OPG's DEEP GEOLOGIC

REPOSITORY

FOR LOW & INTERMEDIATE LEVEL WASTE

Maximum Flood Hazard Assessment

March 2011

Prepared by: AMEC NSS Ltd.

NWMO DGR-TR-2011-35

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EXECUTIVE SUMMARY

Ontario Power Generation (OPG) has entered a process to seek Environmental Assessment and licensing approvals to construct a Deep Geologic Repository (DGR) for Low and Intermediate Level Waste (L&ILW) near the existing Western Waste Management Facility (WWMF) at the Bruce nuclear site in the Municipality of Kincardine, Ontario.

In support of the design of the proposed DGR project, maximum flood stages need to be estimated as these could potentially affect the DGR project. This report provides an assessment of potential flood hazard risks associated with coastal, riverine and direct precipitation flooding.

Coastal Flood Hazard

The estimation of lake flooding for the Bruce nuclear site considered potential extreme water levels in Lake Huron, storm surge and seiche, wind waves, and tsunamis.

Monthly mean lake levels range from 176.3 to 176.6 m (176 m chart datum) and the historical maximum is 177.5 m. An assessment of possible future lake levels including potential climate change effects indicates that future Great Lakes water levels are uncertain, though in the survey completed there is a preponderance of predicted decreases in lake levels versus lake level increases. The predicted ranges are on the order of a 0.5 m rise to a 1.5 m fall.

For an assessment of potential lake flooding, it is the maximum or extreme water levels that are of interest. A 500-year maximum daily mean of 178.4 m, based on a previously completed Gumbel analysis of historical water level measurements from nearby Goderich, was chosen as an extreme lake level for the investigation of potential lake flooding. To this was added a predicted maximum storm surge of 1.3 m resulting from passage of a severe Alberta Clipper storm and nearshore propagation of 100-year extreme waves from offshore which result in significant wave heights of up to 6 m within 100 m of the shoreline.

For a cross-section of the site topography from the lake shoreline near MacPherson Bay to the southwestern boundary of the DGR operational area, which represents the shortest distance from the lake, resultant wave setup and wave uprush estimates are as high as 0.48 m and 1.6 m respectively. These result in an extreme water level prediction of 181.8 m which translates to a horizontal distance of approximately 500 to 550 m inland. This is well-removed from the DGR operational area. It is concluded that there is no potential for lake flooding.

A regional screening, which included review of the historical record and potential earthquake and landslide tsunamigenic sources, concluded that the Bruce nuclear site is not subject to tsunamis.

Riverine Flood Hazard

The riverine flood hazard assessment has considered the Probable Maximum Flood (PMF) within the Stream ‘C’ and Little Sauble River watersheds, and within local drainage areas that will be directly impacted by the site development, all factors that could affect the proposed DGR development. Pertinent literature, studies, and historical data were assembled and examined in light of the proposed DGR development. Where necessary to support the assessment, suitable hydrologic and hydraulic models were developed and applied.

The design flood event used to determine the flood hazard is the PMF event. The PMF is the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area. Probable Maximum Precipitation (PMP) is defined as the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year, with no allowance made for long-term climatic trends (WMO 1986, ASCE 1996). It is common practice that the PMF is the flood which is a direct result of the PMP. This assessment concluded that there is no riverine flood hazard.

A sensitivity analysis investigating the impact of more extreme Lake Huron water levels, including the 100-year and 500-year lake levels in combination with the PMF was also completed. This analysis concluded that PMF water levels in proximity to the critical DGR operational areas and infrastructure were not influenced by changing lake levels.

Direct Precipitation Flood Hazard

A series of hydraulic models were developed, based on DGR project site grading and ditching, as defined in the Preliminary Safety Report (OPG 2011a) to assess the impact of the PMF on the DGR site. It was concluded from the results of this analysis that the PMF in proximity to the critical DGR operational areas and infrastructure would be 186.6 m. It was found that:

- The potential for floodwater entering the underground works can be mitigated by setting collar elevations at the maximum computed PMF elevation plus an appropriate freeboard;
- Increasing the general DGR operational site elevation (presently set at 186 m) is not anticipated to result in higher computed PMF water levels;
- Increasing the elevation/grade of Interconnecting Road in the vicinity of the DGR site is anticipated to increase PMF water levels across the DGR site; and
- If the final design for drainage works (e.g. ditches and culverts) is of a similar nature to that depicted in the Preliminary Safety Report, then computed PMF water levels will be similar to that documented in this report. "Upsized" drainage infrastructure could, however, potentially have a positive influence on computed PMF water levels (e.g. lower water level) and conversely downsizing could have a negative impact.

Conclusions of the Flood Hazard Assessment

This flood assessment concluded that there is no potential for lake or riverine based flooding and the DGR area is not affected by tsunamis.

However, a PMP event occurring directly at the DGR site has the potential to generate flood levels in excess of 186 m (the DGR site preliminary design elevation). The maximum water surface elevation was estimated to be about 186.6 m (i.e., maximum 60 cm PMF level) at a number of locations around the operational area of the DGR site based on scenario #3 of the evaluation which was based on general stormwater/channel ditch configurations, culverts internal to the DGR site and the allowance for out of channel spills. As such, it is recommended that future design efforts recognize and accommodate this potential flood hazard.

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1. INTRODUCTION

Ontario Power Generation (OPG) has entered a process to seek Environmental Assessment and licensing approvals to construct a Deep Geologic Repository (DGR) for Low and Intermediate Level Waste (L&ILW) near the existing Western Waste Management Facility (WWMF) at the Bruce nuclear site in the Municipality of Kincardine, Ontario. The proposed DGR project will be constructed about 680 m below ground surface in the low permeability limestone formation. Nuclear Waste Management Organization (NWMO) has been tasked by OPG with managing the DGR project and conducting all technical and licensing activities, including preparing the license application.

In support of the design of the proposed DGR project, maximum flood stages need to be estimated as these could potentially affect the DGR project. AMEC NSS was retained by NWMO to provide consulting services for the Derivation of Probable Maximum Flood and Estimation of Lake Flooding for the Bruce nuclear site (hereinafter referred to as “the Project”).

It should be noted that although this Project is not governed by specific guidelines with regard to the flood risk assessment, available guidelines from the International Atomic Energy Agency (IAEA 2003) and the Canadian Nuclear Safety Commission (CNSC 2008) provide a framework for the quantification of flood risk at nuclear sites. The most relevant aspect of these guidelines with regard to the present assessment is the use of the Probable Maximum Precipitation as the design rainfall for evaluation of potential flood risk.

1.1 Scope of Work

The Project consisted of the following tasks:

Task 1: Project Quality Plan

A Project-specific Quality Plan (PQP) prepared in line with the requirement of the DGR Project Quality Plan (NWMO 2009a).

Task 2: Description of Existing Bruce Nuclear Site Conditions for Flood Hazard Analyses

A description of the existing Bruce Site conditions for the flood hazard analyses based on existing information available to the Project team was prepared. This was accomplished by compiling the relevant information for the Bruce nuclear site. This included, but was not limited to, the following.

- Watershed: The local Stream ‘C’ watershed, which is bounded by the Underwood Creek watershed to the north and Little Sauble River watershed to the south, and discharges into Lake Huron via Baie du Doré. The Stream ‘C’ catchment upstream of the Bruce site encompasses an area of approximately 860 ha (~3.3 sq miles).
- Site Drainage: Local site drainage contributing watershed, including Stream ‘C’, occupies a drainage area of about 200 ha, of which 25 ha comes from the Western Waste Management Facility (WWMF) and the immediate surrounding area (including most parts of the DGR location), and discharges into the railway ditches and a wetland immediately east of the site. The railway ditch drains into Stream ‘C’.
- Coastal and Lake Setting: Lake Huron hydrology and circulation, and wind and wave conditions. This includes definition of long return period, e.g., 100- and 500-year, still lake water levels.
- The existing Bruce nuclear site conditions for potential flooding hazard.

Task 3: Definition of Probable Maximum Precipitation (PMP)

- Define PMPs for a range of durations including 6, 12, and 24 hours storms; and
- Get agreement with NWMO on the range of PMPs to be studied.

Task 4: Derivation of Probable Maximum Flood (PMF) with PMP

The PMFs for the chosen range of PMPs were derived. The assumptions to be used in this task included, but were not limited to, the following:

- PMP is the design storm event for this work;
- Final grade at the DGR site is the current site grade;
- Waste rock piles;
- Internal storm drainage system of the Waste Rock Management Area (WRMA) and DGR operational area; and
- 100-year still lake level.

Task 5: Estimation of Potential Lake Flooding Level

The potential flooding level due to lake-related causes was assessed. The assessment included:

- Extreme water levels in the lake;
- Flooding by storm surges and seiche; and
- Flooding by waves and tsunamis.

It should be noted that this Project does not engage in design of the drainage systems for DGR waste rock management and surface facilities area. This project focuses specifically on the identification of potential impacts to the DGR site from extreme flood producing events given the current preliminary design of the drainage system and other site parameters.

2. BRUCE NUCLEAR SITE

2.1 Physical Setting

The Bruce nuclear site is located on the eastern shore of Lake Huron at latitude 44° 19' N, longitude 81° 34' W and within the municipality of Kincardine, Bruce County, Ontario Canada. The location of the Bruce nuclear site, covering an area of about 932 ha, is shown in Figure 2.1 (OPG 2005).

There are two watersheds in the vicinity of the Bruce nuclear site, i.e., Penetangore River watershed and Lake Fringe watershed which consists of several sub-watersheds. Within these watersheds numerous small rivers and creeks, including Underwood Creek, Little Sauble River, Tiverton Creek, Andrews Creek, and Penetangore River, discharge directly into Lake Huron. Detailed description of some of these watersheds can be found in Chapter 3.

Figure 2.1: Location of Bruce Nuclear Site

The Bruce nuclear site was developed in stages between 1970 and 1987 by Ontario Hydro (Bruce Power 2004). Although OPG, Ontario Hydro's successor, is the owner of the Bruce nuclear site, the majority of the site is controlled by Bruce Power, the current operator of the Bruce Nuclear Generating Stations (BNGS). Bruce Power also controls all access to the site.

OPG has retained control of the portion of the Bruce nuclear site encompassing the WWMF and surrounding lands. WWMF stores L&ILW from the operation of OPG's 20 nuclear reactors, including those operated by Bruce Power. The proposed DGR is expected to be constructed in the area near the WWMF.

2.2 The Deep Geologic Repository

2.2.1 Overview of the DGR

The DGR would be designed for the long-term management of L&ILW currently stored at the Bruce nuclear site and future L&ILW generated by OPG-owned nuclear generating stations through the remainder of their operating lifetimes. The DGR project includes the site preparation, construction, operation and long-term performance of above- and below-ground facilities. The preliminary design of the DGR is illustrated in Figure 2.2 (OPG 2011a). The proposed DGR concept is similar to facilities in operation in Sweden, Finland and the United States (OPG 2005).

The DGR would be constructed in competent sedimentary bedrock beneath the Bruce nuclear site. The estimated size of the surface facilities for the DGR is approximately 30 ha, including the construction laydown area and rock pile. The footprint of the underground facilities is approximately 40 ha. All surface facilities for the DGR would be located on OPG-owned land at the Bruce nuclear site near the existing WWMF, and the underground repository would be entirely within the boundaries of the Bruce nuclear site.

The DGR surface facilities consist of the underground access and ventilation buildings, associated temporary or permanent buildings, and related infrastructure. The DGR underground facilities would be comprised of access-ways (shafts, ramps and/or tunnels), a series of horizontal emplacement rooms excavated at a nominal depth of approximately 680 m below surface, and various underground service areas and installations. The DGR surface and underground facilities are illustrated in Figure 2.3 and Figure 2.4, respectively (Chapter 6, OPG 2011a).

The operation of the DGR would be co-ordinated with the existing WWMF. Waste packages received would be lowered to the emplacement horizon and then stacked within the emplacement rooms. When each emplacement room is full, it would be isolated by end walls. Once all the waste has been emplaced, and following an interim monitoring period, the entire DGR repository would be closed.

2.2.2 Site Features

The layout of the DGR project area is presented in Figure 2.5 (OPG 2011b). The general features of the DGR site include:

- The existing WWMF site;
- The proposed DGR site;
- A railway drainage ditch that lies between the existing WWMF and the DGR site;
- Two wetland areas; and
- Roadways.

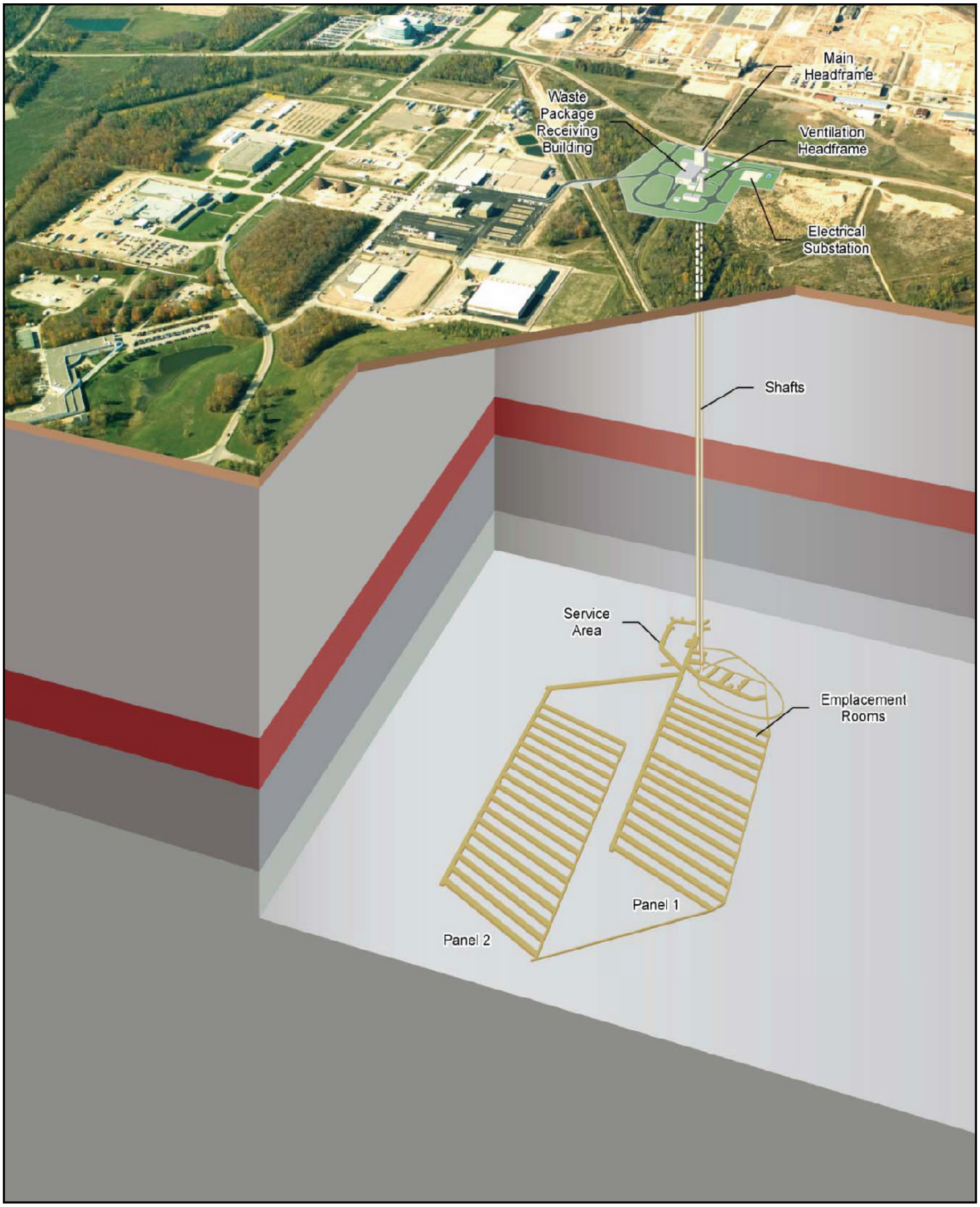

Figure 2.2: Preliminary Design of DGR at Bruce Nuclear Site

The general built features of the proposed DGR development include:

- Roadway crossing of the railway ditch (noted above);
- Vegetated buffer and perimeter ditch;
- Stormwater retention pond;
- Waste Rock Management Area (WRMA);
- Primary working areas of the DGR including the waste package receiving building; and
- Electrical substation and emergency generator.

