land Cover Percentages for Each Catchment

Land Cover Type	CA1 (%)	CA2 (%)	CA3 (%)	CA4 (%)
Open Water	5.95	3.29	0.00	10.12
Fen	0.18	0.15	0.00	0.00
Bog	2.90	5.06	0.00	0.00
Sparse Treed	8.15	6.91	3.45	4.48
Mixed Treed	2.51	4.23	1.23	0.00
Coniferous Treed	71.79	79.49	95.32	85.40
Disturbance	8.53	0.87	0.00	0.00
Total	100.00	100.00	100.00	100.00

Another factor that can have a significant influence in land cover is forest fires which can remove vegetation and modify large areas, leaving the terrain exposed to the effects of precipitation. Forest fires are normally associated with higher runoff amounts, increased erosion, and slope failure which may generate landslides and debris flows, however, an analysis of the effects of forest fires was not part of the scope of work for this assessment.

2.6 Surficial Soils

The available information regarding surficial soils was obtained from the Soils of Canada (Derived) National Geospatial Layer published by Agriculture and Agri-Food Canada (AAFC 2013). This layer shows soil attributes such as drainage condition, parent material, soil classification, soil order code, soil group and organic group. Due to the remote location of the Ignace study site, there is limited information in the database that describes the existing surficial soil types.

Furthermore, the layer shows that all catchments are contained within the same soil order code as shown in Table 3. A description of each soil attribute was obtained from the Data Product Specification document that is provided with the geospatial layer and from The Canadian System of Soil Classification (AAFC 1998).

Table 3: Surficial Soil Characteristics

Attribute	Value	Description
Soil Drainage	W – Well Drained	Water is removed from the soil readily but not rapidly. Excess water flows downward readily into underlying pervious material or laterally as subsurface flow. Soils have intermediate available water storage capacity (4-5 cm) within the control section. Water source is precipitation. On slopes subsurface flow may occur for short durations, but additions are equalled by losses. (AAFC 1998)
Kind of Material	M- Mineral	Mineral materials contain sand, silt and clay as well as coarse fragments in variable proportions, but percent organic matter is less than 30%. (AAFC 1998)
Local Surface	H - Hummocky	A very complex sequence of slopes extending from somewhat rounded concavities (or swales) of various sizes to irregular conical knolls (or knobs) and short discontinuous ridges. Slopes are generally 4-70%. (AAFC 1998)
Soil Order Code	Brunisolic	This includes soils that are calcareous to the surface and very slightly weathered, and others that are strongly acid (i.e., pH < 5.5). They occur in a wide range of climatic and vegetative environments including boreal forest, mixed forest, shrubs, grass, heath and tundra. (AAFC 1998)
Soil Great Group Code	Dystric Brunisol	These are acid brunisolic soils that lack a well-developed mineral-organic surface horizon. They occur widely typically under forest vegetation. (AAFC 1998)
Organic Group	Mesisol	Organic soils that are formed in organic materials that are in an intermediate stage of decomposition and are typically saturated with water. (AAFC1998)

2.7 Bedrock Geology

Bedrock geology information for the Study Site was obtained from the Digital Northern Ontario Engineering Geology Terrain Study (NOEGTS) published by the Ontario Geological Survey (MNR 2005). The available geospatial raster layer presents details regarding bedrock geology and land characteristics such as landform type, relief, and drainage condition. For the purposes of this qualitative assessment, the entire study site and catchments are located within the same bedrock class which is shown in Table 4.

The NOEGTS Study uses a terrain unit letter code classification system to summarize the material, landform, topography, and drainage for each zone. This system uses a numerator over denominator nomenclature as shown below:

MATERIAL – LANDFORM

TOPOGRAPHY – DRAINAGE

This classification system for the study area shows the following terrain unit letter code:

RN - (tsMG) (pOT)

Mn - D

Therefore, the bedrock geology in the study site can be described as formed by bedrock knobs (RN) where the dominant landform is mainly formed by till and sand in a ground moraine (tsMG) and a subordinate landform of peat with organic terrain (pOT).

Furthermore, the topography is classified as mainly moderate local relief/knobby and hummocky (Mn) and the drainage condition is dry (D).

Further descriptions of each element are provided Table 4 and were reproduced from the Ontario Engineering Geology Terrain Study User's Manual (Gartner et al. 1981) and from the Northern Ontario Engineering Geology Terrain Study 26 (Mollard and Mollard 1981).

Table 4: Bedrock Geology Classification

Attribute	Value	Description
Landform	RN	Bedrock knob – This landform is characterized by an irregular bedrock surface having complex multiple slopes of varying steepness. The cover of glacial deposits overlying the bedrock knob is generally thin and discontinuous (Mollard and Mollard 1981).
Dominant Landform	tsMG	Till (dominant), sand (subordinate)/Ground Moraine – Glacial tills with a silty sand matrix an abundance of pebbles, stones and boulders. (Gartner at al. 1981).
Subordinate Landform	pOT	Peat/Organic Terrain – Organic material consisting of peat and muck often confined, with stagnant drainage and wet surface conditions. Many organic areas are prone to flooding and contain poor engineering characteristics (Gartner et al. 1981).
Local Relief	Mn	Mainly moderate local relief/knobby, hummocky – Area of mixed drainage conditions with the existence of potentially wet ground (Gartner et al. 1981)
Surface Drainage Condition	D	Dry surface conditions interpreted from aerial photographs (Gartner et al. 1981).

3. METEROLOGICAL CONDITIONS

3.1 Baseline Climate Variables

Climate variables for the Ignace study area are provided in Golder (2020) to enhance the understanding of extreme rainfall projections by providing more context with respect to baseline conditions.

These variables were calculated for the period of 1914 to 1992 to maintain consistency with the period that was applied to calculate PMP and IDF values. The data includes mean monthly and yearly values for precipitation and temperature, as well as relevant WMO indices such as rain and snow, snow depth, potential evapotranspiration, drought index, wind speed and relative humidity. A summary of relevant information is provided in Table 5.

The data shows that the annual total average rainfall amount at the Revell site is 747.6 mm, and the wettest months of the year are June to September with monthly precipitation amounts ranging between 88.7 mm to 94.7 mm. The maximum wind speed gust and direction was also included from climate normals measured at Station Sioux Lookout (6037775) to evaluate wave generation potential in nearby lakes. The maximum wind gust speed at this station was recorded in the month of December with a value of 111 km/h and a predominant direction towards the northwest.

Table 5: Monthly Baseline Climate Parameters

Parameter	Jan	Feb	Mar	Apr	May	Jun
Mean Temperature ºC*	-18.5	-15.6	-8.3	1.5	9.5	15.0
Min. Temperature ºC*	-25.5	-25.9	-15.1	-2.8	4.5	11.7
Max. Temperature ºC*	-11.1	-6.2	-1.3	8.4	13.9	19.0
Mean Precipitation (mm)**	39.6	35.2	40.1	48.9	59.8	94.7
Min. Precipitation (mm)**	2.5	5.0	5.0	0.0	1.3	36.9
Max. Precipitation (mm)**	157.5	86.4	114.4	113.1	165.6	216.4
Parameter	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Mean Temperature ºC*	18.2	16.6	10.9	4.4	-5.3	-14.9
Min. Temperature ºC*	14.6	13.7	7.2	-1.3	-10.7	-21.4
Max. Temperature ºC*	21.5	20.6	13.9	10.7	-0.6	-8.0
Mean Precipitation (mm)**	97.4	88.7	91.9	55.0	53.9	44.2
Min. Precipitation (mm)**	21.3	21.9	11.1	14.6	5.1	1.7
Max. Precipitation (mm)	213.9	208.3	275.6	139.2	147.3	111.8

*Table 28 of Golder Report (2020)
**Table 27 of Golder Report (2020)

3.2 Extreme Rainfall Events

This assessment requires the determination of flooding hazard standards that will define the hydrologic input in the form of extreme rainfall events. In Ontario, these flood standards are defined in the *River & Stream Systems: Flooding Hazard Limit Technical Guide* by the Ontario Ministry of Natural Resources and Forestry, formerly the Ministry of Natural Resources (2002).

The Technical Guide defines three types of flood events that can be used as flood standards; these include synthetic storms derived from Hurricane Hazel (1954) and the Timmins storm (1961), statistically derived flood events with an annual exceedance probability (AEP) of 1/100 (100 year return period event), and observed historical events that exceed this flood event.

The Technical Guide also notes that the magnitude of each storm depends on other factors, and therefore Ontario has been divided in three zones each with their own flood hazard criteria. The study site is located within Zone III, where the flood hazard criteria are defined by the flood produced by the Timmins storm or the 0.01 AEP flood event, whichever is greater.

Other extreme events can include larger storms where a lower AEP is assigned such as 0.001 or 0.0001 (the 1,000- and 10,000-year return period events, respectively) and the probable maximum precipitation event. Moreover, it is recognized that this preliminary assessment will rely on independent studies to select the range of extreme rainfall events which may be different than the ones described in the Technical Guide; however, the description of flood standards is presented as a reference for the purposes of this qualitative assessment.

Further information regarding the development of the probable maximum precipitation (PMP) for different conditions is included in the Golder report. The analysis included the development of a consolidated baseline for PMP calculations from data derived from historical weather records. Two main stations were used for the analysis, while 18 more weather stations provided additional weather records. Further details of this analysis are included in Chapter 3 of the Golder report.

3.2.1 Probable Maximum Precipitation

The definition of the PMP event can be different between jurisdictions; however, for the purposes of this qualitative assessment the definition has been obtained from the *Dam Safety Guidelines* published by the Canadian Dam Association (CDA 2007).

The Dam Safety Guidelines define the Probable Maximum Flood generated by the PMP as the "most severe flood that may be expected to occur at a particular location". Therefore, the PMP is defined as the largest storm that has been observed or that is expected to have occurred in the catchment due to a sudden shift of the storm track with a correction to maximize for air moisture. The ratio for air moisture is calculated with the maximum expected air moisture that could have occurred and the actual air moisture that occurred during the passage of the storm.

Furthermore, the World Meteorological Organization (WMO) defines the PMP as the "greatest depth of precipitation for a given duration meteorologically possible for a design watershed or a given storm area at a particular location at a particular time of year, with no allowance made for long-term climatic trends" (WMO 2009).

Even when the definition of the PMP is straightforward, most times its calculation is not because of lack of reliable data or potential differences that may arise from its interpretation.

The NWMO commissioned an independent study to determine the probable maximum precipitation (PMP), intensity-duration-frequency (IDF) curves, and snowpack accumulation data for both sites considering current and future climate conditions (Golder 2020). Those results are being used as input parameters for this study. AECOM applied the parameters reported by Golder (2020) without any review or verification, given that such task is out of the scope of work of this assessment.

3.2.2 Timmins Storm

The Timmins storm was a summer storm that occurred over Timmins, Ontario in September 1st, 1961 and generated severe damage and loss of life on the banks of Town Creek. Following the analysis of this storm, MNRF adopted its formal definition as a 12-hour event with a total rainfall depth of 193 mm. This storm is applicable to catchments smaller than 25 km^2 within Zone III, and therefore it is directly applicable to the study site (MNR 2002).

The Golder Report (2020) also mentions two major precipitation events that occurred in 1941 and 2002, the latter being referred to as the 49th parallel storm. The total 1-day precipitation registered at Ignace for the 1941 storm was 122.4 mm, while the 2002 event include large precipitation amounts at nearby stations such as Mine Centre (293.2 mm) and Atikokan AUT (194 mm) over three days between June 8th to 11th.

It is also stated by Golder that the 49th parallel storm was found to be larger than the Timmins Storm for all durations above 12 hours. This is based on an analysis by the Ontario Ministry of Natural Resources (2006).

3.2.3 Annual Exceedance Probability Storms

These storms are produced with maximum precipitation that is defined by statistical methods, where historical precipitation records are fitted into a given statistical distribution. The results are provided as intensity-duration-frequency curves where maximum precipitation for different AEP and storm durations are provided.

As an example, the Ontario Ministry of Transportation provides an online tool to calculate IDF values within the province (MTO 2016). A search with this tool indicated that the maximum rainfall depth at the site that corresponds to a 24-hour storm with an AEP of 1% is 131.4 mm (100-year return period).

A detailed analysis of IDF statistics was completed by Golder (2020) and is included in Section 3.2. The analysis included sub-daily, daily, and multi-day IDF curves for the Ignace study site based on nearby stations. As an example, the spatially interpolated IDF curves for the study area indicate that the 24-hour event with a 100-year return period is 125.5 mm and in agreement with the MTO IDF online IDF Curve Lookup tool.

4. QUALITATIVE ASSESSMENT OF HYDROLOGICAL HAZARDS

The qualitative assessment of flood hazards includes a preliminary evaluation based on the supporting information that was gathered for this report. Even when this preliminary assessment of flood hazards focuses on floods generated by direct rainfall on-site and catchment flooding, other factors have been included following the Specific Safety Guide SSG-18 by the International Atomic Energy Agency (IAEA 2011), specifically the items included in Section 5 of the document which provides recommendations regarding the analysis of hydrological hazards.

4.1 Storm Surges

Storm surges are created by a combination of factors such as strong winds, wind direction, fetch, atmospheric pressure, and terrain bathymetry (USACE 1984). The study site and catchments do not contain any major waterbodies where these effects can be of significance.

Furthermore, the Atlas of Canada 6th Edition (NRCan 2009) includes a map reproduced as Figure 6 with locations with different levels of frequency and severity of storm surges in coastal regions. As shown in the map, there are no identified locations inland within northern Ontario that are at risk of storm surge effects.

The nearest waterbody to the study site is Mennin Lake; however, this lake is located more than 1 km away from the study site. The existing topography, site orientation, distances, and historical wind speeds in the area make the site out of reach of any possible surges or seiches from Mennin Lake, Michele Lake, Agimak Lake, or Lake Superior. For these reasons any flooding hazards due to storm surge are not considered to be significant for the study site. Additionally, the location, topography and distance to major waterbodies such as Agimak Lake (50 km), and Lake Superior (250 km) also support this conclusion.

4.2 Wind Generated Waves

Like storm surges, wind generated waves are dependent on physical parameters such as wind velocity, fetch, wind direction, and water depth. It was indicated in Section 3.1 that the highest wind gust recorded within the record of climate normals was 111 km/h with a predominant direction towards the north. The longest fetch in this direction within Mennin Lake is 2 km where different wind durations are possible.

Based on this information and using Figure 4.1 of the *Guide to Wave Analysis and Forecasting* document (WMO 1998), it can be inferred that the maximum wave height is 1.2 m, which is not sufficient to reach the general site area within the study site, or even advance across the 1 km of land that separates the lake to the study site boundary.

For other waterbodies the distance increases even further adding topographic features and obstacles that will prevent any effects at the study site. As an example, the approximate vertical difference between Mennin Lake to the proposed site elevation is 40 m, and for Lake Superior is 248 m, therefore, for the purposes of this assessment flooding hazards due to wind generated waves are not considered to be significant.

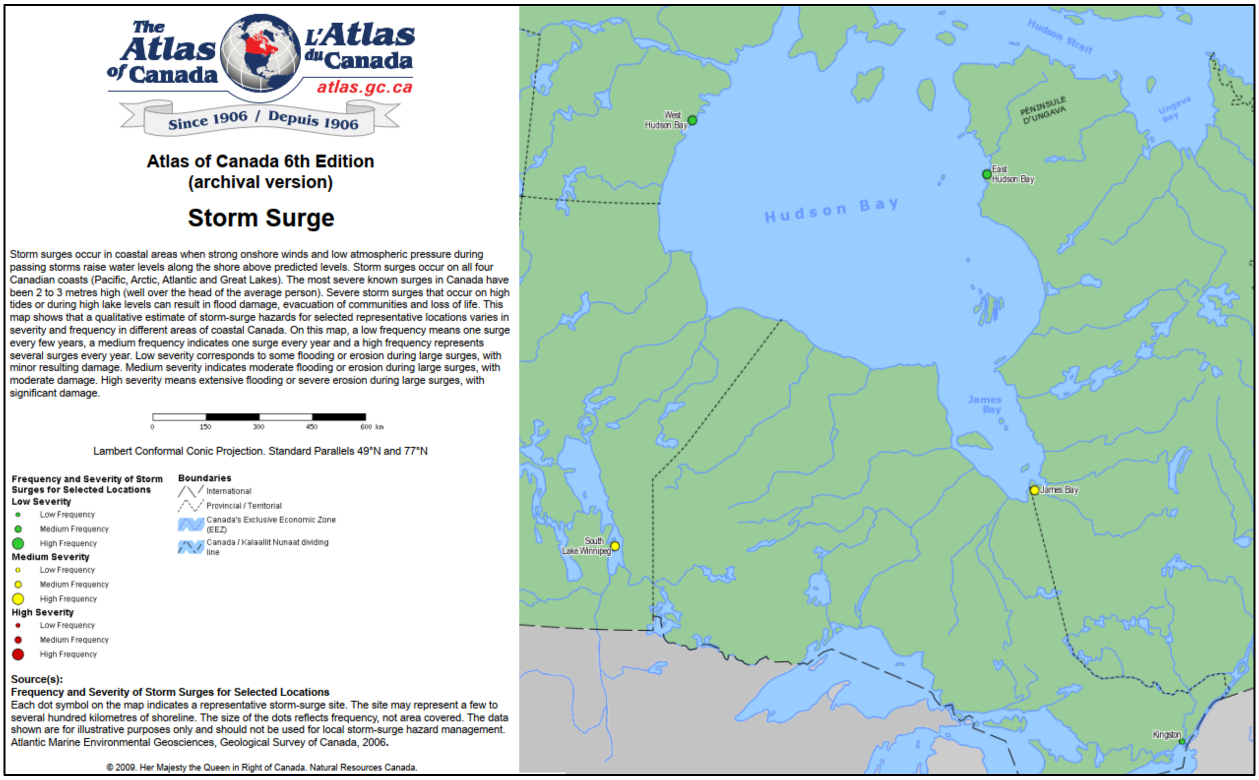

Figure 6: Potential Location of Storm Surges in Ontario (modified map)

4.3 Tsunamis

Given the location and characteristics of the study site, flooding hazards caused by tsunamis are not considered to be significant. A landslide created near a lake shore may create a large displacement of a volume of water creating a tsunami like event; however, the study site is not located next to large bodies of water needed to cause such event.

As indicated previously, other larger lakes such as Agimak Lake, Michele Lake or Lake Superior are too far away to generate any realistic hazards due to tsunamis on the study site.

4.4 Seiches

Seiches are long period standing waves that remain after the forces that created them have ceased to act (USACE 1984). Like the previous factors, seiches are not considered to be significant for this study site with regards to flood hazards. The existing topography, site orientation, distances, and historical wind speeds in the area make the site out of reach of any possible seiches from Mennin Lake, Michele Lake, Agimak Lake, or Lake Superior.

As indicated previously, other larger lakes such as Agimak Lake or Lake Superior are too far away to generate any realistic hazards due to tsunamis on the study site.

4.5 Extreme Precipitation Events

If large enough, rainfall events have the potential to generate localized flooding on the study site and adjacent watercourses. Extreme rainfall events such as the Timmins storm, the 49th parallel storm or the PMP have been identified as large rainfall events that can occur within the site.

Flooding hazards can also be intensified by other factors including but not limited to antecedent soil moisture conditions, snowmelt rates, drastic changes in land cover caused by external factors (i.e., forest fires), the distribution of rainfall over time, climatic conditions and temporary blockages caused by rainfall events (i.e., debris flows). For these reasons flood hazards from extreme rainfall events are considered a significant factor, and the risk should be evaluated.

As part of this qualitative assessment, locations where flooding hazards have been identified are shown in Figure 7; these areas (shown in blue) include watercourses and waterbodies that have the potential to create flooding which can expand laterally and reach proposed infrastructure (i.e., site access roads, excavated rock management area, site surface facilities). Additionally, terrain features such as surface depressions can generate localized flooding within the study site.

Both types of flooding from rivers and local features were included in this assessment as flooding from upstream areas and rainfall on-site.

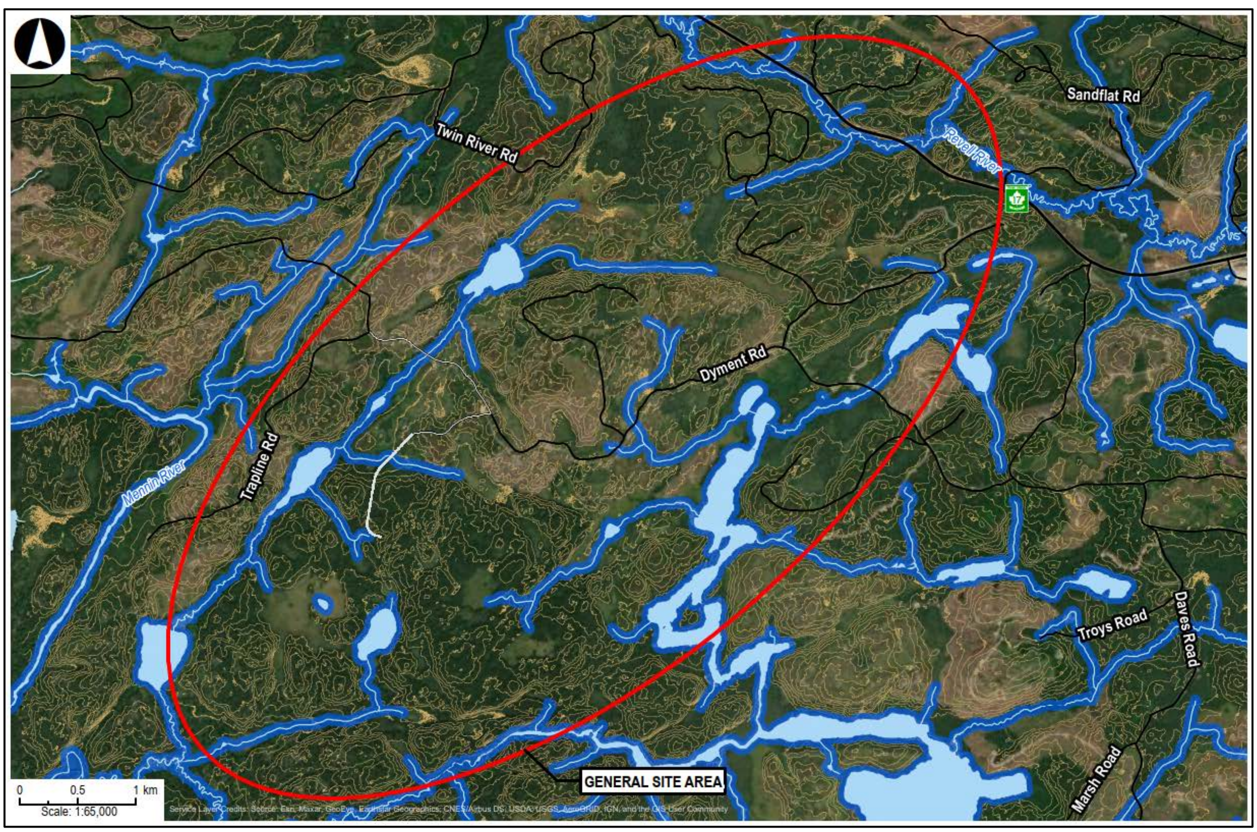

Figure 7: Potential Locations of Flood Hazards (Watercourses and Waterbodies)

4.6 Floods Due to the Sudden Release of Impounded Water

A review of available spatial layers indicated that there are no mapped dams or man-made structures within the study site or in the upstream areas of any catchment within the limits of this assessment. This evaluation is based on a desktop review of mapped structures in Ontario which are presented in a digital spatial later, without field verification work which was not part of this analysis. Furthermore, the identified hydraulic structures on the highway and nearby railway are downstream of the study site and the current site conceptual design does not include any water impoundment works within or upstream of the study site.

It is possible, however, that natural obstructions such as beaver dams, ice jams, or debris may cause a sudden release of impounded water. If this occurs, the waterbodies and wetlands will act as buffer zones that can attenuate the effects of the generated transient waves. The location of the study site in the upstream areas of the catchments also minimize the flooding potential due to a release of impounded water.

Therefore, flooding hazards due to a sudden release of impounded water are not considered to be a significant factor for the study site.

4.7 Bore and Mechanically Induced Waves

Following the same rationale that was applied to storm surges and wind induced waves, bores induced by tides or any other factor and mechanically induced waves are not considered a significant factor for the study site with regards to flood hazards.

4.8 High Groundwater Levels

Shallow or near surface groundwater levels have the potential to reduce soil infiltration and storage capacities, therefore, increasing the amount of overland runoff. Wetlands, fens and bogs are general indicators of local high groundwater levels, and they can also be created by the interception of groundwater.