Of particular relevance to this flood risk assessment are four surface features that are directly connected to the underground workings of the DGR site. These four features are potential ingress points for flood water to the underground areas. They are:

- Main shaft;
- Intake plenum;
- Exhaust plenum; and
- Ventilation shaft.

The electric and emergency power facilities, critical to DGR operations, are also relevant with regard to this flood risk assessment.

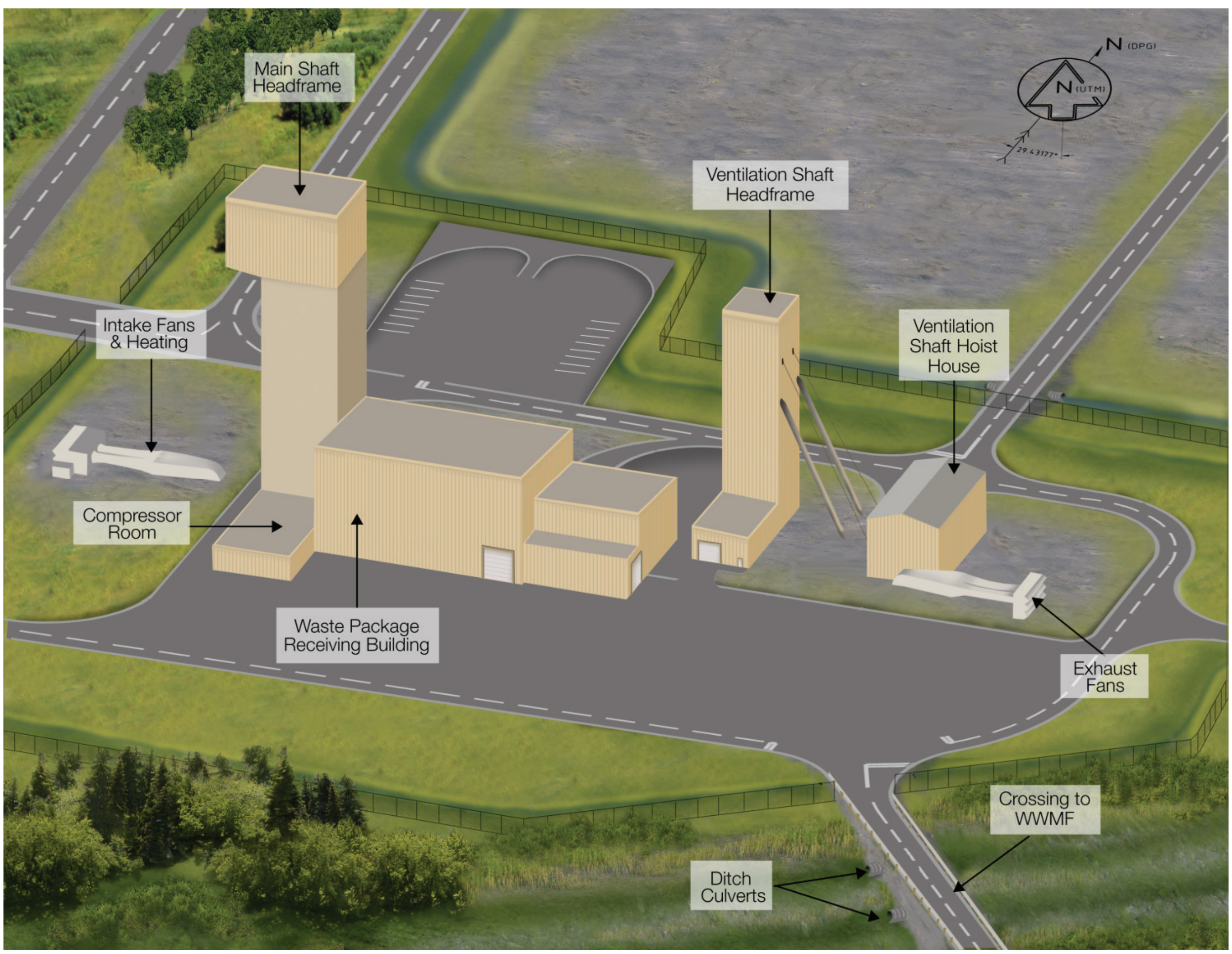

Figure 2.3: Illustration of DGR Surface Facilities

2.2.3 Topography

A detailed topographic survey of the Bruce nuclear site was completed by 4DM Inc. for OPG. The Digital Elevation Model (DEM) and Light Detection And Ranging (LIDAR) files for the site were developed in the UTM NAD83 (Zone 17) co-ordinate reference system.

The LIDAR data indicates that the OPG controlled lands change in elevation between 180 to 195 m above sea level (mASL). Lake Huron is shown to have a surface water elevation of 176 m. The lands designated for the DGR project have elevation changes between 181 m (in the northern portion of the site) and 187 m (in the southern portion of the site).

The site is generally flat with open natural and anthropogenic landscapes and wooded areas (Bruce Power 2008a).

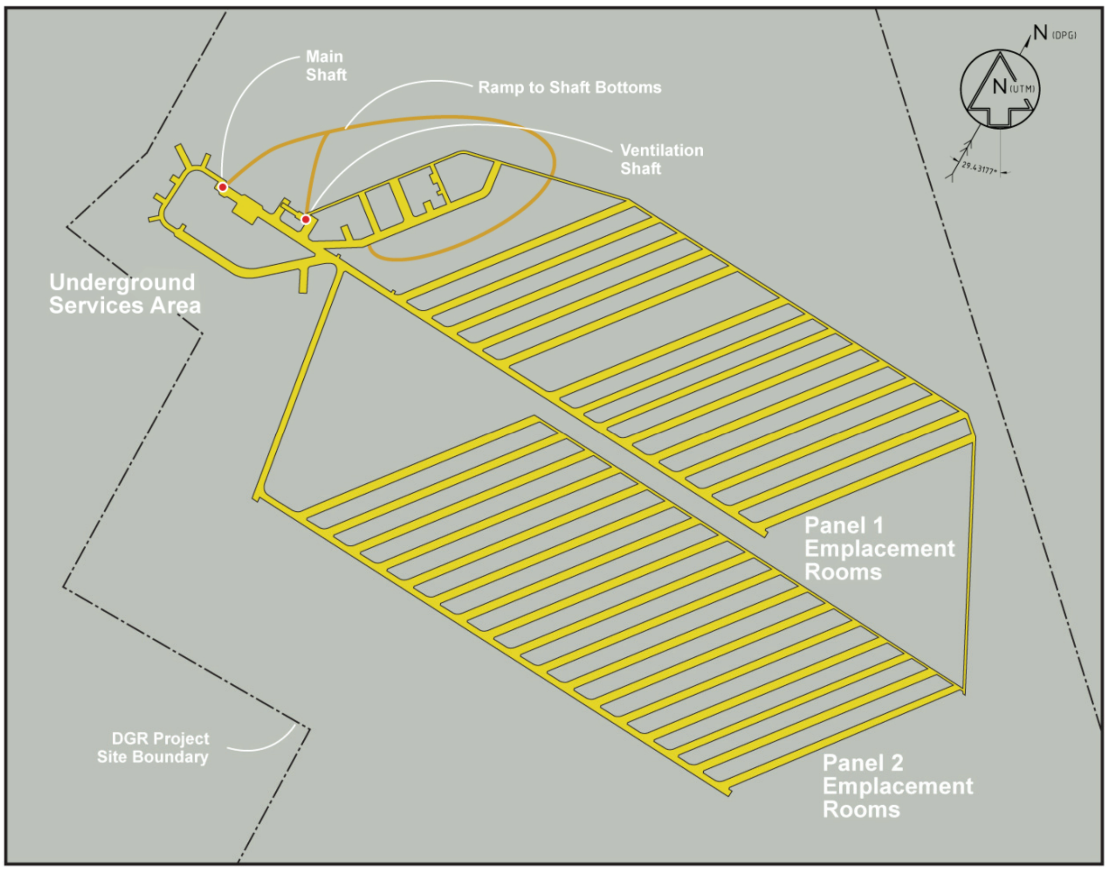

Figure 2.4: Illustration of DGR Underground Facilities

2.2.4 Surficial Soils

The DGR site is located within the Lake Fringe Watershed as defined by the Saugeen Valley Conservation Authority (SVCA). The following description of area surficial soils is provided in the “Lake Fringe Watershed Report Card” (SVCA 2008):

- 23% silty loam;
- 18% clay loam;
- 16% fine to moderately coarse sandy loam;
- 12% silty clay;
- 11% medium to moderately fine loam;
- 6% organic material;
- 6% other (including small percentages of alluvium, breypan, bottomlands, etc);
- 6% coarse sandy loam and loamy sand;
- 0.3% gravel; and
- 1.7% undefined.

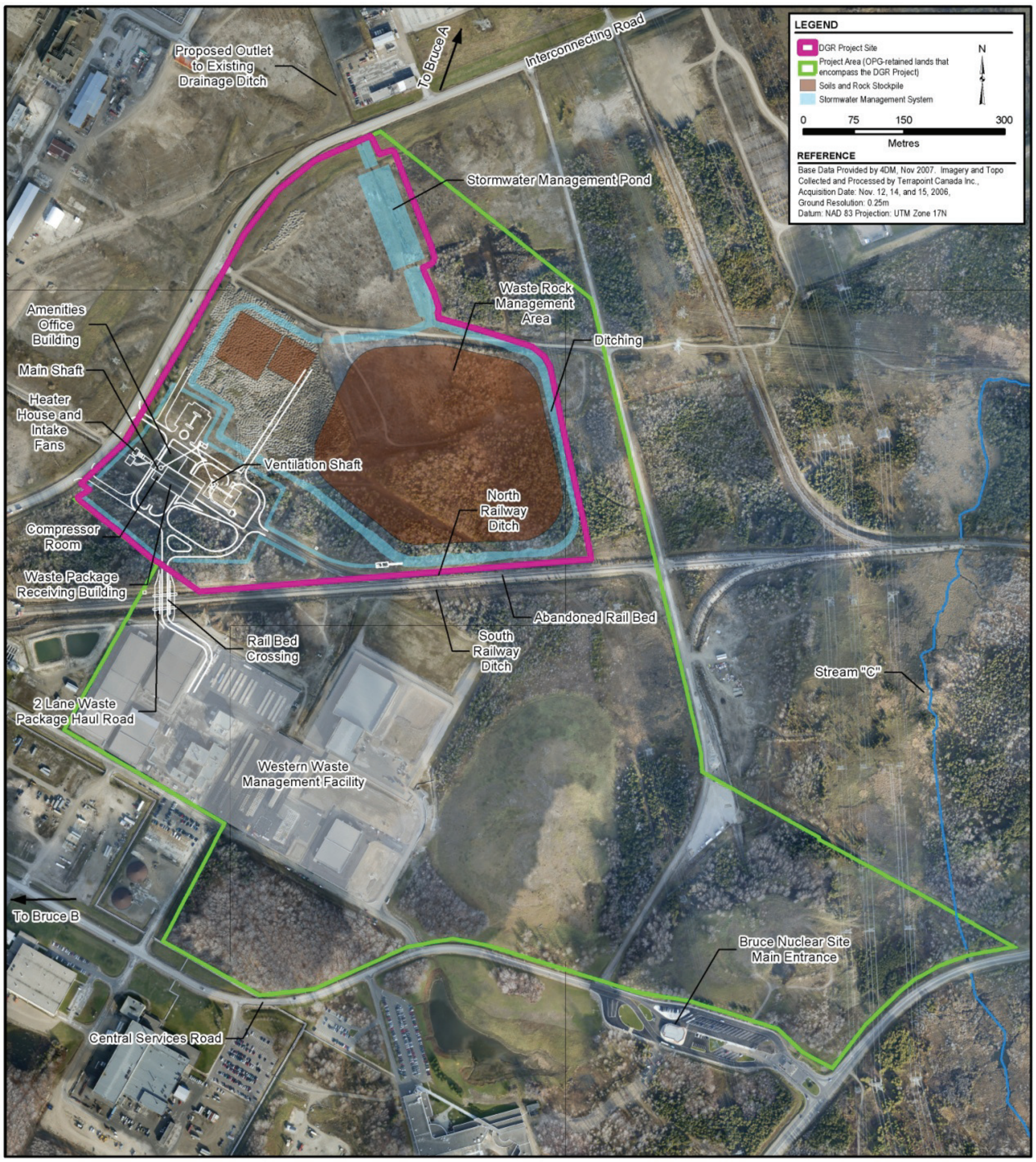

Figure 2.5: Layout of the DGR Project Area

3. POTENTIAL FLOOD HAZARDS

Floods can occur at any time of the year. Floods can result from heavy rains, snowmelt, spring break-up and ice jams on rivers, wind-generated storm surges or seiches across large lakes, waves propagating onshore, tsunamis, or the failure of dams. Lands that are vulnerable to flooding are referred to as flood plains or hazard lands.

Canada's most expensive natural disasters have historically been floods. Flood-related disasters have resulted in substantial economic losses. During the 20th century, flooding caused at least 168 disasters in Canada that resulted in several billion dollars in losses and the deaths of at least 195 people (NRCAN 2007). The Canadian insurance industry has now identified water as the number one cause of damage to homes in Canada (IBC 2009).

In Ontario, flooding is considered to be the most significant natural hazard in terms of death, damage and civil disruption (OMNR 2010). Ontario has a history of severe flood events, including, the following.

- The Hurricane Hazel flood of 1954 that caused 81 deaths and estimated damages of $133 million which occurred in the Toronto area (OMNR 2010). The current Ontario regulatory definition of Hurricane Hazel totals 211 mm over 12 hours.
- The Peterborough flood of July 15, 2004 resulted in insured losses exceeding $88 million. A record 175 mm of rainfall was experienced over the City, with rainfall totals exceeding 235 mm in many neighbourhoods. It was noted that during the hour between 3:30 am and 4:30 am, a rainfall of 78.8 mm was measured (Environment Canada 2010a).
- Southern Ontario rains of August 19, 2005 caused the highest insured loss in the province's history, exceeding $500 million. The storm dumped 103 mm of rain in one hour across a swath of North York and surrounding area (Environment Canada 2010a).
- The Harrow storm of July 19 and 20, 1989 caused widespread flooding due to 450 mm of rain in a 30-hour period (Environment Canada 2010a).

Information from these and forty-four (44) other flood related disasters in Ontario over the period 1900 through present are compiled in the Canadian Disaster Database (Public Safety Canada 2009).