While there is indication of local high ground water levels, an assessment of the potential for groundwater to penetrate below ground components of the facility is beyond the scope of this surface water study. However, consideration for areas that have potential high groundwater within the catchment and contributing areas upstream will be accounted for in the surface flow hydrological assessment through the selection of soil infiltration parameters for those areas.

4.9 Summary and Conclusions

A qualitative assessment has been completed as part of the preliminary assessment of potential flooding hazards for the Revell site. This qualitative assessment was based on the guidelines provided in the IAEA Safety Standards entitled *Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations* (IAEA 2011).

The Revell Site is a 1925 hectare property located approximately 45 km west of the Town of Ignace and just south of Highway 17. The property is bounded to the north by Highway 17, to the west and south by Mennin River and Mennin Lake, and to the east by forested land and wetlands which extend towards Highway 622. The DGR conceptual design consists of various surface facilities and an underground repository. The study site location is shown in Figure 2.

Four catchments were delineated within the study site and are labeled CA1 to CA4 in Figure 3 along with the drainage network of streams and lakes. Three of these catchments drain towards the south, while the remaining catchment drains north towards Highway 17. Relevant properties of these catchments are also shown in Table 1.

Based on aerial imagery, there is clear evidence of extensive logging activities and a network of access roads in the area where the study site is located; no further development or infrastructure has been identified. Predominant land cover types within the study site include forest, disturbance, and open water; however, a large portion of the property towards the north has been cleared and only small patches of forested land remain. Land cover percentages for all four catchments are shown in Table 2.

The soil within the site is assumed to include dystric brunisolic soils which are calcareous to the surface and very slightly weathered, and others that are strongly acid (i.e., pH < 5.5). They occur in a wide range of climatic and vegetative environments including boreal forest, mixed forest, shrubs, grass, heath and tundra. The bedrock geology is formed by bedrock knobs where the dominant landform is mainly formed by till and sand in a ground moraine and a subordinate landform of peat with organic terrain. Furthermore, the topography is classified as mainly moderate local relief/knobby and hummocky with a dry drainage condition.

As shown previously, the IAEA Safety Standards document includes seven hydrological hazards which are storm surges, wind generated waves, tsunamis, seiches, extreme precipitation events, floods due to the sudden release of impounded water, bores and mechanically induced waves, and high groundwater levels.

The results of the qualitative analysis show that based on the available information and site conditions, flooding hazards due to extreme precipitation events require further consideration and other hydrological hazards are determined to be of no significance. A preliminary determination of areas where flood hazards may be of concern are shown in Figure 7. It is also recognized that effects of extreme precipitation events can be compounded by other factors such as wildfire, natural obstructions, ice jams, and antecedent soil conditions.

Given the small catchment size, steepness of local terrain, and general soil conditions, any reductions in surface flows due to infiltration or evapotranspiration are negligible. Moreover, any existing or proposed surface infrastructure (such as roads or drainage features) are likely to measurably impact surface water hazards.

Finally, a set of extreme PMP rainfall events will be selected from Golder (2020) based on different parameters and time projections. The input of these PMP storms to a hydrologic model that calculates excess runoff and then a hydraulic model that translates excess runoff into water depths is the next step of this preliminary flood hazard assessment.

4.10 Other Considerations

Other factors to consider for future potential impacts due to flooding include the following, however, these were not part of the scope of work for this preliminary flooding assessment:

- The effects of land cover changes due to forest fires, land development, changes to vegetation due to drought and/or climate change patterns, and natural obstructions such as landslides and beaver activity.

5. SURFACE FLOOD HAZARD ASSESSMENT

The next step is to carry out the preliminary flood hazard assessment based on the findings presented in previous sections as well as the scope and objectives of this project. 14 scenarios were evaluated to define the extent of surface flooding at the Revell Site, focusing on catchments CA1 and CA2.

A summary of the steps that were completed for this assessment and details regarding the development of hydrologic and hydraulic models for the catchments is included below.

5.1 Proposed Assessment Scenarios

As defined in the Scope of Work, 14 scenarios were included in this preliminary flood hazard assessment. These scenarios are divided by period (current, mid-century, and end-of-century), climate change scenario (three PMP risk projections) and by type of flood (direct rainfall on-site and rainfall on upstream catchments).

The distinction between types of flood recognizes that the site receives direct rainfall amounts that can create local water accumulation and ponding, while flooding on upstream catchments is defined as rainfall that generates streams to exceed their normal conveyance capacity, which in turn increases floodplain extents and therefore has the potential to impact proposed project components such as roads, hydraulic structures, buildings and related infrastructure.

The assessment of both flood types required the development of a hydrologic model for all catchments (CA1 to CA4) by using the hydrologic software HEC-HMS (version 4.8), as per the approved software plan. HEC-HMS was used to simulate rainfall processes and calculate excess runoff that is conveyed towards each catchment outlet.

The excess rainfall was then applied to a two dimensional (2-D) hydraulic model of each catchment developed in the software HEC-RAS (version 5.0.7), as per the approved software plan. HEC-RAS calculates the water elevation and velocities at each catchment based on the inputs provided by HEC-HMS as well as the selected parameters which are specific to each catchment (i.e., Manning’s roughness coefficients, boundary conditions, terrain characteristics). Further details regarding the flood hazard assessment are provided below.

5.2 Hydrologic Model Development (HEC-HMS)

The hydrologic software HEC-HMS was developed and is maintained by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers and is specifically designed to simulate hydrologic processes in rural dendritic watersheds. The software includes sub-routines for hydrologic simulations such as infiltration, application of unit hydrographs, and hydrologic routing. HEC-HMS also includes procedures necessary for continuous simulation including evapotranspiration, snowmelt, and soil moisture accounting.

HEC-HMS was used to calculate the resultant hydrographs and peak flows for all catchments (CA1 to CA4) to define the critical rainfall distribution that was used for hydraulic modelling. Additionally, the model was expanded to include all 14 scenarios that were part of the analysis.

5.2.1 Model Setup

The HEC-HMS hydrologic model was setup to simulate catchments CA1 to CA4 as individual elements connected to independent outlets. Each catchment element must have a surface area where precipitation occurs, the selection of which hydrologic processes are simulated by the model was made based on the characteristics of the rainfall distributions of interest and the scope of this project.

Given that the extreme PMP distributions used in this preliminary assessment are mainly single events with short durations of 3, 6, 12 and 24 hours (with the exception of the rainfall on snow event), the hydrologic model was adjusted to include routing and infiltration parameters with the SCS curve number and SCS unit hydrograph methods, while other parameters such as baseflow, evapotranspiration and canopy storage were not applied because the rainfall distributions are too short for these processes to have any influence in the resultant hydrographs.

The total surface area of each catchment was applied to the hydrologic model, which in turn calculates total rainfall volumes by multiplying the surface area by the rainfall depth. The hydrologic model applies the rainfall amounts following the defined rainfall distributions and calculates reductions to account for infiltration loses.

5.2.2 Delineation of Catchment Areas

Catchment areas were delineated with the provided LiDAR DEM during the Qualitative Assessment as shown in Figure 3. Further details about each catchment are also included in Table 1. The largest catchment areas are CA1 and CA2.

Catchments CA3 and CA4 were included in the analysis, however, they are not considered to be relevant with respect to the general site area.

5.2.3 Other Modelling Parameters

Based on the selection of the SCS curve number and SCS unit hydrograph methods, the hydrologic model required four parameters: three are related to the calculation of infiltration loses for each catchment, and one is related to the hydrologic routing.

The SCS curve number method requires the calculation of initial abstraction, percentage of directly connected impervious area within the catchment, and the composite CN for each catchment. The parameters related to the SCS curve number for all catchments are shown in Table 6.

Table 6: SCS Curve Number Parameter Calculation

Catchment	Area (ha)	Basin Type	Soil Type (%) CN=54	Soil Type (%) CN=70	Composite CN (rounded)	Initial Abstraction (mm)
CA1	1632	Northern	90.6	9.4	56	20
CA2	1198	Northern	99.0	1.0	55	21
CA3	110	Northern	100.0	0.0	54	22
CA4	87	Northern	100.0	0.0	54	22

The selected SCS curve number values are based on the predominant soil types within the study area, these are shown in Table 2 and were assigned SCS CN values of 54 and 70 for well drained silty sand loams with forested and disturbed land covers, respectively.

A composite CN was then obtained by multiplying the product of each percentage area by its corresponding CN value. As an example, the composite CN for catchment CA1 is calculated by adding the product of each individual CN value by the percentage of soil type area (i.e., 54*0.906+70*0.094 = 55.5 which rounded is 56).

The initial abstraction accounts for precipitation that is kept by the catchments near the beginning of a rainfall event and is therefore not made available as excess runoff during such event. The initial abstraction therefore simulates the capacity of a catchment to store rainfall mainly by interception and depression storage.

The initial abstraction must be taken from the total precipitation before any runoff can occur in the hydrologic model. The initial abstraction for each catchment was calculated as a function of the CN value as per the MTO Design Manual (1997).

The time of concentration (Tc) which is related to the hydrologic routing was calculated with the Uplands overland flow method. The length and slope for both the overland flow and channel paths were calculated with the available LiDAR data provided by NWMO.

The overland velocities were estimated with the Uplands Method, based on the terrain slopes and land cover types. The time of concentration for each catchment was then calculated by dividing the channel length with the velocity for the overland flow and channel flow components separately, and then adding both components into a single time of concentration.

The hydrologic model requires the input of the lag time, which is approximated as 0.6 times Tc. The parameters that were used for the calculation of Tc are included in Table 7.

Table 7: Parameters for the calculation of Tc (Uplands Method)

Catchment	Area (ha)	Overland Flow			Channel Flow			Tc (min)	Lag Time (min)
		Length (m)	Slope (%)	Velocity (m/s)	Length (m)	Slope (%)	Velocity (m/s)		
CA1	1632	2700	2.1	0.13	6800	0.3	0.4	642	385
CA2	1198	1800	2.7	0.14	8000	0.3	0.4	541	325
CA3	110	700	3.2	0.16	1100	0.8	0.7	100	60
CA4	87	1300	2.1	0.12	1800	0.6	0.6	224	134

5.2.4 Validation of the Hydrologic Model

The hydrologic model provides calculations of peak flows and volumes for each considered scenario by using input parameters such as catchment area, precipitation amounts, and the equations that define other hydrologic processes (i.e., SCS curve number and SCS unit hydrograph).

An important step for hydrologic modelling is to check that the results are consistent with observed data when feasible, which means to calibrate the model, or at least to review that other methods provide similar results.

For a hydrologic model a calibration procedure requires long term flow records at the site or at nearby catchments that can be transposed to the site. In this regard, a detailed model calibration procedure is not feasible at the Revell Site given that local flow monitoring records are not available, and the nearest flow monitoring stations are too far away and do not have characteristics similar to the Revell Site.

Since model calibration is not feasible, a validation of the model was completed by checking the results of the 100-year event from the hydrologic model with the Modified Index Flood Method (MIFM). The MIFM method relies on a regional frequency analysis of annually recorded maximum peak flow rates to produce a statistical regression for the 25-year runoff event for an equivalent catchment area of 25 km^2, with factors applied for other flood events.

Once the HEC-HMS model is consistent with the results from MIFM, it was then assumed that the hydrologic model can simulate other rainfall events including the PMP. Details of the MIFM and its application are included in Chapter 8 of the MTO *Drainage Management Manual* (1997), while the parameters that were applied to the method for the Revell Site are shown in Table 8.

Table 8: Calculation of the Modified Index Flood Method

Catchment	Area (km^2)	Basin Type	Lag Time (min)	Q_{25} Base (m^3/s)	Peak Factor	Q_{100} MIFM (m^3/s)	Q_{100} HEC-HMS (m^3/s)
CA1	16.32	Northern	385	6.57	2.2	18.0	19.5
CA2	11.98	Northern	325	4.82	2.4	14.5	15.8
CA3	1.10	Northern	60	0.44	2.5	1.4	1.4
CA4	0.87	Northern	134	0.35	2.5	1.1	1.2

The results of the MIFM show the calculated peak flows for the 100-year flood event for catchments CA1 to CA4. Additionally, the HEC-HMS model was used to calculate the same peak flows corresponding to the 100-year event with IDF values from Golder (2020).

The results show differences of 7% and 8% between peak flow values for catchments CA1 and CA2, respectively, noting that the HEC-HMS results are higher than MIFM. For catchments CA3 and CA4 the results are not reliable, however, this is likely due to the range of applicability of the method (i.e., >5 km^2).