An internet review of information regarding historical flooding in the vicinity of the DGR site focused primarily on the Saugeen River, the largest river system in the jurisdiction of the SVCA. Some localized flooding of residences along the beach in Inverhuron has been recorded (IDRA 2009).

Although no flood damage to the existing facilities at the Bruce nuclear site has been reported since operations began in the early 1970s (Bruce Power 2008b), potential flooding scenarios at a location such as the DGR site could be attributed to a number of conditions including:

- Flood hazards associated with riverine flooding;
- Flood hazards specific to on-site precipitation; and
- Flood hazard risks associated with coastal flooding.

An overview focusing on each of these flooding scenarios in the context of the DGR site is provided in the following sections.

3.1 Riverine Drainage

The DGR site is located within the area known as the Lake Fringe Watershed. The Lake Fringe Watershed is a narrow strip of land along Lake Huron stretching from Kincardine to South Hampton. The Lake Fringe Watershed is comprised of wave cut terraces of glacial Lake Algonquin and Lake Nipissing with boulders, gravel bars and sand dunes (SVCA 2008).

Within the Lake Fringe Watershed numerous small rivers and creeks discharge directly into Lake Huron. A number of these watercourses flow through or adjacent to the DGR site, including Little Sauble River, Underwood Creek and Stream ‘C’, as illustrated in Figure 3.1. These watersheds bound surface drainage from the Bruce nuclear site.

Table 3.1 provides general information about these watersheds.

Table 3.1: Summary Information for Watersheds Located near the Bruce Nuclear Site

Watershed	Drainage Area [2] (ha)	Watershed Length:Width Ratio	Average Watershed Slope (%)
Little Sauble River	4,441.9	3.8	0.8
Stream ‘C’	1,183.9 [1]	10.3	0.8
Watershed ‘UN1’	190.6	3.6	2.2
Watershed ‘UN2’	257.8	2.8	2.2
Watershed ‘UN3’	323.0	7.3	1.3
Underwood Creek	2,050.0	5.0	0.8

Notes:
1. Drainage area to discharge point at Baie du Doré. Drainage area delineation on the Bruce nuclear site based on (GOLDER 2011).
2. Drainage areas outside of the Bruce nuclear site were refined based on site LIDAR mapping. Areas beyond the LIDAR mapping were delineated using Ontario Base Mapping (OBM) data.

Stream ‘C’ is the only natural watercourse that traverses the Bruce nuclear site. Stream ‘C’ is a former tributary of the Little Sauble River that was diverted, and presently flows in a constructed channel (Bruce Power 2008a), to Baie du Doré during the initial development of the Bruce nuclear site in the 1960s (OPG 2001). The drainage area of Stream ‘C’ is reported to be 1,042 ha at the North Access Road. A portion of Stream ‘C’ is located in proximity to the DGR site (within about 600 m). No historic data on Stream ‘C’ water levels through the Bruce nuclear site are available nor is there any documented or anecdotal evidence of flooding problems associated with this watercourse (Bruce Power 2008b).

The distance between the Little Sauble River and Stream ‘C’ just below the shoreline of the old Lake Algonquin and Lake Nipissing is only about 1 km. The watershed divide in this approximate location is only about 1 m above the top of bank of the Little Sauble River and Stream ‘C’ (abstracted from LIDAR data). This suggests the possibility of floodwaters breaching this boundary and flowing into the adjacent watershed.

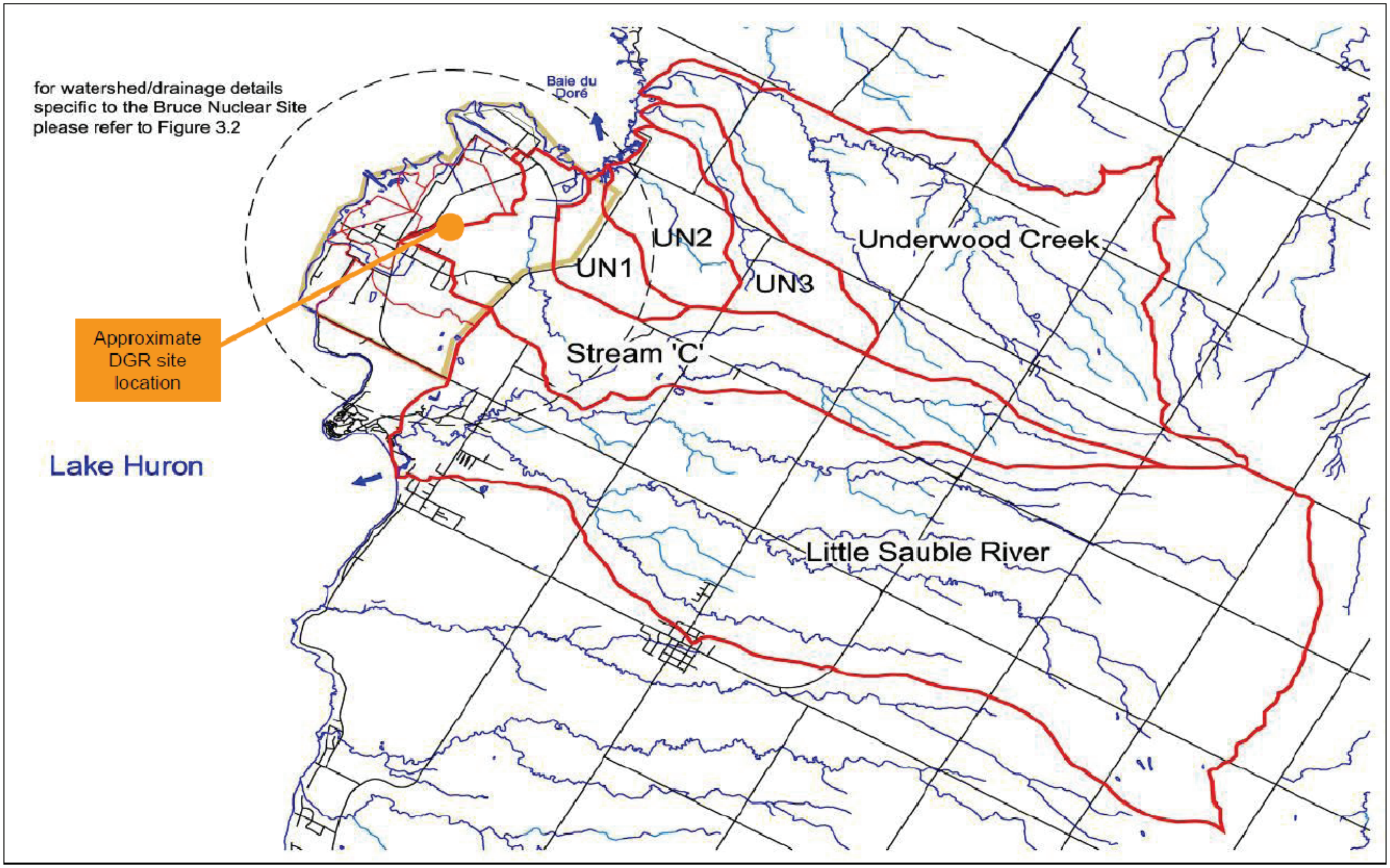

Figure 3.1: Local Watersheds in Proximity to the Bruce Nuclear Site

Some other relevant comments with regard to flooding potential in these watersheds include:

- No water retaining structures (such as dams) have been identified from the available information; and
- Numerous roadway culverts have been identified along the subject watercourses. Flooding resulting from transient obstructions (such as debris and/or ice) is a relevant consideration.

Reports focused on floodplain calculations for the Little Sauble River upstream of the 2nd Concession Road were also obtained from the SVCA (CRA 1985a, CRA 1985b, CRA 1989). A review of these documents indicated the following:

- Floodplain calculations were based on the 100 year and Regional Floods; and
- No spill was identified from the Little Sauble Creek to Stream ‘C’.

A site reconnaissance visit was conducted by AMEC staff on April 14 and 15, 2010. The focus of this visit was field measurement of culverts to be included in the hydraulic modeling effort for this project. No observations were made during this site visit that indicated information contrary to that documented in the background materials.

The review of the remainder of the background material did not identify any reference to historical flooding in the subject watersheds.

3.2 Local Site Drainage

The Bruce nuclear site, including areas controlled by OPG, has an extensive system of catchbasins, sub-surface storm sewers, manholes and open ditches and culverts (GOLDER 2011). Stormwater runoff from the site discharges to Lake Huron through several outfalls and natural features. The sub-surface storm sewer system has been generally designed to a 10 year standard (OPG 2001). The delineation of drainage areas within the Bruce nuclear site is illustrated in Figure 3.2 (GOLDER 2011). Drainage areas for these subcatchments are provided in Table 3.2.

The DGR site, in its predevelopment state, is located within the Stream ‘C’ (about 30%) and MacPherson Bay South (about 70%) subcatchments. This DGR development area is generally flat with an average overland slope of 0.006 m/m and is drained via a system of ditches within railway and road right-of-ways. These drainage ditches are expected to contain water only as a result of rainfall events. Land cover across the proposed DGR site is generally open brush areas with construction debris is some locations. No paved areas are presently located within the DGR development zone (GOLDER 2011).

A feature of the DGR development is a perimeter ditch system that encompasses the site (see Figure 2.5). This system will encompass both the ‘built’ area of the DGR and the WRMA. The purpose of the perimeter ditch system is to ensure that all drainage from the DGR site is directed to the retention pond for treatment before discharge (GOLDER 2011).

The perimeter ditch will result in a minor reduction, of about 4.2 ha or about -0.3%, to the drainage area contributing to the Stream ‘C’ watershed.

Stormwater runoff from the ‘built’ area of the DGR will be collected in a network of vegetated, trapezoidal drainage ditches. Drawing H333000-WP404-10-042-0001 of the Preliminary Safety Report (OPG 2011a) indicates a typical section for the DGR surface facilities perimeter ditch as having a 1 m bottom width, minimum 1 m depth and 2.5H: 1V side slopes.

Figure 3.2: Drainage Areas Internal to the Bruce Nuclear Site

Table 3.2: Summary Information for Watersheds Located within the Bruce Nuclear Site

Watershed	Approximate Drainage Area[1](ha)
Bruce A	33.5
Bruce B West	29.9
Bruce B North	117.7
Bruce B South	160.5
Douglas Point North	12.5
Douglas Point South	41.3
MacPherson North	47.9
MacPherson South	94.1

Notes:
1. Abstracted from (GOLDER 2011).

Stormwater runoff from the WRMA will be collected in a network of vegetated, trapezoidal drainage ditches with widths in the 9 m to 17 m range. Drawing H333000-WP404-10-042-0001 indicates a typical section for the WRMA perimeter ditch as having a 3 – 5 m bottom width, minimum 1 m depth and 2.5H:1V side slopes (OPG 2011a). Channel slopes as indicated on the drawing are generally less than 0.5%.

The perimeter ditch system will discharge through a stormwater retention pond designed for the purposes of management of stormwater runoff water quality. The design basis for the on-site drainage system including the stormwater quality retention pond, drainage ditches, etc. is the 100-year 24 hour rainfall event (OPG 2011a). Drawing H333000-WP404-10-042-0001 (OPG 2011a) indicates a pond surface area of about 1 ha.

The retention pond has been designed (OPG 2011a) with capacity to:

- Retain the 6 hour, 25 mm storm for a period of 24 hours; and
- Safely pass the 1:100 year storm event without overtopping of the embankments and erosion of the outlet system.

Water from the retention pond will then be discharged via a controlled outlet (having an invert elevation of 180.5 m (OPG 2011a)) into the existing drainage ditch network along Interconnect Road and ultimately to Lake Huron through the MacPherson North subcatchment.

The shaft pad area of the DGR has a preliminary design elevation of 186.0 m (OPG 2011a).

3.2.1 Capping of the Waste Rock Piles

The limestone pile capping is not currently being recommended. However, capping is recommended for shales and soils to be left for more than one year (OPG 2011a).

3.2.2 On-Site Hydrologic and Hydraulic Analyses

The hydrologic and hydraulic analyses of on-site conditions for the purposes of quantifying flood risk will focus only on the DGR site in an operational state.

The Bruce nuclear site has an extensive stormwater conveyance system. The sub-surface stormwater infrastructure has been designed to a minimum 10 year design event. The PMP design event used for this study is substantially in excess of this design event. As such, the hydrologic and hydraulic analyses will assume a conservative condition whereby these sub-surface stormwater conveyance systems are not functional during the PMF.

The Bruce nuclear site above ground stormwater conveyance system is also extensive. Above ground stormwater conveyance systems are generally designed to accommodate a 100 year design event. The most significant of these features, namely the ‘built’ area and WRMA perimeter ditches and the stormwater retention facility will be integrated into the hydrologic and hydraulic analyses, as appropriate.

While the flood hazard assessment will be based on uncapped waste rock piles, the implications of capped versus uncapped waste rock piles to the stormwater runoff and PMF water levels will also be discussed.

3.3 Lake and Coastal Setting

Lake flooding hazards may arise from a number of factors in isolation or combination: high lake levels, the uprush of waves onto the beach including possible wave overtopping of shoreline structures, and potentially other water-related hazards such as waves from passing ships or the piling of lake ice. Erosion of shorelines is a related consideration and potential concern.

This section presents an overview of existing lake conditions with focus on those parameters that affect and determine the magnitude and frequency of such potentially hazardous events. These include lake levels, wind and wave conditions, storm surge and seiche, together with offshore bathymetry and shoreline profiles in the regions of interest.

3.3.1 Lake Huron

The Bruce nuclear site is located in Bruce County on the eastern shore of Lake Huron, near the community of Tiverton, about 60 km from Goderich to the South, 70 km from Owen Sound and the Bruce Peninsula to the northeast, and about 250 km northwest of Toronto.

Lake Huron, which contains Georgian Bay, is the second largest of the Great Lakes by surface area and third largest by volume.

Table 3.3 summarizes several key physical parameters of Lake Huron (Environment Canada and U.S. EPA 1995). Lake Huron has a total drainage basin area of 134,100 km^2, with 41,700 km^2 from Michigan and 91,100 km^2 from Ontario. Lake Huron has a retention time, traditionally defined as the time it would take to replace the water volume of the lake, of about 22 years.

Precipitation and runoff amount to about 45% of the lake's inflow; 33% is due to inflow from Lake Superior and 22% from Lake Michigan. Evaporation accounts for about 19% of the lake's outflow, while outlet flow through the St. Clair River, Lake St. Clair, and the Detroit River to Lake Erie accounts for 81% of the lake's discharge (GOLDER 2008).

Table 3.3: Lake Huron Characteristics

length	332 km
breadth	245 km
shoreline length (including islands)	6,157 km
average depth	59 m
maximum depth	229 m
volume	3,540 km^3
water surface area	59,600 km^2
chart datum IGLD 1985 [1]	176 m

Figure 3.3 shows the Great Lakes, with the location of the Bruce nuclear site on the shore of Lake Huron shown with a blue X: drainage area; relief, and urban areas within the region are illustrated (Environment Canada and U.S. EPA 1995).

A west to east section view of the Great Lakes shown in Figure 3.4 illustrates the chart datum and depths associated with each lake (DFO 2008).

3.3.2 Lake Levels

Lake levels are variable both in the short-term and long-term and are influenced by natural causes and human intervention.

Natural causes by far induce the greatest magnitude of change. Natural causes include precipitation, evaporation, inflow and outflow, wind, atmospheric pressure, tides[2] or high water level, and ice whereas human-induced changes include diversions, water control structures, and, in some parts of the Great Lakes and connecting channels, ship wakes[3].

[1] In this report, land elevations and (land or river) water surface elevations are given in metres or metres above sea level (mASL). All lake water level elevations are given in metres referenced to a chart datum which is IGLD 1985. IGLD 1985 has its zero base at Rimouski, Quebec near the mouth of the St. Lawrence River (approximate sea level). Hence, the elevations share a datum that is essentially the same.

[2] The Great Lakes and Lake Ontario are considered to be essentially non-tidal since though astronomical tides – the alternate rise and fall of lake water level as a consequence of the simultaneous action of the moon's, sun's, and earth's gravitational forces, and the revolution of the moon about the earth, and the earth and the sun – occur in a semi-diurnal pattern, the largest spring tides are less than 5 cm in height.

[3] This is not likely a concern near the Bruce nuclear site given the nearest shipping lane (e.g., for lake freighters) is 40 km offshore (Golder 2008).

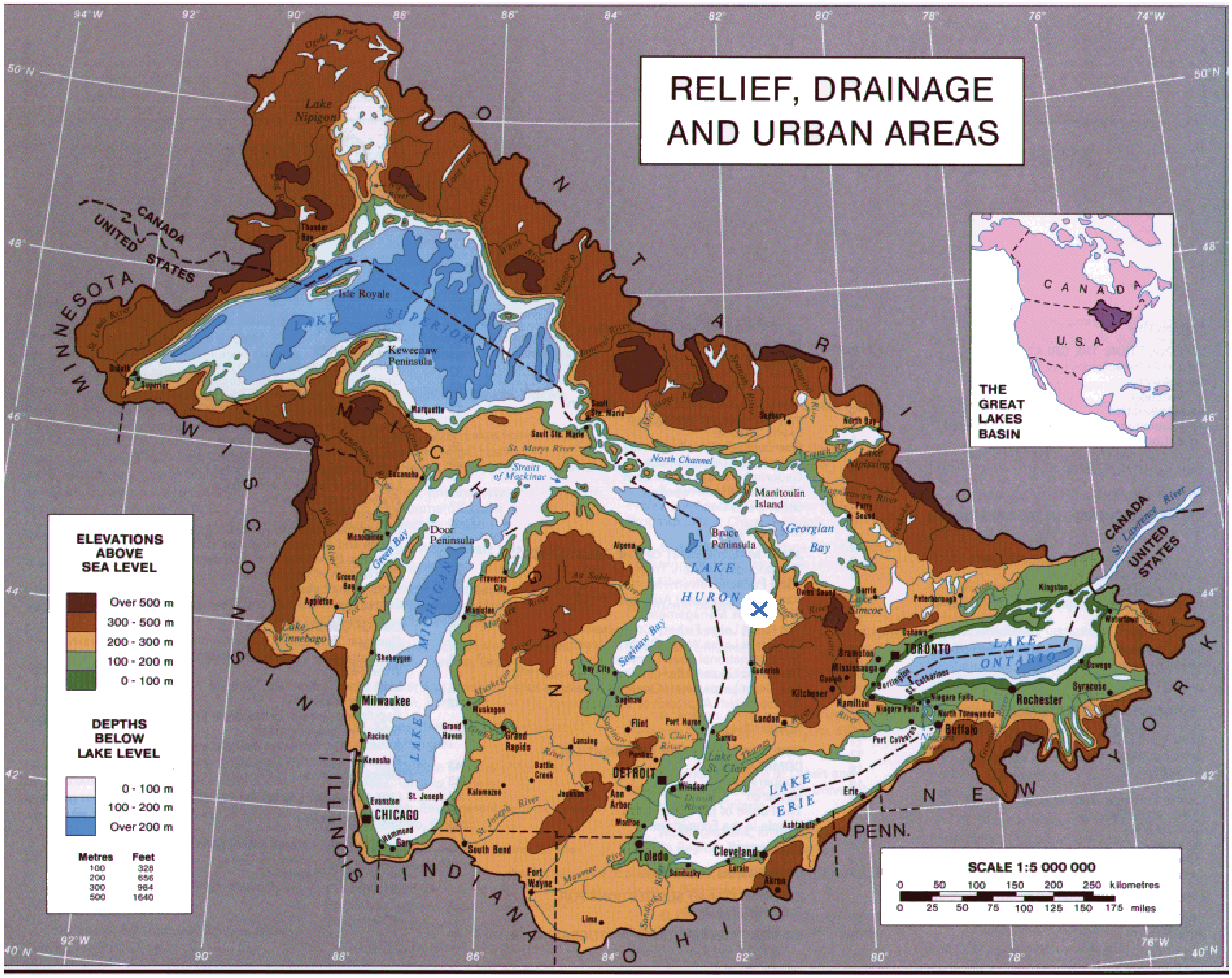

Figure 3.3: Great Lakes Relief, Drainage, and Urban Areas

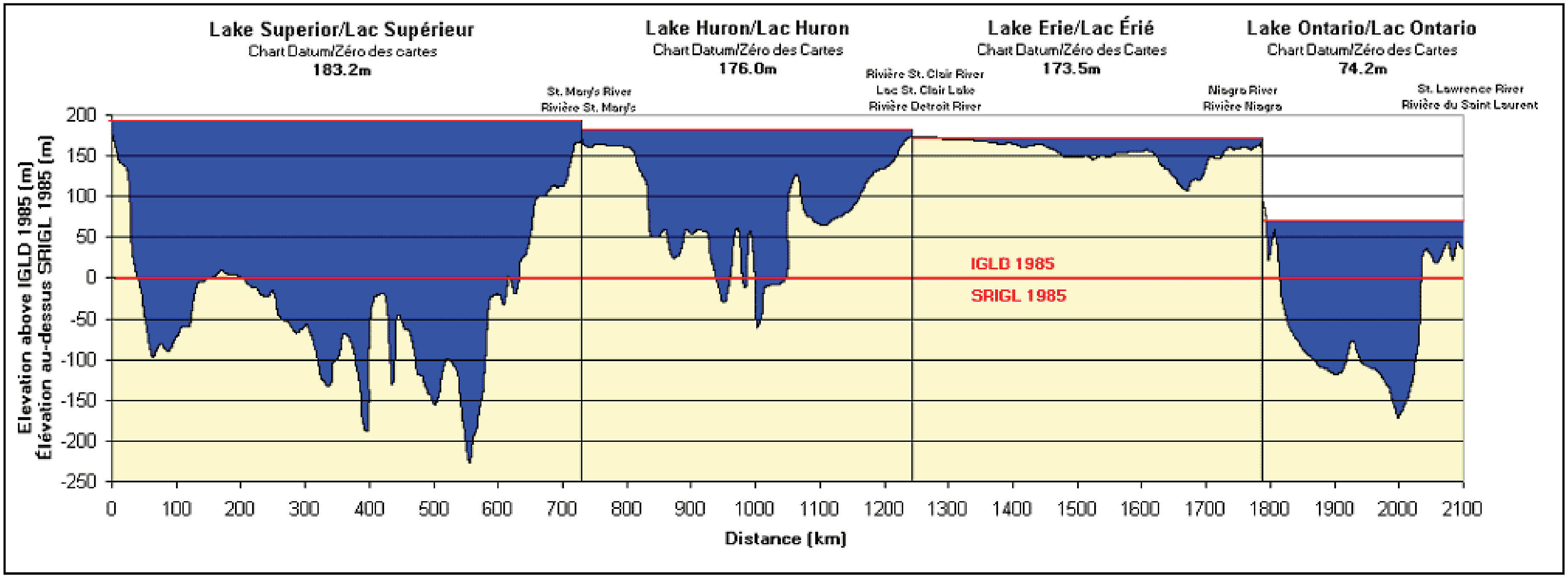

Figure 3.4: Great Lakes Profile

Short-term changes may include seasonal fluctuations due to precipitation and evaporation, and temporary lake level changes due to storms passing through the region result in storm surge or wind setup: high winds blow over the lake surface pushing the water to one shore or another raising the lake level at the shore.

As demonstrated by historical lake level records (for Lake Huron this includes 1918 to the present, and these are summarized below) large, long-term, lake level changes vary between seven and thirty years. These patterns are neither regular nor readily predictable, and are instead directly influenced by changes of climate and hydrological patterns across the entire Great Lakes Basin (Parts 1 (Physical Features and Processes) and 3 (Flooding Hazard) in OMNR 2001).

International Lake Superior Board of Control

Human intervention includes diversions and water control structures. For Lake Huron, regulation provided by the International Lake Superior Board of Control Joint Commission acknowledges and attempts to address the needs of various interest groups, including navigation, hydropower, and property owners adjacent to the lakes and rivers. Background information in the next four paragraphs is taken from the mandate of the International Lake Superior Board of Control (International Lake Superior Board of Control 2009b).

Water flows into Lake Huron, out of Lake Superior, through a collection of structures that stretch across the St. Mary's River. These include three hydropower plants, five navigation locks, and a gated dam at the head of the St. Mary's River rapids, known collectively as the Compensating Works which allow boats to bypass the St. Mary's River rapids which fall about 6 m in a distance of 1.2 km.

The release of water from Lake Superior through the various structures has been completely regulated since the completion of the Compensating Works in 1921.

The main objective of the present regulation plan is to determine a flow that brings the levels of Lake Superior, Michigan and Huron to nearly the same relative position within their respective ranges of actual historic levels. The plan also tries to prevent the level of Lake Superior from rising above or falling below certain water levels. The plan also contains provisions to safeguard against high levels in the harbour below the locks, provides a fixed minimum release, limits winter flows, and employs a forecast of future water supply conditions.

The ability to regulate the outflow from Lake Superior does not mean that full control of lake levels is possible. This is because the major factors affecting the water supply to the Great Lakes, e.g., precipitation over the lake, evaporation, and runoff, cannot be controlled, nor can they be accurately predicted over the long-term.

Historical Perspective and Existing Conditions

Water Level stations include those at Goderich and Tobermory, Ontario, and at numerous locations on the Michigan shoreline, including Lakeport and Harbor Beach. Table 3.4 summarizes some details of these data sets. Of note are maximum measured lake levels at these stations of 177.60 m at Goderich, and 177.73 m at Harbor Beach both during the October-November 1986 time period.

Figure 3.5 shows recent, present, and historical extreme water levels for Lake Huron (DFO 2010a). Recorded monthly mean levels are shown in the solid black line; dashed lines show the probable range of future levels; the all-time (period of record 1918 to 2009) average is shown in the thicker grey line; red and blue note historical maximum and minimum levels respectively together with year of occurrence. Water level is shown in metres above chart datum (176 m, IGLD 1985) on the left axis, and in metres above IGLD 1985. There is an annual seasonal cycle, with maxima in October, and minimums in March.

Table 3.4: Lake Huron Water Level Station Summary Notes

Location	Period of Record	Proximity to Bruce nuclear site	Historical Extreme High/Low Water Levels (m above IGLD 1985) and Measurement Dates
Goderich, ON	May 1914 to present	67 km to the south-southwest	177.603/175.442 09-Nov-86/24-Jan-65
Tobermory, ON	May 1962 to present	103 km to the north	177.576/175.472 06-Oct-86/23-Jan-65
Harbor Beach, MI	Sep 1955 to present	106 km to the west-southwest	177.730/175.427 06-Oct-86/23-Dec-07
Lakeport, MI	Sep 1991 to present	155 km to the southwest	176.706/175.251 29-Sep-09/23-Dec-07

Notes:

Goderich, Tobermory (DFO 2010b); Harbor Beach, Lakeport (NOAA 2010)

Table 3.5 presents a companion table of the monthly historical average, minimum and maximum, and the 2000-2009 average water level values, which are about 0.4 m below historical values (DFO-CHS 2010).

Monthly mean lake levels range from 176.3 to 176.6 m or 0.3 to 0.6 m above the chart datum of 176 m referred to IGLD 1985. The historical maximum (October 1986) of 177.5 m is 1.5 m above chart datum[4]. The maximum over the past 10 years (July and August 2009) of 176.44 is 0.44 m above chart datum. The minimum over the past 10 years (July and August 2009) of 175.68 is 0.32 m below chart datum.

As of Fall 2009, Lakes Superior and Michigan-Huron levels remained below average, but were above levels of 2008. Lake Superior was 13 to 17 cm below average during the past six months. Lakes Michigan-Huron were 13 to 22 cm lower than average. Levels of Lake Superior have been consistently below average since April 1998, while levels of Michigan-Huron have been consistently below average since January 1999 (International Lake Superior Board of Control 2009a).

Figure 3.6 shows Lake Huron yearly average and extreme monthly lake levels for the past 10 years(DFO-CHS 2010). The 2007 minimum monthly mean of 175.68 m is 0.1 m above the historical minimum of 175.58 m (March 1964).

[4] The monthly mean levels are the average of water levels recorded at a network of gauging stations on Lakes Michigan-Huron: this would explain the difference between lake maximum 177.5 m and the Harbor Beach station maximum of 177.730 m.

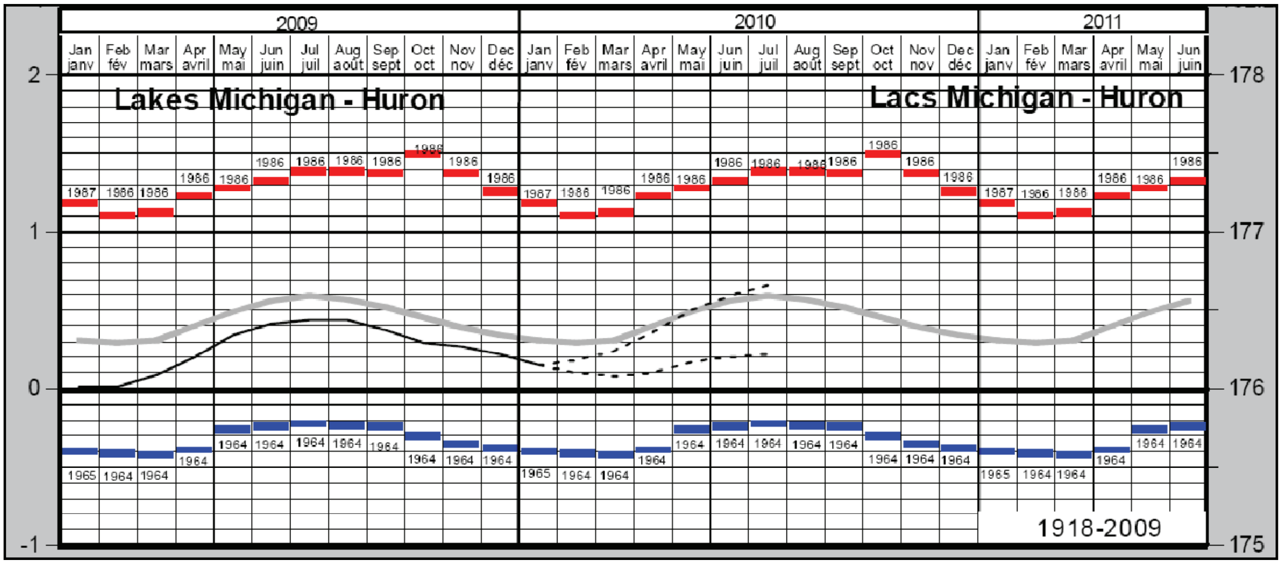

Figure 3.5: Lake Huron Water Levels

Table 3.5: Lake Huron Water Levels

	Water Levels(m IGLD 1985)					
	1918-2009			2000-2009		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Jan	176.31	175.60	177.18	175.90	175.70	176.10
Feb	176.29	175.59	177.11	175.89	175.75	176.20
Mar	176.31	175.58	177.12	175.92	175.73	176.20
Apr	176.40	175.61	177.23	175.99	175.82	176.34
May	176.49	175.74	177.28	176.09	175.92	176.41
Jun	176.56	175.76	177.33	176.18	176.00	176.44
Jul	176.59	175.78	177.39	176.20	176.04	176.44
Aug	176.57	175.77	177.39	176.18	176.00	176.37
Sep	176.52	175.76	177.38	176.12	175.94	176.29
Oct	176.45	175.70	177.50	176.04	175.87	176.27
Nov	176.39	175.65	177.38	175.99	175.77	176.22
Dec	176.34	175.62	177.26	175.95	175.68	176.27
Yearly average	176.43	175.68	177.29			
Minimum monthly	176.22	175.58	177.11			
Maximum monthly	176.60	175.78	177.50			

Extreme Values

The Bruce New Nuclear Hydrology and Water Quality Technical Support Document (TSD) (GOLDER 2008) reports extreme Lake Huron water level estimates from a Gumbel analysis of historical water level measurements from the nearby station at Goderich[5]. 100-year return period values of a maximum daily mean water level of 178.0 m above IGLD 1985, and a maximum instantaneous water level value of 178.3 m above IGLD 1985 are predicted. 500-year return period values of a maximum daily mean water level of 178.4 m above IGLD 1985, and a maximum instantaneous water level value of 178.6 m above IGLD 1985 are predicted.