Furthermore, the peak flows for catchments CA3 and CA4 are not considered critical since these catchments are very small.

Given that the results of the hydrologic model and MIFM are close, it was assumed that the hydrologic model is capable to simulate larger events within the Revell Site.

5.3 Selection of PMP and Snowpack Accumulation Values

The preliminary flood hazard assessment requires the determination of extreme runoff amounts for current and future conditions at the Ignace study area. Runoff is generated by rainfall and/or snowmelt, which forms the hydrological input to the catchments of interest. Extreme hydrologic inputs, such as the probable maximum precipitation (PMP) and rainfall on snow projections, are selected from the parameters included in the Golder (2020) report.

The Golder report provides a detailed assessment of baseline climate conditions and climate projections that extend to the year 2100 at the Ignace study area. Further projections beyond the year 2100 are provided by Golder in a qualitative basis only since current climate change models do not extend further. For the purposes of this preliminary flood hazard assessment, projections beyond the year 2100 are not part of the scope and therefore are not included in the analysis.

The selection of extreme hydrologic inputs is required to calculate excess runoff at the Revell Site within the Ignace study area. The HEC-HMS hydrologic model includes four defined catchments within the Revell site (CA1 to CA4); hydrologic parameters are provided for each catchment, and the model determines the resultant flow hydrographs and peak flows for each catchment.

Additionally, an assessment was completed to estimate which rainfall durations should be considered when determining potential highest peak flows for each catchment. The durations selected were based on the analysis carried out by AMEC and presented in the report *OPG's Deep Geologic Repository for Low & Intermediate Level Waste Maximum Flood Hazard Assessment* (2011).

The rainfall durations considered include the 6-hr and 12-hr LRIA (OMNR 2004) and the SCS Type II 24-hr distribution. These are normalized and given in hourly percentages of total precipitation as shown in Table 5.10 of AMEC (2011) to create the rainfall distributions.

Additionally, based on the characteristics of the Ignace study area, the Chicago rainfall distribution was also added to represent a short event with a high and concentrated rainfall intensity. The considered rainfall distributions are included in Table 9.

The hydrologic modelling of the Ignace study area was completed to determine which events generate the highest peak flows, which were carried forward for hydraulic simulations.

Table 9: PMP Rainfall Distributions* (AMEC 2011)

Duration (hr)	SCS Type II – 24 hr	LRIA – 12 hr	LRIA – 6 hr	Chicago – 3hr
0	0.0	0.0	0.0	10.0
1	1.1	2.0	8.0	75.0
2	1.2	3.0	9.0	15.0
3	1.2	3.0	11.0	
4	1.4	4.0	49.0	
5	1.5	6.0	15.0	
6	1.7	51.0	8.0	
7	1.9	15.0		
8	2.2	4.0		
9	2.6	4.0		
10	3.4	3.0		
11	5.4	3.0		
12	42.8	2.0		
13	10.9			
14	4.6			
15	3.6			
16	2.6			
17	2.2			
18	1.9			
19	1.6			
20	1.5			
21	1.3			
22	1.2			
23	1.2			
24	1.1			

*Values are indicated as percentages of total rainfall

5.3.1 Determination of Extreme Hydrologic Inputs

The Golder report presents the procedures applied to develop baseline climatic datasets based on an analysis of historical weather records near the Ignace study area. 20 weather stations were evaluated, and two stations (Ignace 6033690 and Ignace TCPL 58 6033697) were selected for the development of a consolidated climate baseline that includes the period between the years 1950 to 1993.

The analysis of future climate scenarios was completed by Golder with two distinct data ensemble sources that provide 136 bias-corrected climate projections, namely the BCCAQ (version 2) and LOCA. The BCCAQ version 2 is the Pacific Impact Consortium data ensemble which uses bias correction/constructed analogues with quantile mapping reordering. This dataset consists of an ensemble of 24 models with 72 projections that consider three representative concentration pathways (RCP 2.6, RCP 4.5 and RCP 8.5).

The LOCA data ensemble consists of 32 models with 64 projections including RCP 4.5 and RCP 8.5. Additional details of each model are included in Section A.3 of Golder (2020). It is also mentioned that the BCCAQv2 dataset contains drawbacks with regards to data interpretation and for this reason the LOCA approach was selected for further analysis.

The projections were developed for three distinct periods and are defined as current period (present to 2040), mid-century period (2041-2070) and end-of-century period (2071-2100).

It is also noted that different phases of the proposed deep geological repository overlap the future climate projection periods. As such, for the purposes of this preliminary assessment, the site characterization, preparation, and construction are assumed to occur between 2023 to 2043, the operational phase from 2043 to 2083, and the extended monitoring phase from 2083 and beyond 2100. Furthermore, as stated by Golder, the overlap between climate projections and proposed project phases means that different levels of risk may be adapted over time as the project phases are progressing.

The projected changes in the probable maximum precipitation (PMP) estimates were divided in percentiles and provided for timespans that extend to the 2050s (mid-century) and 2080s (end-of-century). These percentiles define the level of uncertainty and show how the PMP projections are distributed, where higher percentiles are associated to higher risk. The projected percent changes in PMP estimates are reproduced in Table 10.

Table 10: Projected Percent Changes in PMP Estimates

Percentiles	2050s (%)			2080s (%)		
	1-Day	2-Day	3-Day	1-Day	2-Day	3-Day
Minimum	-27.4	-30.9	-28.0	-24.6	-17.5	-18.4
5%	-7.5	-6.0	-6.4	-4.5	-4.0	-4.9
25%	8.6	11.2	10.3	12.4	13.3	11.5
50%	**18.7**	18.7	18.5	**25.4**	27.4	25.7
75%	**28.3**	30.0	28.1	**40.2**	44.4	41.3
95%	**55.8**	54.8	51.7	**69.8**	73.6	71.8
Maximum	103.4	79.6	83.7	126.0	111.7	111.4

The determination of a projected PMP value is carried out by multiplying the corresponding percentage to the selected current value. For instance, to obtain the 1-Day PMP value projected to the 2050s, the present 1-Day PMP value must be multiplied by 1.187 to obtain the projection associated with the 50th percentile. Other projections are obtained in the same manner.

The analysis completed by Golder also included the calculation of IDF curves for the Ignace area, which are applied here at the Revell Site. These curves are included for return periods ranging from 2 years to 200 years, where the probability of occurrence is the inverse of the return period; as an example, the 100-year return period event has a 1% probability of occurrence at any given time. The analysis included the interpolation of IDF curves from nearby stations in order to determine the baseline IDF dataset as shown in Table 11.

Table 11: Spatially Interpolated IDF Curves - Ignace Study Area (mm)

Return Period (years)	Duration								
	5 min	10 min	15 min	30 min	1 h	2 h	6 h	12 h	24 h
2	8.3	12.2	14.8	18.8	23.1	28.9	36.6	43.3	48.6
5	11.1	16.1	19.6	24.9	30.0	38.2	50.5	59.5	65.4
10	13.0	18.5	22.8	28.9	34.5	44.5	60.8	71.6	77.9
20	14.8	20.9	25.8	32.8	39.0	50.7	71.6	84.4	91.0
50	17.3	23.8	29.7	37.9	44.8	59.0	87.2	102.7	109.8
100	19.1	26.0	32.6	41.8	49.2	65.5	100.2	118.1	125.5
200	21.0	28.2	35.5	45.7	53.7	72.0	114.4	134.9	142.6
500	23.6	31.0	39.4	50.9	59.7	81.0	135.5	160.0	167.9
1000	25.5	33.2	42.3	54.9	64.4	88.1	153.5	181.3	189.5
2000	27.6	35.3	45.2	59.0	69.2	95.3	173.4	205.0	213.3

5.3.2 Selection of PMP Values

Values for the base PMP event were calculated at the Ignace study area by Golder with the Hershfield method and further validated with the transposition method as well as data reported in a separate study conducted by the Ontario Ministry of Natural Resources (OMNR 2006). As indicated by Golder, the direct calculation of sub-daily PMP values was not completed because the available data were provided with a daily resolution. Instead, an estimation of sub-daily PMP values was undertaken using proration methods from available IDF curves. Relevant PMP values reported by Golder (2020) are reproduced in Table 12.

Table 12: PMP Summary Statistics and Comparison Values (Golder 2020)

Method/Source	6-hr (mm)	12-hr (mm)	1-Day (mm)	24-Hour (mm)	2-Day (mm)	3-Day (mm)
Hershfield/Golder	328.7	387.4	364.3	411.7**	482.2	510.1
Transposition*/Golder	346.4	408.3	374.0	422.6**	484.7	488.8
OMNR (2006)	---			436.0	---	---

*For watersheds with surface area of 1000 km^2
**Converted to 24-hour duration using a multiplier of 1.13 as recommended by WMO (2009).

The factor of 1.13 that is applied to convert from 1-day to 24-hr PMP is based on WMO guidance to approximate results from statistical analysis such as the Hershfield method. For the Revell Site, the method was applied to precipitation data with a resolution of one day, and therefore, the factor is recommended to estimate values towards the true maxima. This is based on the analysis of rainfall data as indicated by Hershfield (1961).

Another way to explain this is to mention that the 1-day PMP is based on the analysis of one day precipitation records which include the average rainfall for each day, instead of its maximum, and therefore the factor is used to bring the daily averages to a maximum for the day such as the 24-hr PMP.

As shown in Table 12, the corresponding PMP values corresponding to each duration are similar and within the same order of magnitude for all methods. Based on the analysis, the Hershfield method provides PMP values calculated at the Revell site and are therefore considered to have the highest accuracy.

The transposition method can be applied to watershed areas of 1000 km^2, however, all catchments within the study area are small in comparison (16.32 km^2 to 0.87 km^2).

It is also recognized that the 2-day and 3-day PMP values are only 15% to 25% higher than the 24-hr, however, the Revell Site contains small catchments with a time of concentration of less than 6 hours. This low time of concentration combined with the marginal increases in total rainfall over a much longer time span would result in significantly lower hourly intensities when compared to the 24-hour rainfall which will result in significantly lower flow rates through the study site. Therefore, longer rainfall events such as 2-day and 3-day were not considered for further assessment.

Rainfall on snow projections is also provided in the Golder (2020) report to define potential scenarios where peak flooding events may be driven by a combination of rain and snowmelt rather than events driven exclusively by precipitation (i.e., PMP and IDF statistics). Table 25 of Golder (2020) includes the rainfall on snow projections for the Ignace study area; these values are included in Table 13.

Table 13: Rainfall on Snow Projections for the Ignace Study Area (Golder 2020)

Return Period (years)	Duration						
	1-Day	**2-Day**	**3-Day**	**4-Day**	**5-Day**	**6-Day**	**7-Day**
2	38.0	54.2	69.5	83.5	96.2	106.5	117.0
5	51.1	71.8	91.6	110.5	128.5	144.4	160.9
10	59.8	83.5	106.2	128.4	150.0	169.5	190.0
20	68.2	94.7	120.2	145.5	170.5	193.6	217.9
50	79.0	109.2	138.3	167.7	197.2	224.8	254.0
100	87.0	120.1	151.9	184.4	217.1	248.2	281.0
200	95.1	130.9	165.5	200.9	237.0	271.5	308.0
500	105.7	145.1	183.3	222.8	263.2	302.2	343.6
1000	113.8	155.9	196.8	239.3	283.0	325.4	370.5
2000	121.8	166.7	210.3	255.9	302.8	348.6	397.3
Return Period (years)	**10-Day**	**20-Day**	**30-Day**	**50-Day**	**75-Day**	**90-Day**	**120-Day**
2	146.8	208.3	245.7	295.7	328.0	332.7	342.3
5	206.8	300.8	354.0	412.8	449.9	453	455.5
10	246.5	362.0	425.7	490.4	530.6	532.7	530.4
20	284.6	420.7	494.5	564.8	608.1	609.2	602.3
50	334.0	496.7	583.5	661.2	708.3	708.1	695.4
100	371.0	553.7	650.2	733.3	783.3	782.3	765.1
200	407.8	610.4	716.7	805.3	858.2	856.1	834.6
500	456.4	685.3	804.4	900.1	956.9	953.6	926.2
1000	493.1	741.9	870.7	971.8	1031.5	1027.3	995.5
2000	529.9	798.4	937	1043.5	1106	1100.9	1064.7

Since snowmelt processes are dominated by climatic variability, where temperature is the most important parameter, the definition of a significant rainfall on snow event requires the analysis of how rainfall on snow projections are transformed into runoff.