Additional discussion of extreme lake levels including wind setup (storm surge) is presented in Section 3.3.5.

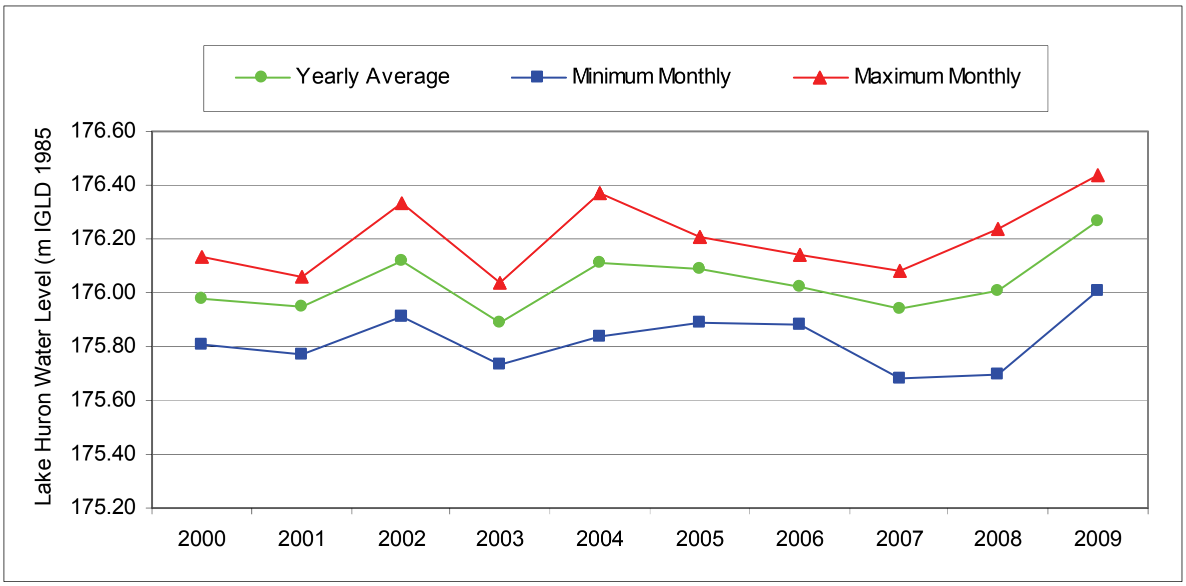

Figure 3.6: Lake Huron Water Levels 2000-2009

3.3.3 Circulation

Currents in the Great Lakes are not strongly persistent. Mean currents depend more on shorter-term atmospheric forcing, changes in pressure as weather systems travel through the region, and winds blowing across the lake, than on a longer-term circulation pattern. Storm-induced currents can be large, on the order of tens of centimetres per second, while average currents are rather weak on the order of several centimetres per second. Nevertheless, the mean circulation is important for many environmental and management issues since it may influence the transport of nutrients and contaminants.

[5] Extreme value estimates were also made from measurements from Tobermory; however, given Tobermory's more exposed location at the end of the Bruce Peninsula the authors recommend using the Goderich estimates as these are more likely representative of the Bruce nuclear site. Estimates for Tobermory were within +/-0.1 m of those for Goderich.

Due to solar warming of the water surface, Lake Huron is stratified in the summer and isothermal in the winter. Baroclinic effects in summer appear to yield a more complex circulation; whereas in winter circulation is almost entirely wind-driven (density-driven currents being quite small in winter) and stronger due to stronger winter winds. In winter, any presence of lake ice will tend to limit the effect of wind on the surface and currents are less.

Astronomical tides, changes in water level caused by the gravitational forces of the sun and moon, do occur in a semi-diurnal pattern on the Great Lakes, though investigations of the U.S. Coast and Geodetic Survey indicate that the largest spring tides are less than 5 cm in height and these minor variations are hidden by greater fluctuations in lake levels produced by wind and barometric pressure changes. Consequently, the Great Lakes and Lake Huron are considered to be essentially non-tidal.

Table 3.6 illustrates seasonal averaged currents in Lake Huron (Beletsky et al. 1999). Circulation is primarily cyclonic (anti-clockwise). Mean coastal summer currents are up to 2 to 4 cm/s, about 8 cm/s in the winter. Seasonal minimum, mean, and maximum averaged currents are reported in (Beletsky et al. 1999). Lake circulation includes a surface flow at about 4.6 cm/s (the largest summer mean currents in Lake Huron) into Georgian Bay implying a return flow at deeper depths. Currents typically change direction with depth and speeds decrease due to baroclinic effects in summer. Much less data are available from which to derive interannual variability measures of the lake circulation. These maps (Figure 3.7) should be considered as examples of seasonal circulation rather than climatology (Beletsky et al. 1999).

Table 3.6: Lake Huron Averaged Currents

Current speed (cm/s)			
Season	**Minimum**	**Mean**	**Maximum**
Summer	0.4	2.4	4.6
Winter	0.2	2.6	7.9

Nearshore the Bruce nuclear site, currents are less like the central lake region. Currents tend to be driven by brief periods of strong winds exerting shear stress at the surface. Changes in current direction tend to lag shifts in wind direction due to the time required for the water to respond to this forcing. Reversals of current direction due to changes in wind direction are common (GOLDER 2008).

The Bruce New Nuclear Hydrology and Water Quality TSD (GOLDER 2008) reports on currents measured at three nearshore locations in the region between 1969 and 1989. The average current speed was about 10 cm/s with maximum speeds of 40 to 50 cm/s recorded. Mean currents varied by month. Relatively stable and slower speeds were seen in the winter; highly variable speeds were seen in summer due to stratified conditions; speeds were greatest in the fall; speeds were less in winter due to ice cover sheltering of the lake surface. Calm conditions were reported about 9% of the time and were five times more likely in winter than the other three seasons. Currents are predominantly parallel to the shore with flow to the northeast about 40-50% of the time and to the southwest about 20-25% of the time. Current directions generally match the prevailing wind direction, particularly in fall and winter.

As also reported in (GOLDER 2008), five months of additional current data from a 600 kHz Acoustic Doppler Current Profiler (ADCP) were collected from May to September 2007 as part of the Bruce A Thermal Impact Monitoring Study, southwest of the Bruce nuclear site about

2 km west of Gunn Point at the southern portion of the study area, at location ‘L14’, in a water depth of about 34 m. The results were similar to the previous historical record. Average current speeds ranged from about 4 to 12 cm/s. Maximum speeds ranged from about 11 to 32 cm/s and were about 21 cm/s on average. Figure 3.8 presents a current rose for the measurement period (GOLDER 2008). More than half the measurements were in the alongshore, northeast and southwest, directions. The majority of observations were to the northeast: 38% of the time.

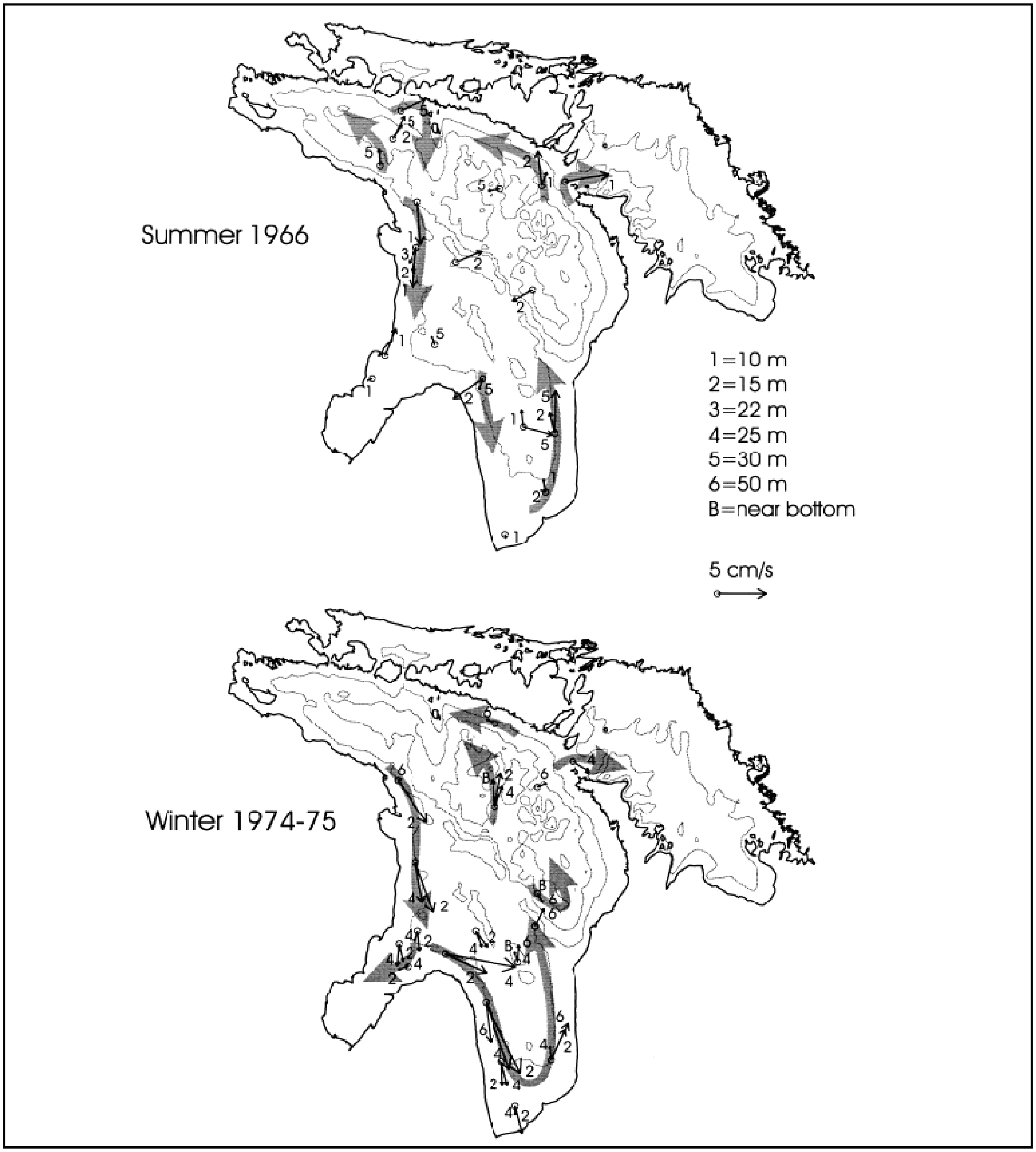

Figure 3.7: Lake Huron Averaged Currents (Depth Contours Shown Every 50 m)

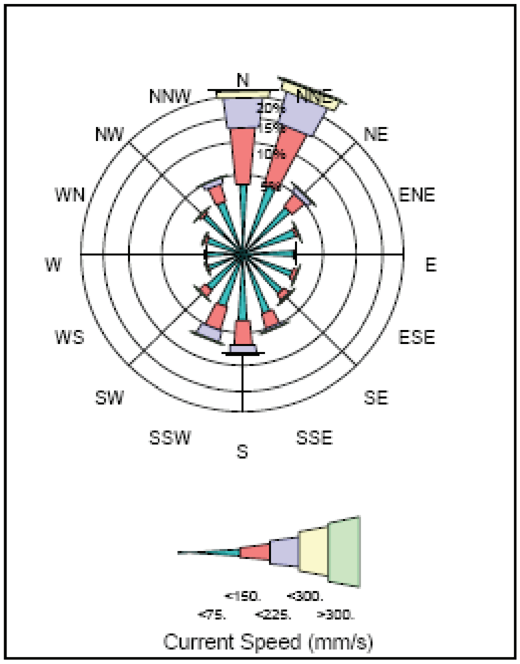

Figure 3.8: Bruce Nuclear Site, Current Rose, May-September 2007

3.3.4 Winds and Waves

A good characterization of the wind and wave climate in the region is provided through the Transport Canada Great Lakes wind and wave atlas (MacLaren Plansearch 1991). The data set used to produce the climatological statistics presented in the atlas were from the U.S. Army Corps of Engineers, Waterways Experiment Station 32-year (1956 – 1987) wind and wave hindcast model of the Great Lakes (Hubertz 1989). An initial statistical analysis was to find the average and maximum significant wave height and wind speed, the ninety-five percent upper limit values, and prevailing wind and wave direction for each hindcast model grid point. The grid point location representing the more severe climate was selected to represent each of eight Great Lakes subareas. For the Bruce nuclear site, a Lake Huron South subarea (shown in Figure 3.9) exists and is appropriate to report.

Figure 3.9 presents a composite of annual wind statistics including percent occurrence, percent exceedance, wind rose, persistence of wind speed, and return period wind estimates (MacLaren Plansearch 1991).

Figure 3.10 presents monthly wind roses and demonstrates the variation in predominant wind directions and wind speed magnitudes experienced during the year (MacLaren Plansearch 1991).

Table 3.7 presents a summary of monthly mean, 95% upper limit and maximum wind speed and most frequent direction (MacLaren Plansearch 1991).

Table 3.7: Monthly Wind Statistics for Lake Huron South

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean speed (knots)	18	16	16	16	14	13	12	12	14	16	17	18	15
95% Upper Limit speed(knots)	34	32	33	33	29	26	24	24	28	30	33	33	31
Maximum speed(knots)	75	65	70	65	61	57	49	51	53	53	71	78	78
Most frequent direction (from)	NW	NW	NE	W	SW	SW	SW	SW	S	S	S	S	SW

Average monthly wind speeds range from 12 knots in July and August to 18 knots in December and January. The annual mean wind speed is 15 knots (28 km/h or about 8 m/s). About 57% of winds are 15 knots or less annually; 86% of winds are less than 25 knots. Maximum monthly wind speeds range from about 50 knots in July and August to 78 knots (144 km/h or 40 m/s) in December. The atlas estimates a 100-year return period maximum speed of about 79 knots with lower and upper 90% confidence limits of 69 and 87 knots, respectively. Winds are most frequently from the southwest in spring and summer, from the south in fall and early winter, and from the northwest in January and February.