The daily snowmelt amount was calculated with the Eastern Canada Forested Basin Equation (Pysklywec et al. 1968) included in Section A.2.4 of Golder (2020) and labeled Equation 38, where a degree-day method was applied. The equation defines snowmelt depleted from the snowpack as a function of mean daily air temperature.

The rationale for the evaluation of PMP values with different rainfall distributions is explained below.

- The SCS Type II distribution with a duration of 24 hours was applied to the PMP value reported by OMNR (2006) since this is the highest value (436 mm) for Ignace study area. The results of the hydrologic model indicated that the SCS Type II distribution creates the highest peak flows for all catchments.
- The LRIA distributions with durations of 6 hours and 12 hours were applied to the corresponding PMP values provided in the Hershfield method (328.7 mm and 387.4 mm, respectively). It is recognized that the transposition method provides higher PMP values, however, its applicability to catchments with an area of 1000 km^2 makes this method less accurate for the Ignace study area.
- The Chicago distribution with a duration of 3 hours was applied to the interpolated PMP value from Table 23 of Golder (2020), which provides sub-daily PMP values for the Ignace study area using the Hershfield method.
- The 20 day-100 year rainfall on snow projection event was evaluated by using the snowmelt function provided in the Golder (2020) report (Section A.2.4), where the relationship between temperature and runoff from melting is defined with a linear function.

The results of the hydrologic modelling that was completed to determine which distributions produce the highest peak flows at each catchment area are presented in Table 14.

As shown in Table 14, the highest peak discharge values are generated by the SCS Type II (24-hr) and the LRIA (12-hr) distributions. The results from both distributions have also similar magnitudes. The next step of the analysis required the selection of the critical rainfall distribution to carry out hydraulic modelling, the SCS Type II (24-hr) was therefore selected as the critical distribution to be applied to all catchments.

It is noted that for CA4 the highest peak flow is generated with LRIA (12-hr), however, the difference in peak flows is negligible (0.1 m^3/s) and catchment CA4 is a small catchment where no development is projected to occur.

Furthermore, the LRIA (12-hr), LRIA (6-hr) and the Chicago (3-hr) distributions were not carried forward for floodplain delineation. Additionally, the rain on snow 20 day-100 year event does not generate high peak flows because the resultant runoff is distributed over a long period of time which in turn decreases its intensity. For the same reason, rain on snow projection events are not considered critical when compared to PMP events with shorter durations; this is in agreement with Section 3.4 of Golder (2020), where it is indicated that for shorter durations extreme rainfall events take prominence over rain on snow events.

Table 14: Selection of Critical Rainfall Distributions at the Ignace Study Area

Catchment	Duration	Distribution	Peak Discharge (m^3/s)
CA1	24 hr	SCS Type II	119.5
	12 hr	LRIA	116.5
	6 hr	LRIA	101.5
	3 hr	Chicago	71.9
	20 days	Rain on Snow	6.8
CA2	24 hr	SCS Type II	98.4
	12 hr	LRIA	96.2
	6 hr	LRIA	85.2
	3 hr	Chicago	60.8
	20 days	Rain on Snow	4.9
CA3	24 hr	SCS Type II	26.6
	12 hr	LRIA	26.3
	6 hr	LRIA	22.3
	3 hr	Chicago	17.0
	20 days	Rain on Snow	0.4
CA4	24 hr	SCS Type II	13.4
	12 hr	LRIA	13.5
	6 hr	LRIA	11.9
	3 hr	Chicago	9.2
	20 days	Rain on Snow	0.3

For longer rain on snow events, the volumetric capacity becomes significant; however, for floodplain assessments the capacity to generate high peak flows is the dominant variable.

Based on the available information, 14 scenarios are proposed to carry out this preliminary flooding assessment as shown in Table 15. The scenarios consider a combination of percentiles applied to the selected critical rainfall distribution (SCS Type II with a 24 hour duration). These scenarios were applied to all catchments during the hydraulic simulations.

Based on the selected risk profile, NWMO can select the appropriate level of risk as defined in Golder (2020) and apply them to each project phase. Further details regarding the hydrologic model, and how the hydraulic simulations were carried out to determine floodplain boundaries, are provided in the following sections.

Table 15: Selected Scenarios - Preliminary Flooding Hazard Assessment

Time Period	Hydrologic Condition	
	Direct Rainfall on Site	Rainfall on Upstream Catchments
Current (present-2040)	Scenario 1: SCS Type II - 24 hr PMP	Scenario 2: SCS Type II - 24 hr PMP
Mid-century (2041-2070)	Scenario 3: SCS Type II - 24 hr PMP 50th percentile	Scenario 4: SCS Type II - 24 hr PMP 50th percentile
	Scenario 5: SCS Type II - 24 hr PMP 75th percentile	Scenario 6: SCS Type II - 24 hr PMP 75th percentile
	Scenario 7: SCS Type II - 24 hr PMP 95th percentile	Scenario 8: SCS Type II - 24 hr PMP 95th percentile
End-of-century (2071-2100)	Scenario 9: SCS Type II - 24 hr PMP 50th percentile	Scenario 10: SCS Type II - 24 hr PMP 50th percentile
	Scenario 11: SCS Type II - 24 hr PMP 75th percentile	Scenario 12: SCS Type II - 24 hr PMP 75th percentile
	Scenario 13: SCS Type II - 24 hr PMP 95th percentile	Scenario 14: SCS Type II - 24 hr PMP 95th percentile

5.4 Hydraulic Model Development (HEC-RAS)

Details of the 2D hydraulic model that was developed for this project are included in the following sections.

5.4.1 Model Setup

The 2D hydraulic model of the Revell Site was created using HEC-RAS version 5.07, which is developed by the U.S. Army Corps of Engineers and is widely used and accepted in Ontario to simulate open channel hydraulics and delineate floodplain boundaries. The program can calculate water surface elevations and other parameters, such as velocity and shear stress along stream networks. It can also model hydraulic structures such as bridges, culverts, and weirs, however, this project included a preliminary assessment and the terrain that was applied to the model is based on the LiDAR data without any modifications.

5.4.2 Model Domain

The domain of the hydraulic model includes all catchment areas as shown in Figure 8. The model domain defines the area where the 2D hydraulic calculations are completed and is formed by a rectangular mesh with a resolution of 25 m by 25 m. A separate mesh was created for each catchment to allow for water routing towards each outlet.

The use of a 2D model allows for the direct calculation of water elevations and velocities in both horizontal directions (i.e., in the direction of the channel as well as laterally towards the floodplain areas), where average water velocities over the water column are used by the model.

The 2D model was also used to input the excess precipitation calculated by HEC-HMS directly into each mesh, hence simulating the transformation of rainfall into runoff with a method known as “rain-on-grid”. This method provides a more realistic approach to surface runoff routing because the precipitation input is transformed into runoff following terrain characteristics and using the assigned Manning's coefficients to represent friction forces exerted by the terrain on the flow.

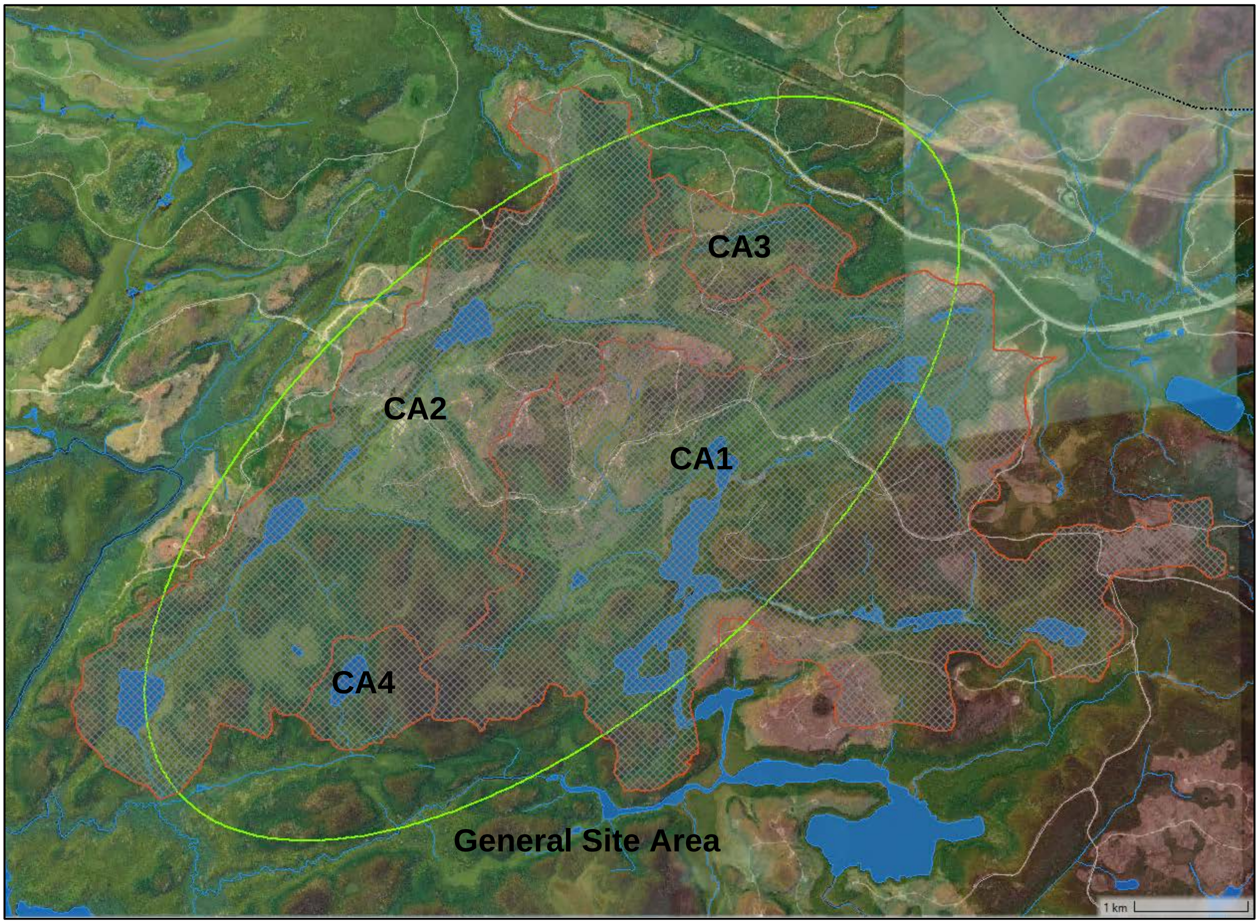

Figure 8: HEC-RAS Model Domain

Additionally, the rain-on-grid method requires the use of a hydrologic model (in this case HEC-HMS) to remove precipitation losses because the terrain in HEC-RAS is represented as fully impermeable, and therefore, the use of total precipitation amounts would be unrealistic. The hydrologic model calculates the excess precipitation (i.e., runoff) for the selected critical rainfall distribution (i.e., 24-hr SCS Type II). Further details are provided in the next section.

5.4.3 Boundary Conditions

The main boundary condition assigned to the model is excess precipitation for each catchment, for the 14 scenarios as shown in Table 16. It is recognized that the type of scenarios are distinguished by the flooding hazard (i.e., rainfall on-site and rainfall on upstream areas); however, the precipitation amounts are the same for each pair, and therefore there are pairs of future scenarios that have the same precipitation input and are shown together in the figures.

For each outlet, a normal channel slope is assigned to estimate the downstream water levels: 0.2% was assigned to catchments CA1, CA3 and CA4, while a value of 2% was assigned to catchment CA2. These were calculated based on terrain characteristics measured from the LiDAR terrain; these boundary conditions are not considered to be critical due to their location and the vertical difference in elevation in the general site area.

Table 16: PMP Total and Excess Precipitation applied to the HEC-RAS Model

Scenario*	Time Period	Total Precipitation (mm)	Excess Precipitation (mm)			
			CA1	CA2	CA3	CA4
Current	Current	436.0	295.0	290.9	272.0	288.4
Cases 3-4 +18.7%	Mid-Century	517.5	369.8	365.4	345.3	362.6
Cases 5-6 +28.30%		559.4	408.7	404.3	383.5	400.9
Cases 7-8 +55.8%		679.3	521.7	516.6	494.9	513.4
Cases 9-10 +25.4%	End-of-Century	546.7	397.0	392.5	372.0	389.3
Cases 11-12 +40.20%		611.3	457.2	452.4	432.0	449.45
Cases 13-14 +69.8%		740.3	580.2	574.8	552.5	571.3

*Percentages based on Golder projections included in Table 10

5.4.4 Manning’s Roughness Coefficients

The Manning’s roughness coefficients simulate the friction forces that are exerted by land surfaces on the water flow. For all catchment areas land cover types were defined from the Ontario Land Cover Compilation Layer V.2 (MNRF 2014) shown in Table 2 and Figure 5.