Figure 3.11 presents a composite of annual significant wave height, Hs, statistics including percent occurrence, percent exceedance, and wave rose (MacLaren Plansearch 1991).

Table 3.8 presents a summary of monthly mean, 95% upper limit and maximum Hs and most frequent direction (MacLaren Plansearch 1991).

Figure 3.12 presents monthly wave roses and demonstrates the variation in predominant wave directions and wave height magnitudes experienced during the year (MacLaren Plansearch 1991).

Average monthly significant wave height ranges from 0.8 m in July and August to 1.4 m for November through January. The annual mean significant wave height is 1.1 m. About 56% of all waves are less than 1 m annually; 86% of waves are less than 2 m. Maximum significant wave heights range from 4.9 m in July to 8.7 m in January. The atlas estimates a 100-year return period maximum Hs of about 9.5 m with lower and upper 90% confidence limits of 8.4 m and 10.6 m, respectively. Waves are most frequently from the southwest from late spring through late fall, and from the northwest from late fall through early spring (MacLaren Plansearch 1991).

Annually, peak wave period, Tp, ranges from less than 4 s to about 12 s. For a 1 s bin resolution reported, Tp is most frequently in the range 4 to 5 s (38% of the time). 87% of the time Tp is less than 6 s (MacLaren Plansearch 1991).

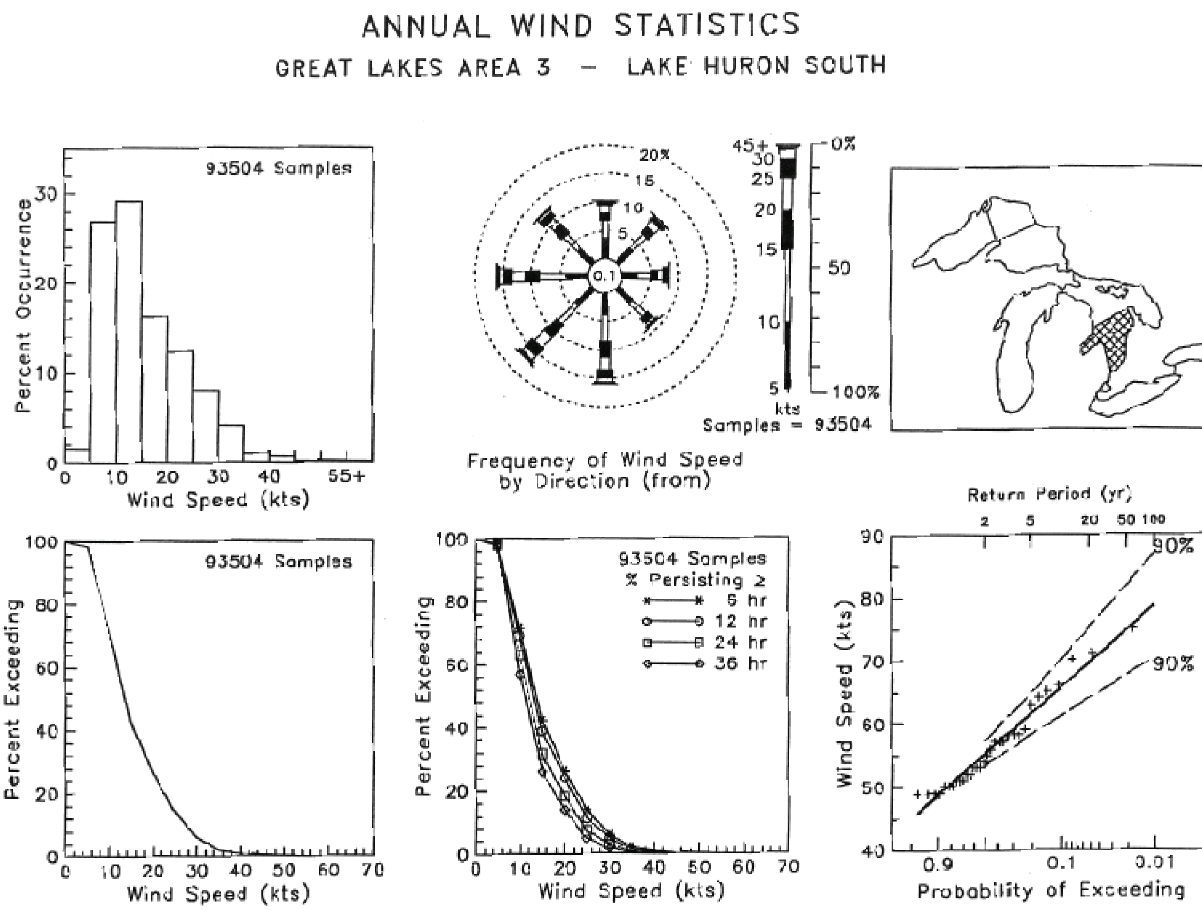

Figure 3.9: Annual Wind Statistics for Lake Huron South

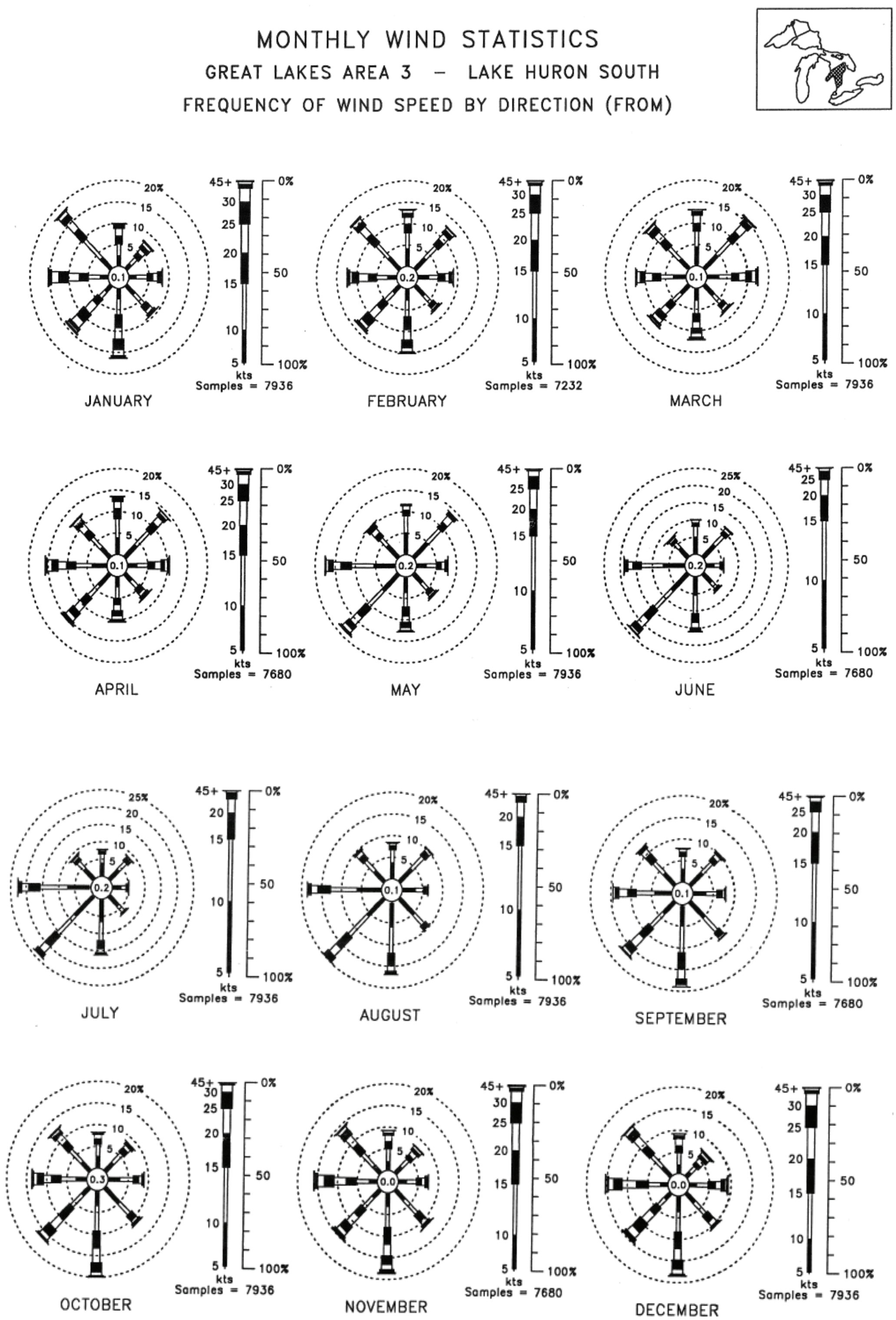

Figure 3.10: Monthly Wind Roses for Lake Huron South

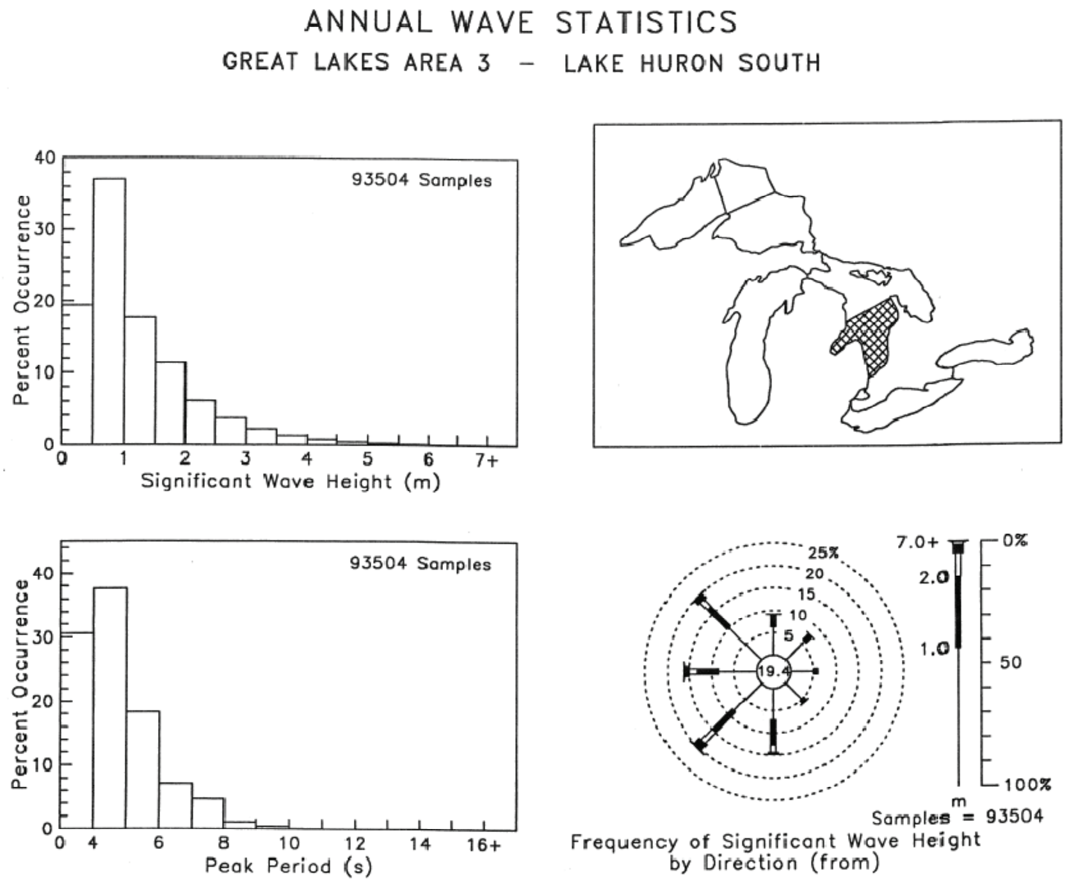

Figure 3.11: Annual Wave Statistics for Lake Huron South

Table 3.8: Monthly Wave Statistics for Lake Huron South

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean Hs (m)	1.4	1.2	1.2	1.2	1.0	0.9	0.8	0.8	1.0	1.2	1.4	1.4	1.1
95% Upper Limit Hs (m)	3.8	3.1	3.1	3.2	2.6	2.3	2.1	2.0	2.5	2.9	3.4	3.3	2.9
Maximum Hs (m)	8.7	8.3	8.6	7.2	8.1	7.5	4.9	6.0	5.3	6.8	7.6	7.6	8.7
Most frequent direction (from)	NW	NW	NW	NW	SW	SW	SW	SW	SW	SW	NW	NW	SW

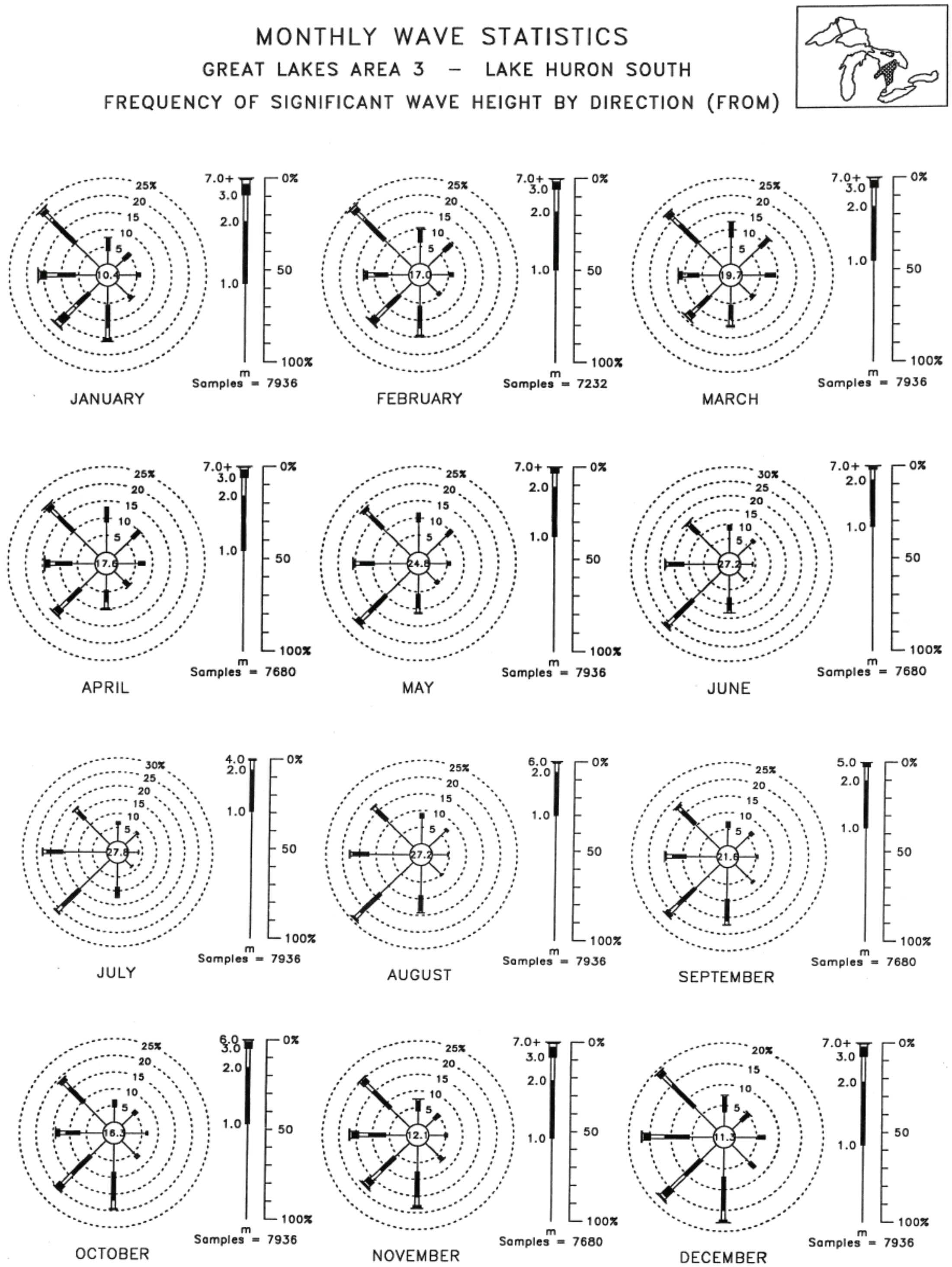

Figure 3.12: Monthly Wave Roses for Lake Huron South

3.3.5 Surge and Seiche

As noted previously, storm surge or wind setup, associated with very low pressure storm systems and strong winds will result in high water levels, and the effects can be particularly manifested along shorelines.

In qualitative terms, the Natural Resources Canada, Atlas of Canada, Natural Hazards - Storm Surge interactive map illustrates the location of storm surge risk (both severity or consequences, and frequency) in Canada. This indicates a low hazard (low frequency, low severity) for eastern shores of Lake Huron (Figure 3.13) (NRCAN 2008). It is cautioned that this map shows a qualitative estimate of storm-surge hazard and the data shown are for illustrative purposes only and should not be used for local storm-surge hazard management[6].

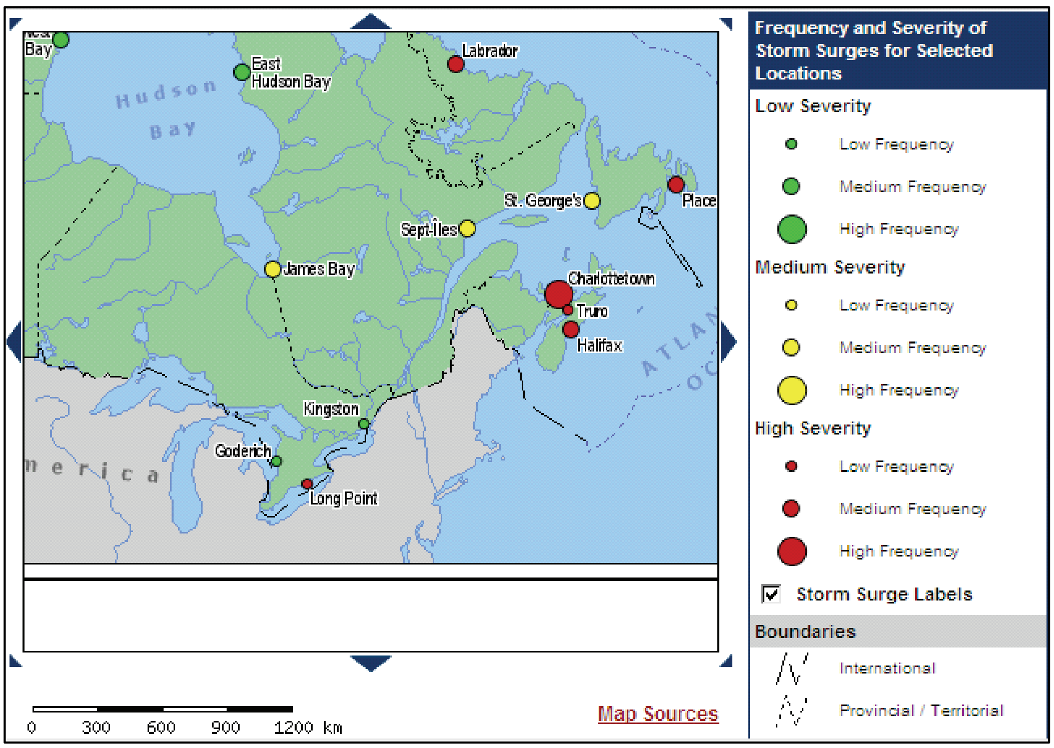

Figure 3.13: The Atlas of Canada: Storm Surge Hazard Map

Quantitative estimates of storm surge have been prepared for the Great Lakes. Recognizing that there are many combinations of static water levels and storm surge (wind setup) which could result in the same local flood level, Ontario Ministry of Natural Resources undertook to estimate 100-year flood levels for the Great Lakes (OMNR 2001). These were determined by

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6 "Each dot symbol on the map indicates a representative storm-surge site. The site may represent a few to several hundred kilometres of shoreline. The size of the dots reflects frequency, not area covered. On this map, a **low frequency means one surge every few years**, a medium frequency indicates one surge every year and a high frequency represents several surges every year. **Low severity corresponds to some flooding or erosion during large surges, with minor resulting damage**. Medium severity indicates moderate flooding or erosion during large surges, with moderate damage. High severity means extensive flooding or severe erosion during large surges, with significant damage." (http://atlas.nrcan.gc.ca/site/english/maps/environment/naturalhazards/storm_surge/storm_surge/1)

calculating the probabilities of all possible combinations of monthly mean lake levels and wind setups which could combine to result in a peak instantaneous stillwater level having a probability of being equalled or exceeded 1% in any given year.

For the Lake Huron shoreline from near Kincardine (South of the Bruce nuclear site) to the tip of the Bruce Peninsula the 100-year flood level estimate is 177.6 m relative to Geodetic Survey of Canada Datum (GSC) (Figure 3.9 and Table A3.1.1 in Part 3 - Flooding Hazard in (OMNR 2001)).

At Goderich, GSC estimate is the same level as IGLD 1985 estimate; at Tobermory, GSC estimate is 0.14 m below IGLD 1985 estimate (Section A3.1.2 in Part 3 – Flooding Hazard in (OMNR 2001)). This estimate of 177.6 m is slightly less than the 100-year daily and instantaneous level values of 178.0 and 178.3 m determined using a different method.

The 100-year surge (wind setup) estimate for this same shoreline stretch is 0.30 m. This is included in the 100-year flood level of 177.6 m noted above. The 200-year value is 0.31 m (Part 3 – Flooding Hazard in OMNR 2001).

Another phenomenon influencing lake levels is the seiche effect caused by both atmospheric pressure and wind-induced water level changes. The seiche effect can be described as the return flow of water from the lake end with an elevated level to the depressed end. This process can result in oscillations of lake levels similar to the sloshing action that occurs in an enclosed tank of water. During seiche effects any given shoreline location may experience alternate periods of elevated and depressed levels over a period of several hours with the initial seiche levels being at much lower elevations than the original wind setup.

An example of sudden and large changes in lake water levels associated with passage of a storm system and squall is reported, for example, in (Hoagman 1997). This summer storm in 1995 caused a dramatic seiche in Lake Huron the evening of July 13th. Water level measurements from four stations are shown in Figure 3.14 (DFO 2010b,NOAA 2010)[7]. At Goderich, in the span of about one and a half hours, lake levels rose 0.53 m from 176.63 m (about equal to the monthly mean lake level for July 1995 for Lake Huron (DFO-CHS 2010)) to 177.15 m, and then precipitously fell 1.08 m (or to 0.56 m below the mean) to 176.07 m before returning to near normal. Smaller seiches up to magnitude about 0.3 m were also subsequently observed, true to the seiche physical mechanism. At Lakeport, a longer period and somewhat larger amplitude seiche was observed. In the span of about five hours, lake levels rose 0.66 m from 176.65 m to 177.22 m, and then precipitously fell 1.40 m (or to 0.81 m below the mean) to 175.82 m before returning to near normal. As at Goderich, several smaller seiches followed. About eight hours later at Lakeport another large seiche of amplitude 0.74 m was observed, followed by several smaller seiches. Measurements at Harbor Beach and Tobermory evidenced a much smaller seiche presence with peak-to-trough amplitudes as large as about 15 to 30 cm.

3.3.6 Lake Ice

Lake ice, in addition to potential navigational concerns, and the potential for ice piling or jamming along the shoreline, limits the transfer of energy from winds blowing over the affected area, with the result that both wave generation and transfer of energy into the water column for generation of lake currents can be reduced in winter time during periods of ice cover.

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[7] 15-minute observations are available for the Canadian stations, 1-hour observations for the U.S. stations for this July 1995 time period.

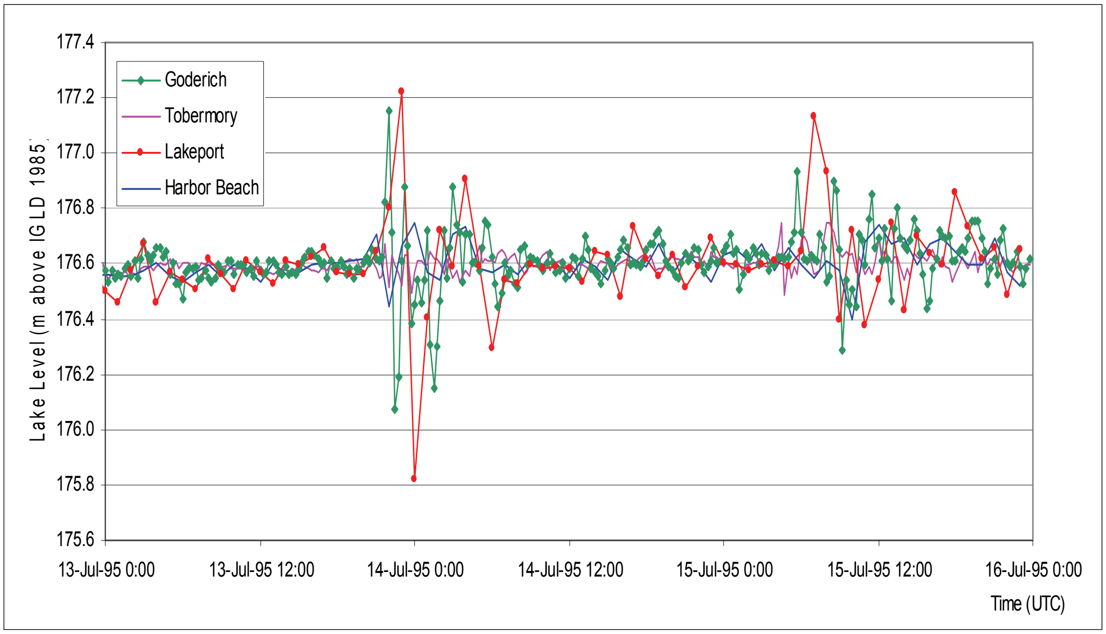

Figure 3.14: Lake Huron Seiche Event, July 13-15, 1995

Further assessment of surge and seiche near the Bruce nuclear site will be presented in Section 4.2. Consideration of seismic effects which might include seiche or tsunami will also be included.

The formation of ice during winter months can affect shoreline processes in two ways (OMNR 2001), namely the following.

- The formation of shorefast ice, in combination with an "ice foot", protects the shoreline area landward of the ice from wave action even when the main body of the lake is ice free. However, local scouring can result from waves breaking directly against the ice foot, and sediments incorporated in the ice may be transported and deposited offshore. Ice that detaches from the shoreline or lake ice that is piled up by wind action against the shoreline can also cause scour. Ice can also remove boulders from the shallow areas, reducing their protective effect.
- Secondly, ice formed within the greater water body, has the effect of reducing wave generation during the winter months and as such, reduces the potential erosion and the volume of sediment transport.

The Canadian Ice Service (CIS) Lake Ice Climatic Atlas (CIS 2008) provides descriptions of the ice regime in Lake Huron including near the Bruce nuclear site. The products in the atlas are based on charts and analysis for the period 1973-2002 from the CIS and the U.S. National Ice Center. Additional ice and climatic products for the Great Lakes are available on the Great Lakes Environmental Research Laboratory (GLERL) website at http://www.glerl.noaa.gov/data/ice/atlas/.

On average, for the eastern portion of Lake Huron, near the Bruce nuclear site, freeze-up occurs around the week of January 15 and break up by early to mid-March, though ice can persist into April.

Considering the week of February 26 as a time of greatest ice presence, ice is present on average between 50 and 84% of the time. In some years there is no ice, in other years maximum concentrations of 10/10 ice coverage have been experienced. The median ice type near the Bruce nuclear site is medium lake ice which has a thickness 15-30 cm.

Based on a review of the collection of these weekly atlas charts, and considering the Bruce nuclear site location, the predominant ice type is reported in Table 3.9 (CIS 2008). New to thin ice is typically present by the first week of the year with associated ice thickness up to 15 cm. By February medium ice thickness up to 30 cm may be encountered. Medium to thick (up to 70 cm) ice is present in February and may persist into March or April.

Figure 3.15 illustrates the ice chart for February 14, 1994, example ice conditions from a maximum ice coverage year (CIS 2008). A strip of fast ice (10/10 ice coverage) is shown along the eastern shore of Lake Huron, near the Bruce nuclear site. Just offshore, the Egg code indicates an ice concentration of 9+/10. Of this, 3/10 is medium lake ice, 15-30 cm thickness, and 7/10 is thin lake ice, 5-15 cm, both in medium floes, about 100-500 m wide.

Ice piling is a potential event in Lake Huron when onshore winds cause ice floes to gain sufficient momentum to drift over open water and pile up against an existing nearshore floe, though as noted above, the probable maximum ice thickness would be 30 cm. For significant deformation of the ice to occur, local ice conditions must first approach 10/10 coverage. After this point, further compression of the ice due to winds or currents may result in the formation of either ice rafts or ridges (Figure 3.16). Ridges are linear features formed from piles of ice blocks when two ice sheets meet. Rafting occurs when one ice sheet overrides or underrides another sheet and is more characteristic of thinner ice sheets. Though winds in the winter are typically onshore more than 50% of the time which might contribute to ice piling along the shore near the Bruce nuclear site, the thicknesses involved, e.g., 30 cm maximum, or that could be produced, are small. Given the freeboard between the shoreline and perimeter structures inland, it is unlikely any ice structures would create or worsen any coastal flood hazard[8]. The presence of any ice will also dampen waves propagating to shore so that any potential flooding from larger waves will be mitigated. Lake ice is not believed to represent a direct contributor to flooding hazards at the site.

3.3.7 Coastal Erosion and Sedimentation

This section provides an outline of the potential for instability of the coastal areas near the lake shoreline due to erosion or sedimentation.

The Bruce nuclear site is located on a headland that extends about 3 km into Lake Huron and consists of MacPherson, Douglas, and Gunn Points.

The underlying bedrock for the region is from the Paleozoic Devonian period sedimentary rock (Figure 3.17) (OMNR 2001). The lake shoreline region encompassing Douglas Point and Bruce B consists either of bedrock exposed at the surface or a covering by a discontinuous, thin layer of drift. To the northeast and east including the area around Bruce A and the DGR Project Area, the surface is comprised of sandy silt to silt matrix, clayey silt along the southern margin, moderately stony, strongly calcerous.

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[8] The Ontario MNR Flooding Hazards introduction, to “Other water related flooding hazards” (i.e., those other than flood level and wave uprush allowance), notes “in some cases, ice has piled up more than five metres high and pushed 45 metres inland” (OMNR 2001), though no further details such as where in the Great Lakes – St. Lawrence River system, the event occurred. The DGR site is about 1 km from the lakeshore.