Each land cover type was assigned a corresponding Manning’s coefficient based on accepted engineering methodologies and guidelines. The selected Manning’s coefficients included in the model are summarized in Table 17.

Table 17: Selected Manning’s Roughness Coefficients

Land Cover Code	Description	Manning’s Coefficient
1	Clear Open Water	0.001
7	Swamp	0.06
8	Fen	0.06
11	Sparse Treed	0.045
14	Mixed Treed	0.045
15	Coniferous Treed	0.045
18	Disturbance	0.03

5.4.5 Derivation of Probable Maximum Flood Levels

The HEC-RAS model simulations were completed for each catchment area based on the defined boundary conditions and hydraulic input parameters. The floodplain boundaries calculated for each scenario are presented in Figures 9 to 15. The results include flooding from upstream areas as well as flooding on-site. The results show floodplain boundaries and water elevations within the general site area.

Figure 9: Scenarios 1 and 2 – Floodplain Boundaries for Current Condition

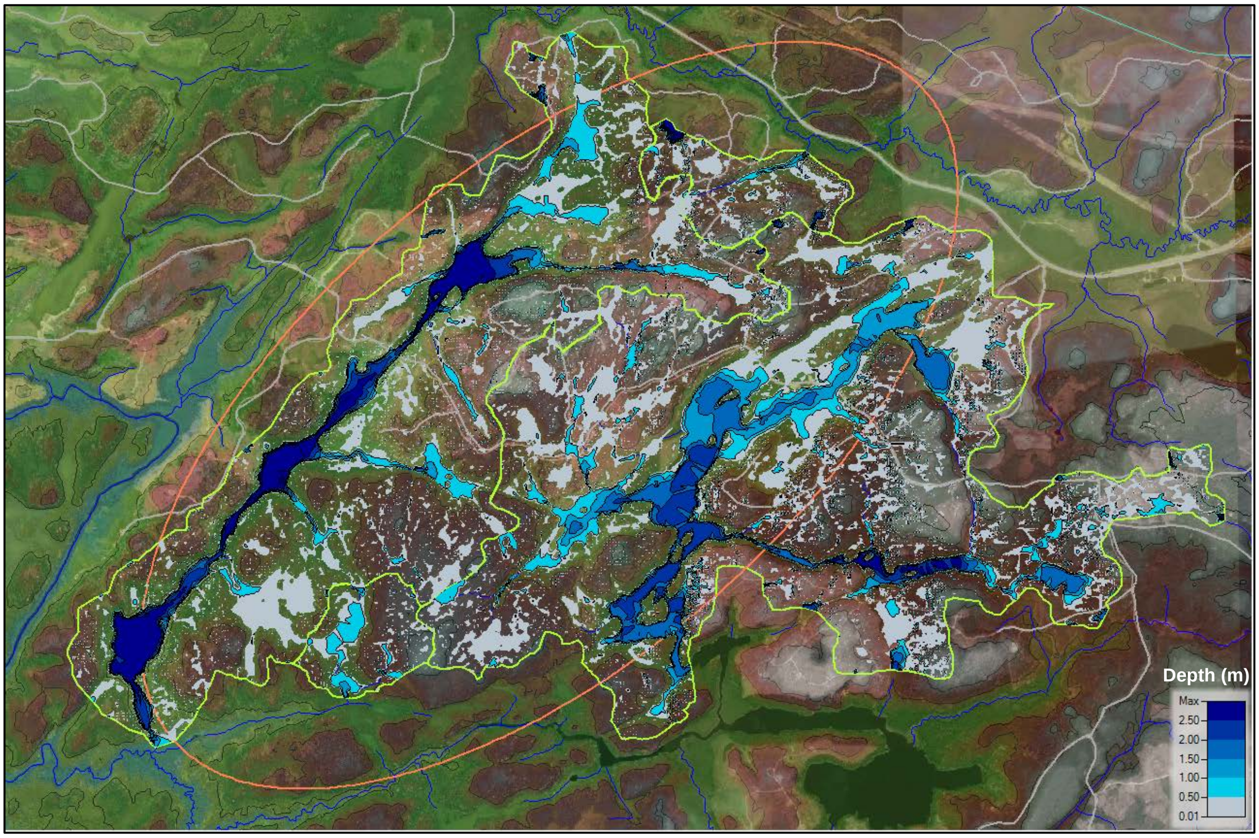

Figure 10: Scenarios 3 and 4 – Floodplain Boundaries for Mid-Century (50%)

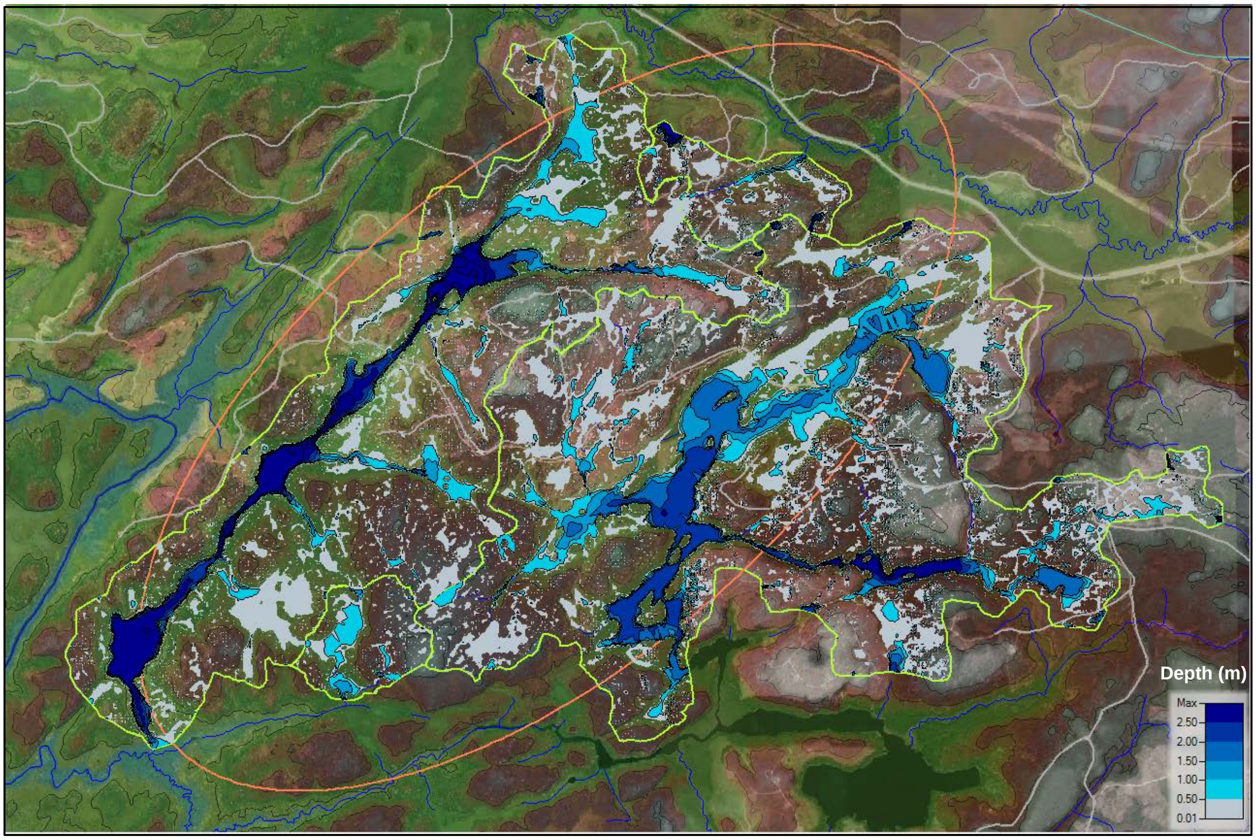

Figure 11: Scenarios 5 and 6 – Floodplain Boundaries for Mid-Century (75%)

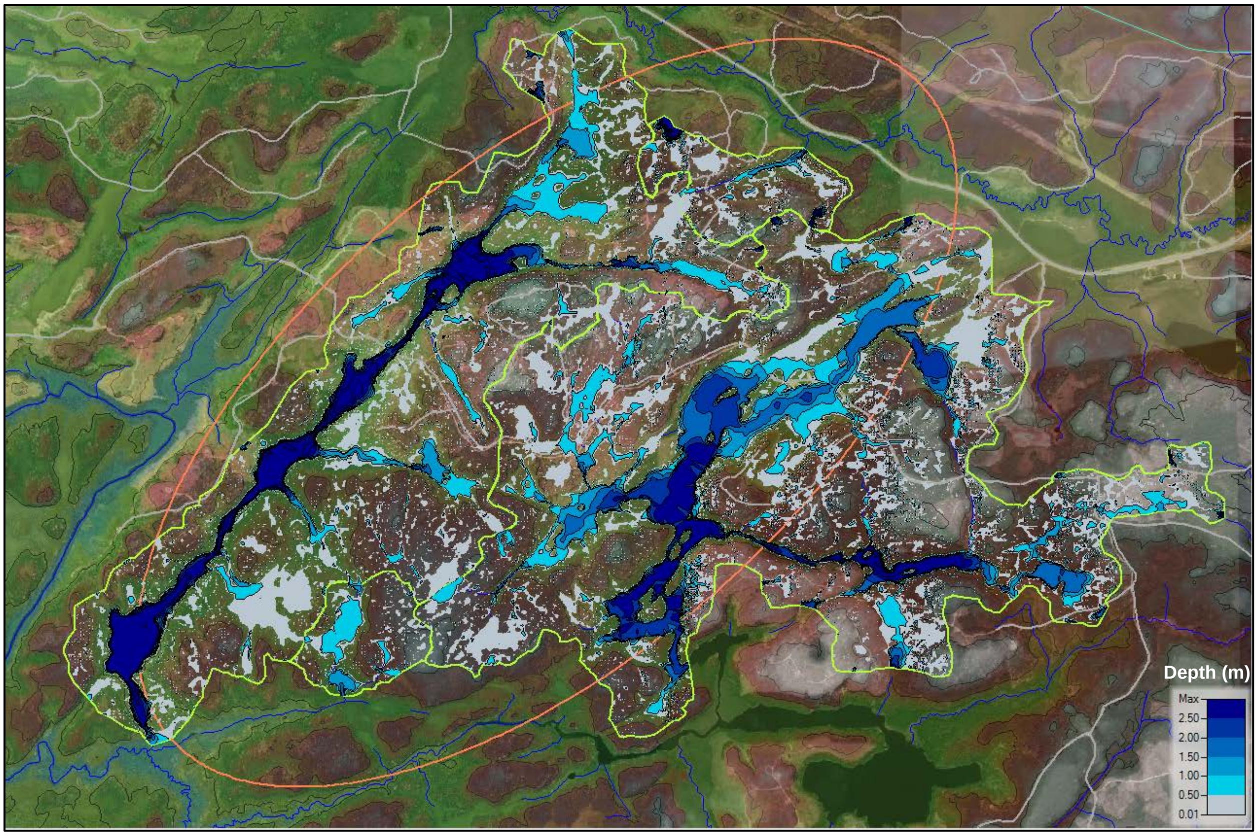

Figure 12: Scenarios 7 and 8 – Floodplain Boundaries for Mid-Century (95%)

For the mid-century scenarios, the model results show that increasing precipitation amounts have a minimal impact on floodplain boundaries. This is because the proposed Revell site is located at the upstream divide of catchments CA1 and CA2, and therefore there is limited area where precipitation can accumulate and be transformed into surface runoff as it is routed downstream.

The same effect can be observed in the end-of century scenarios. Additionally, the floodplain boundaries within the floodplains are similar for all scenarios because, unlike the main channel, once the floodplain is active it takes a significant amount of flow to increase water elevations.

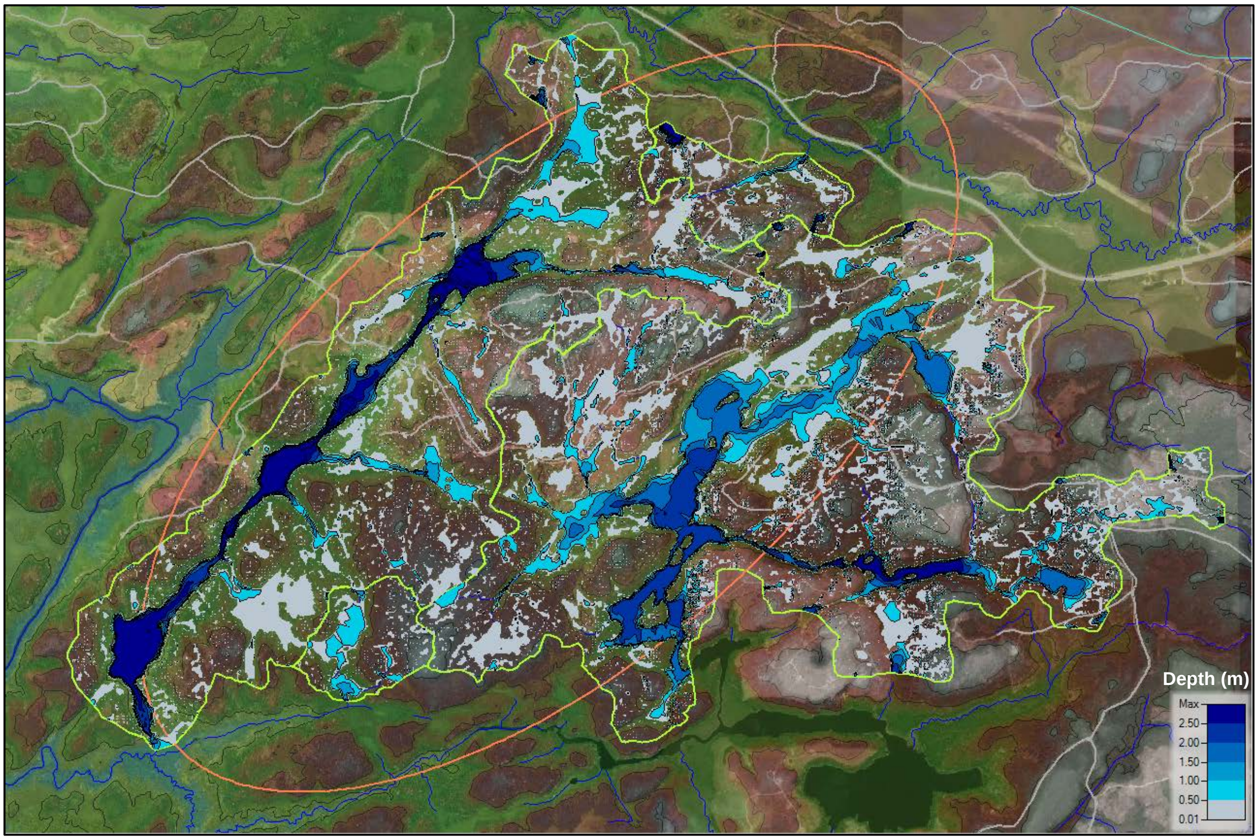

Figure 13: Scenarios 9 and 10 – Floodplain Boundaries for End-of-Century (50%)

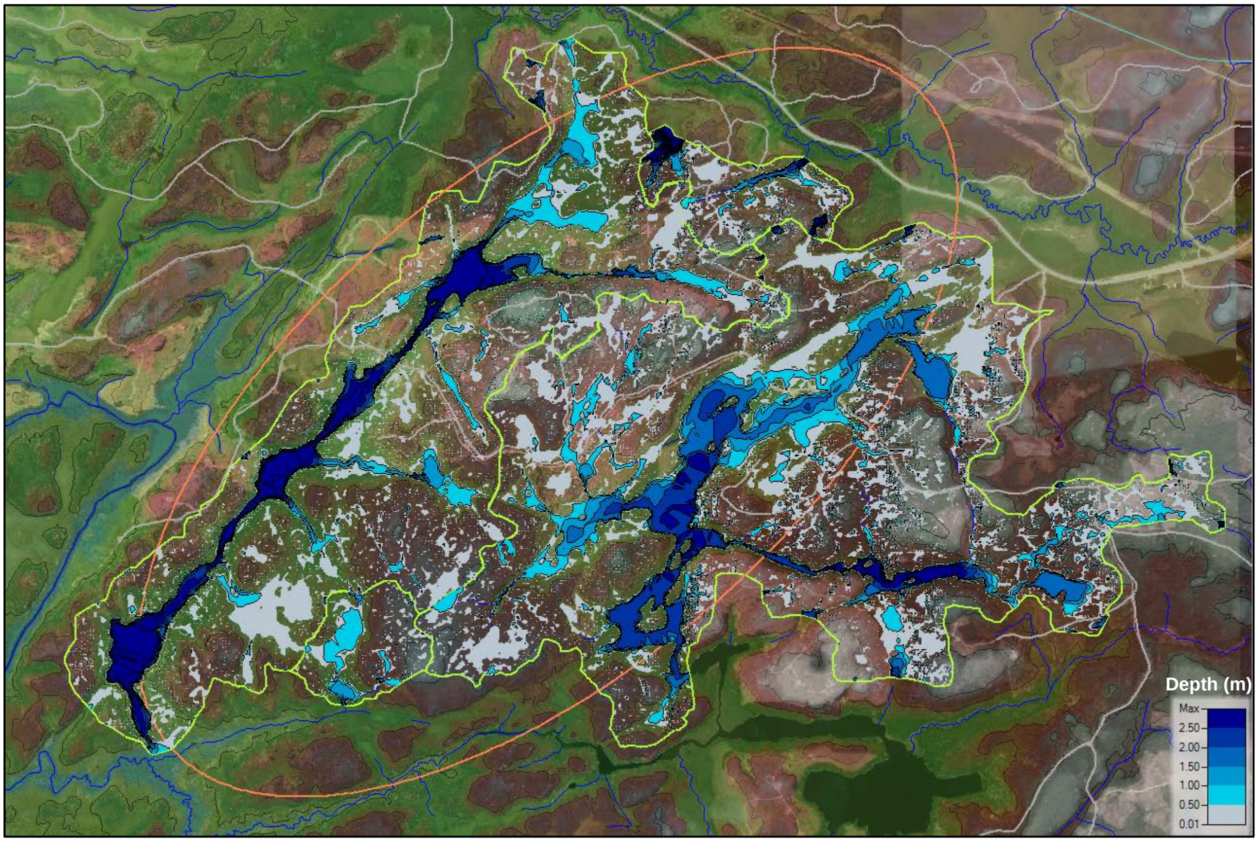

Figure 14: Scenarios 11 and 12 – Floodplain Boundaries for End-of-Century (75%)

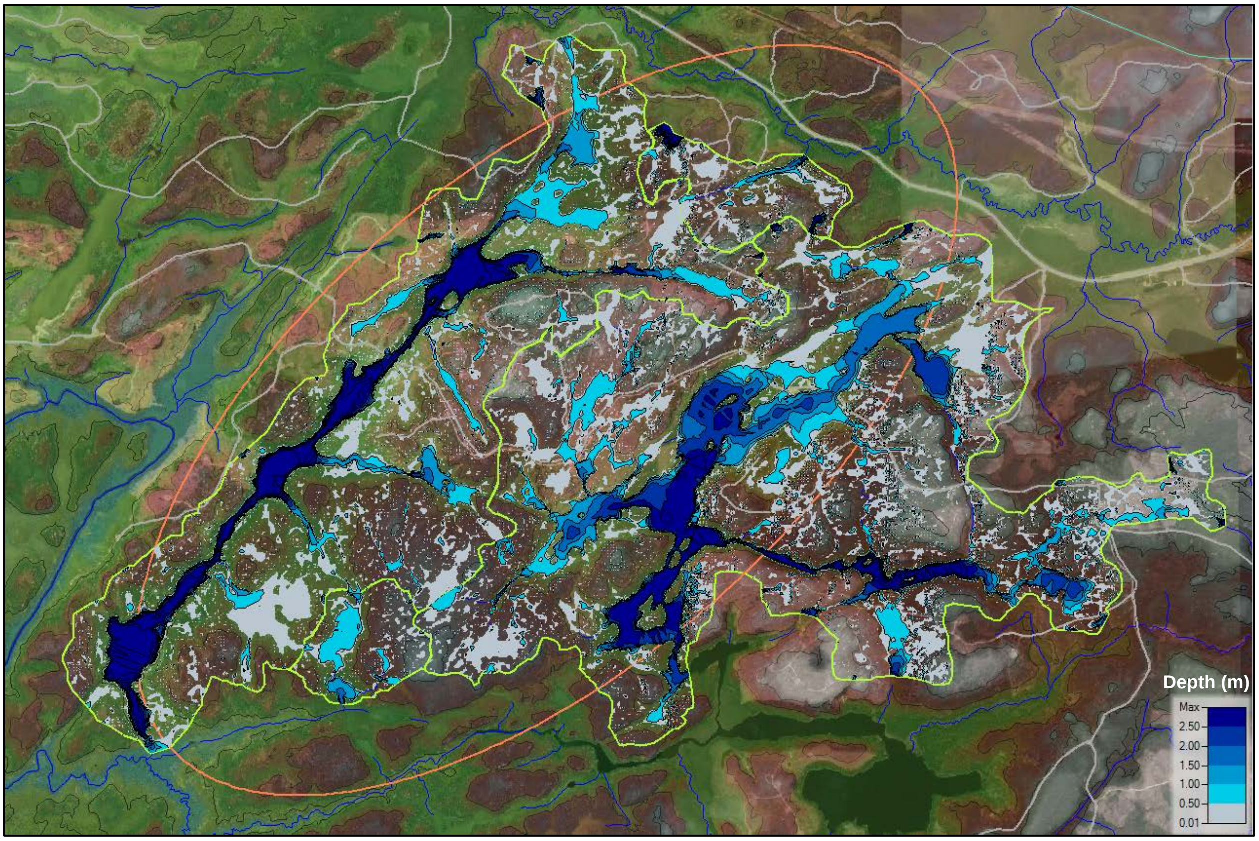

Figure 15: Scenarios 13 and 14 – Floodplain Boundaries for End-of-Century (95%)

As shown in the figures, surface flooding is present across different areas within the site for all scenarios. This is in part because the LiDAR data shows the existing terrain without future grading works. It is expected that the proposed stormwater management measures and site grading will address major flooding for proposed infrastructure.

The model results also show areas where surface ponding occurs, therefore, a more detailed analysis of impacts is warranted to determine areas of concern based on the proposed site grading for surface facilities and the road access to the site and the rock waste area.

6. SENSITIVITY ANALYSIS

To assess the impact of variations in input parameters on peak flows (hydrologic model) and water levels (hydraulic model) a sensitivity analysis was completed.

Two input parameters from the hydrologic model and one parameter from the hydraulic model were selected; these are the SCS curve number (CN), the time of concentration (Tc) and the Manning's roughness coefficient.

As part of the sensitivity analysis, the base input parameters for each of the hydrologic and hydraulic models were increased by 20%. For the hydrologic parameters, each drainage area has its own CN values assigned as shown in Table 6, therefore for each drainage area the CN was increased by 20% to carry out hydrologic simulations for all 14 scenarios.

Similarly, the time of concentration for each drainage area (Table 7) were increased by 20% to carry out the hydrologic simulations. For the sensitivity analysis for the hydrologic model parameters, the simulations with modified SCS curve numbers and times of concentration were completed separately. The results of the sensitivity analysis for the hydrologic modeling are summarized in Table 18 and Table 19.

Table 18: Percent Change in CN - 20% increase vs. Base Model

Catchment Area ID	Percent Change % of Peak Flow - Scenarios						
	1-2	3-4	5-6	7-8	9-10	11-12	13-14
CA1	13	11	10	9	11	9	8
CA2	13	11	11	9	12	10	8
CA3	16	13	12	10	13	12	9
CA4	14	11	11	9	11	10	8

Table 19: Percent Change in Tc - 20% increase vs. Base Model

Catchment Area ID	Percent Change % of Peak Flow - Scenarios						
	1-2	3-4	5-6	7-8	9-10	11-12	13-14
CA1	-13	-13	-13	-13	-13	-13	-13
CA2	-13	-13	-13	-13	-13	-13	-13
CA3	-10	-10	-10	-10	-10	-10	-10
CA4	-12	-12	-12	-12	-12	-12	-12

The results of the sensitivity analysis for hydrologic parameters shows that the increased CN values resulted in increased peak flows for all catchment areas and scenarios, it was also observed that the increases were consistent between all scenarios for each drainage area, where the highest values correspond to the current condition (scenarios 1-2) while the lowest changes occurred for scenarios 13-14. Overall, the hydrologic model is not extremely sensitive to changes of the SCS curve number.

An increase by 20% of the time of concentration (Tc) resulted in peak flow decreases for all drainage areas under all scenarios. The percent difference in peak flows versus the base model is consistent between all scenarios for all drainage areas. The sensitivity analysis on the hydrologic parameters indicates that the resulting peak flows are impacted by changes to both CN and time of concentration, however across scenarios, the change is consistent, and the differences are not significant.

The Manning's roughness coefficient was selected as the hydraulic parameter for the sensitivity analysis to assess the impact on the resulting water levels. The Manning's n is based on land cover characteristics with the base parameters included in Table 17.

The selected Manning's coefficients were increased by 20% for all land cover types within the drainage areas except for clear open water which has a Manning's roughness of 0.001 and is not expected to change. To assess the impact on the water levels, two comparison points were chosen as shown in Figure 16.

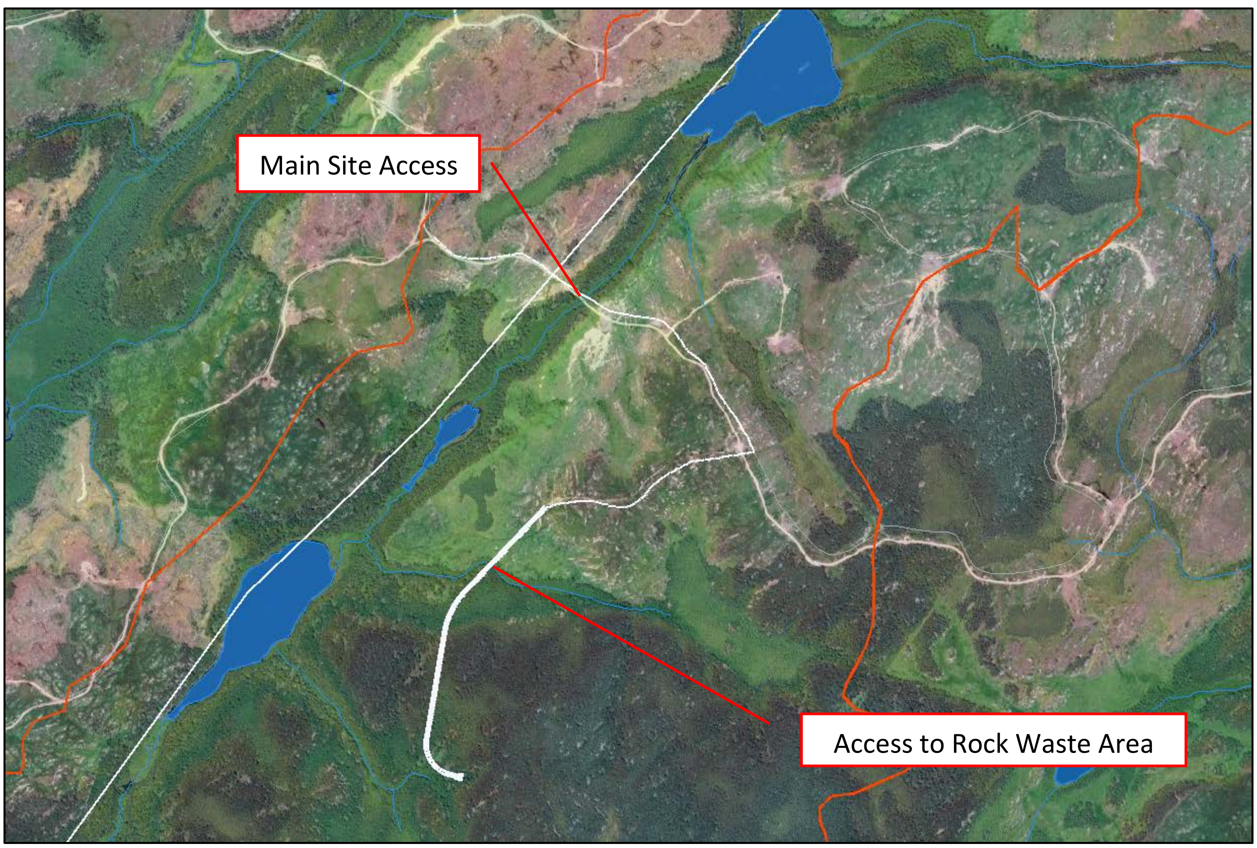

Figure 16: Location of Points for Water Level Changes - Sensitivity Analysis

The results of the sensitivity analysis from the hydraulic model are summarized in Table 20.

Table 20: Percent Change in Manning's Coefficient vs. Base Model

Location	Percent Change % of Water Elevations - Scenarios						
	1-2	3-4	5-6	7-8	9-10	11-12	13-14
Main Site Access	2.0	2.0	2.2	1.7	2.0	1.7	1.5
Access to Rock Waste Area	0.5	0.2	1.0	0.7	0.5	0.5	0.7

The results of the sensitivity analysis on water elevations indicate that the increase in Manning's roughness coefficient has a limited impact with minimal increases ranging from 0.2% to 2.2%.

Overall, the sensitivity analysis for peak flows (hydrologic model) and water elevations (hydraulic model) at the sampled points show that a change in model parameters have a limited impact on the model results, suggesting that the hydrologic and hydraulic models are able to simulate all scenarios and maintain a narrow range of results even with changes in parameters. This condition is favourable with respect to the requirements of this preliminary flood hazard assessment because the model results are consistent without large variations when certain parameters are modified.

7. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made for the Revell site within the Ignace study area:

- A qualitative hazard assessment was carried out following the Specific Safety Guide SSG-18 by the International Atomic Energy Agency (IAEA 2011), specifically the items included in Section 5 of the document which provides recommendations regarding the analysis of hydrological hazards. The results of the qualitative analysis show that, based on the available information and site conditions, flooding hazards due to extreme precipitation events require further consideration and other hydrological hazards are determined to be of no significance.

- Catchment delineations were completed using the Ontario Flow Assessment Tool (OFAT) and then refined using GIS software with the available LiDAR data. The catchment areas were labeled CA1 to CA4.

- A total of 14 scenarios were included in this preliminary flood hazard assessment. These scenarios are divided by period (current, mid-century, and end-of-century), climate change scenario (three PMP risk projections) and by type of flood (direct rainfall on-site and rainfall on upstream catchments).

- The SCS Type II distribution with a duration of 24 hours was applied to the PMP value reported by OMNR (2006) since this is the highest value (436 mm) for Ignace Study Area.

- A hydrologic model of the Revell Site was developed for this assessment with the software HEC-HMS. The results of the hydrologic model indicated that the SCS-Type II distribution creates the highest peak flows for all catchments.

- A hydraulic model was created with the software HEC-RAS, to transform excess precipitation amounts into surface runoff. The results of the model for all 14 scenarios were mapped and show areas where surface ponding occurs as well as the floodplain boundaries at streams within the site.

- The results from HEC-RAS show that surface ponding may occur across portions of the site based on current topography, before grading and ditches. It is recommended to repeat the analysis of surface flooding once there is a specific site location, grading and general arrangement of the surface facilities.

- Even when flooding is present at the locations indicated above, there is limited opportunities for runoff to accumulate given the location of the site at the divide of catchments CA1 and CA2.

- The model also indicated the potential for surface ponding and overtopping along the stream in catchment CA2 where a potential access road to the site is located. It is recommended to consider grading the road access to reduce the depth of water overtopping and provide adequate conveyance during extreme events.

- Incorporate a contingency plan to access the site if a PMP event occurs and the main road access becomes closed.

8. ABBREVIATIONS AND ACRONYMS

AECOM – AECOM Canada Ltd.

AEP – Annual Exceedance Probability

BCCAQ – Bias Correction/Constructed Analogues with Quantile

CDA – Canadian Dam Association

CN – Curve Number

DEM – digital elevation model

DGR – Deep Geological Repository

GIS – Global Information System

Golder – Golder Associates Ltd.

HEC – Hydrologic Engineering Center

HMS – Hydrologic Modeling System

IAEA – International Atomic Energy Agency

IDF – Intensity-duration-frequency

LiDAR – Light Detection and Ranging

LOCA – Localized Constructed Analogs

LRIA – Lake and Rivers Improvement Act

MIFM – Modified Index Flood Method

MNR – Ministry of Natural Resources

MNRF – Ministry of Natural Resources and Forestry

MTO – Ministry of Transportation

NOEGTS – Northern Ontario Engineering Geology Terrain Study

NRCan – Natural Resources Canada

NWMO – Nuclear Waste Management Organization

OFAT – Ontario Flow Assessment Tool

OLCC – Ontario Land Cover Compilation

PMP – probable maximum precipitation

RCP – Representative Concentration Pathways

RAS – River Analysis System

SCS – Soil Conservation Service

SWM – stormwater management

UFPP – Used Fuel Packaging Plant

USACE – United States Army Corps of Engineers

WMO – World Meteorological Organization

REFERENCES

AAFC. 1998. Agriculture and Agri-Food Canada. Soil Classification Working Group. The Canadian System of Soil Classification. Third Edition. Publication 1646, (Revised). 187 pp.

AAFC. 2013. Agriculture and Agri-Food Canada. ISO 19131 Soils of Canada, Derived – Data Product Specification. Ottawa, Canada. 89pp.

AMEC. 2011. OPG's Deep Geologic Repository for Low and Intermediate Level Waste Maximum Flood Hazard Assessment. NWMO DGR-TR-2011-35. AMEC NSS Ltd. Canada. 158pp.

CDA. 2007. Canadian Dam Association. Dam Safety Guidelines. Toronto, Canada. 86pp.

ESRI. 2020. Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Maps were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved.

Gartner, J.F., Mollard, J.D., and Roed, M.A. 1981. Ontario Engineering Geology Terrain Study Users' Manual. Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study Volume l, 51pp.

Golder. 2020. Climate Change Impacts on Climate Variables for a Deep Geological Repository (Ignace Study Area). Nuclear Waste Management Organization Technical Report NWMO-TR-2020-04. Toronto, Canada.

International Atomic Energy Agency (IAEA). 2011. Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations: Safety Guide. Jointly sponsored by the International Atomic Energy Agency and the World Meteorological Organization. Vienna, Austria. 172pp.

MNR. 2002. Ontario Ministry of Natural Resources. Water Resources Section. Technical Guide – River and Stream Systems: Flooding Hazard Limit. Peterborough, Canada. 118p.

Mollard, D.G. and Mollard, J.D. 1981. Mount Royal Area (NTS 52H/NE), District of Thunder Bay. Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 26, 18 pp.

MTO. 1997. Drainage Management Manual. Drainage and Hydrology Section, Transportation Engineering Branch. Ontario Ministry of Transportation. Toronto, Canada. 257 pp.

MTO. 2016. Ontario Ministry of Transportation, IDF Online Lookup Tool. http://www.mto.gov.on.ca/IDF_Curves/map_acquisition.shtml

NRCan. 2009. National Research Canada. Atlas of Canada 6th Edition. Ottawa, Canada.

OMNR. 2004. Ontario Ministry of Natural Resources. Lake and River Improvement Act Technical Guidelines – Criteria and Standards for Approval. Ontario, Canada.

OMNR. 2006. Ontario Ministry of Natural Resources. PMP for Ontario. Prepared by IBI Group.

Ontario Geological Survey, Ministry of Northern Development and Mines, and Northeast Science and Information Section, Ministry of Natural Resources. 2005. Digital Northern Ontario Engineering Geology Terrain Study (NOEGTS); Ontario Geological Survey, Miscellaneous Release-Data 160pp.

Pysklywec, D.W., K.S. Davar and D.I. Bray. 1968. Snowmelt at an Index Plot. Water Resource. 4(5), 937-946

USACE. 1984. Shore Protection Manual. Volume I. Coastal Engineering Research Center, U.S. Army Corps of Engineers. Washington, USA. 337pp.

WMO. 2009. Manual on Estimation of Probable Maximum Precipitation (PMP). WMO-No. 1045. Secretariat of the World Meteorological Organization. Geneva, Switzerland. 291pp.

WMO. 1998. Guide to Wave Analysis and Forecasting. Secretariat of the World Meteorological Organization. Geneva, Switzerland. 168pp.