Table 3.9: Median of Predominant Ice Type when Ice present, Lake Huron, near Bruce Nuclear Site

Week	Lake Ice Stage of Development	Frequency of Presence of Lake Ice (%)
11-Dec	Open water or Ice Free	0
18-Dec	Thin Lake Ice	0
25-Dec	New to Thin	1-15
1-Jan	New	16-33
8-Jan	New to Thin	16-33/34-50 (NE)
15-Jan	New	51-66
22-Jan	Thin	51-66 (farther offshore)/67-84 (alongshore)
29-Jan	Thin	51-66
5-Feb	Medium Lake Ice	51-66
12-Feb	Thin to Medium	51-66 (farther offshore)/67-84 (alongshore)
19-Feb	Thin to Medium	67-84
26-Feb	Thin to Medium to Thick	51-66/67-84 (NE and SE)
5-Mar	Medium to Thick	34-50 (farther offshore)/51-66 (alongshore)
12-Mar	Medium to Thick	51-66
19-Mar	Medium to Thick	34-50
26-Mar	Medium to Thick	34-50
2-Apr	Thick	16-33 (farther offshore)/34-50 (NE and SE)
9-Apr	Thick	1-15 (farther offshore)/16-33 (alongshore)
16-Apr	Thick	1-15/16-33 (northeast)
23-Apr	Thick	1-15
30-Apr	Thick	1-15
7-May	Open water/Thick	0/1-15 (northeast)

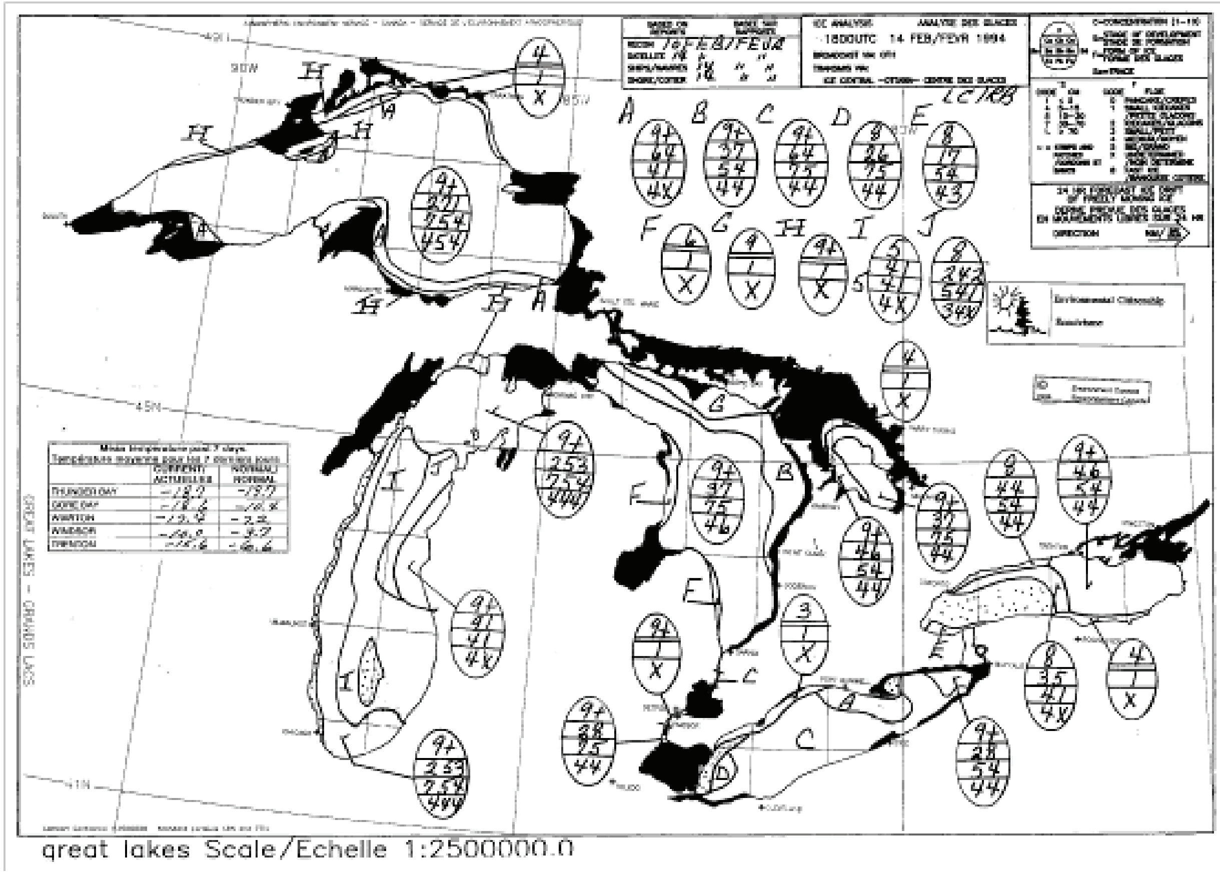

Figure 3.15: Example of a Maximum Ice Coverage Year, February 14, 1994

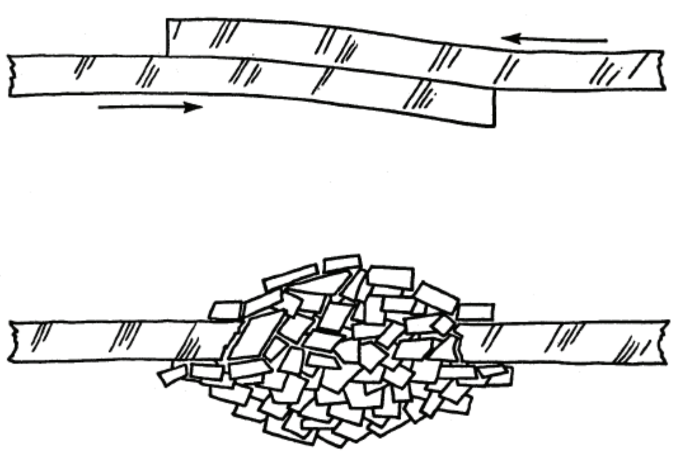

Figure 3.16: Illustration of Ice Rafting and Ridging Deformation

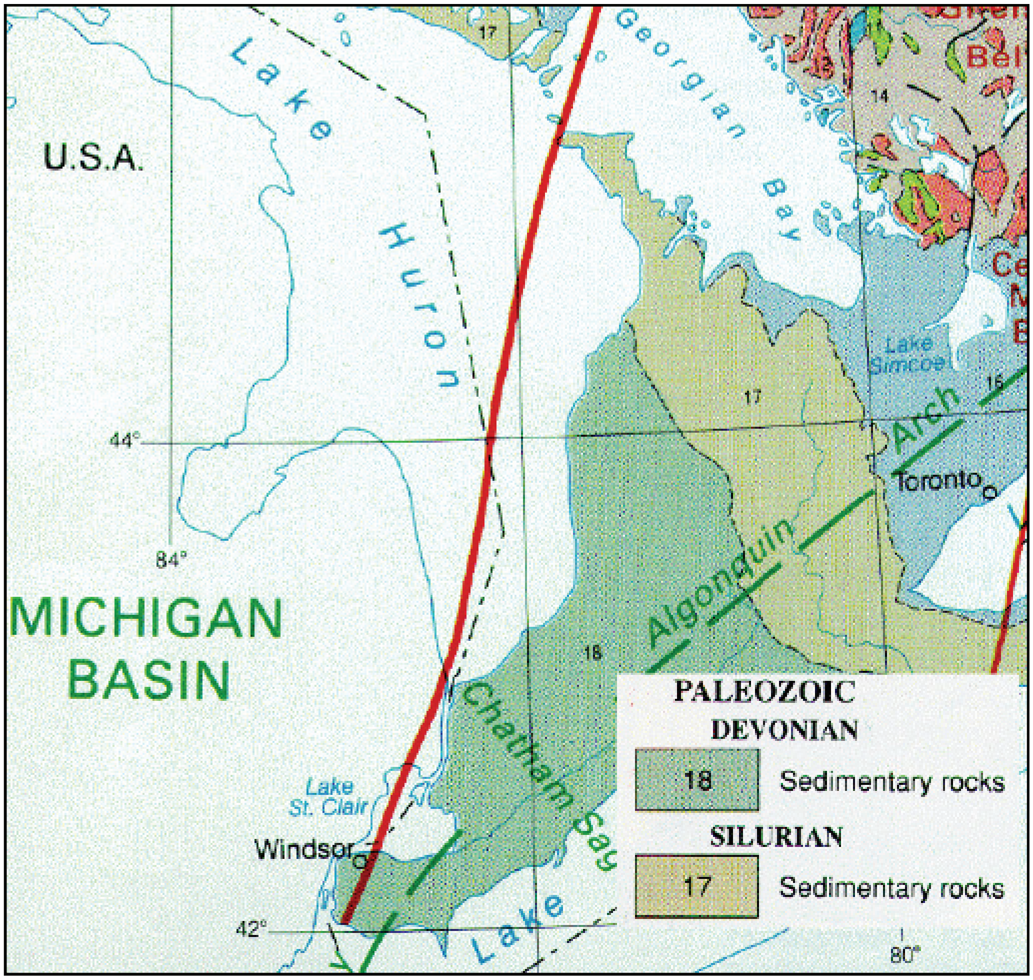

Figure 3.17: Southeast Lake Huron Bedrock

The shoreline region near the Bruce nuclear site is classified as being susceptible to light erosion, though it is not indicated as being flood prone (see Figure 3.18) (OMNR 2001). This light susceptibility to erosion is illustrated through the following shoreline description taken from (Bruce Power 2005).

“The shoreline from MacPherson Point to Gunn Point is dominated by a flat to gently sloped rocky platform that extends offshore to a distance of approximately 300 m: this platform then drops to a depth of 2 to 3 m. Bedrock is exposed along the shoreline and this rocky area is typically covered by cobbles and gravel. Shallow slopes continue out into the lake with depths of 20 m occurring within about 1.8 km offshore west of MacPherson Point, and 5.3 km offshore to the north of Loscombe Bank.

North of MacPherson Point, the shoreline is indented to form Baie du Doré which is approximately 1.8 km wide at its mouth and extends approximately 1.5 km inland to the southeast. Baie du Doré terminates northward at Scott Point beyond which an irregular shoreline extends northwards about 9.5 km to MacGregor Point. This shoreline consists of rocky headlands with intervening beaches: beach materials being predominantly sandy gravel.

South of Gunn Point, the shoreline is indented to form Inverhuron Bay about 2.5 km wide at its mouth and extends northeastwards about 1 km. Inverhuron Bay terminates southwards at

McRae Point beyond which an irregular shoreline extends in a north-northeast to south-southwest direction 10.3 km to Kincardine. This shoreline consists of bedrock outcrops and gravelly sandy deposits between headlands."

Beach material along the shoreline is typically derived from erosion of the glacial till and glaciolacustrine deposits.

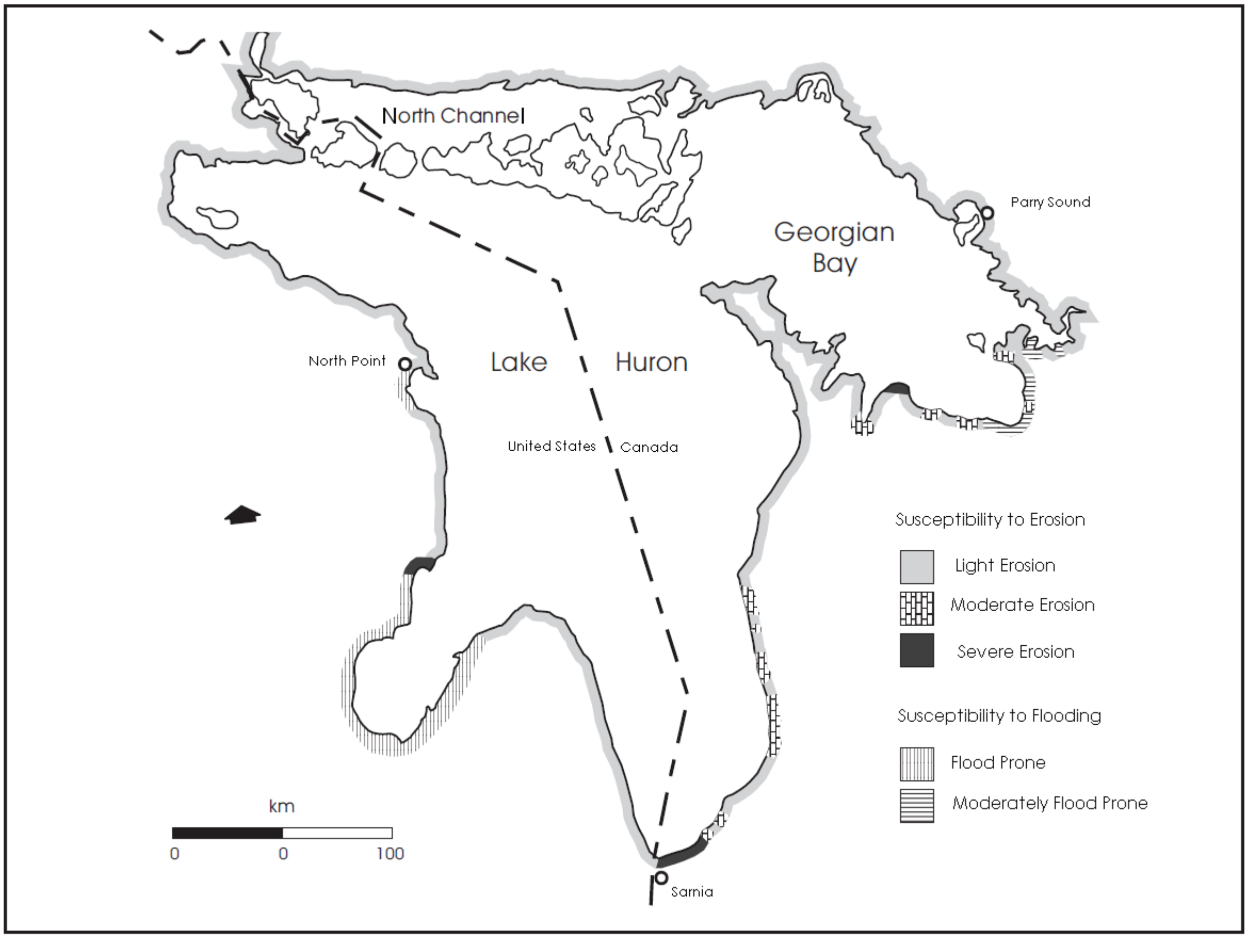

Figure 3.18: Flood and Erosion Prone Areas: Lake Huron

3.3.8 Coastal Proximity to Bruce Nuclear Site

The DGR Project area, encompassing all site structures, systems, and components (SSC), covers an area of approximately 0.15 km^2. Its northern perimeter is located about 600 m southeast of MacPherson Bay. The main SSC in the western portion of the DGR area are about 1 km from the shorelines at MacPherson Bay to the north and Douglas Point to the northwest (Figure 3.19, which also notes locations of shoreline photos taken, as presented in Section 4.3.1). Of relevance to this flood risk assessment, are primarily the main shaft (from which the red radial lines in Figure 3.19 originate) and nearby ventilation shaft, as well as the electric and emergency power facilities. Elevations over the DGR site range from 181 mASL to 187 mASL (OPG 2011a).

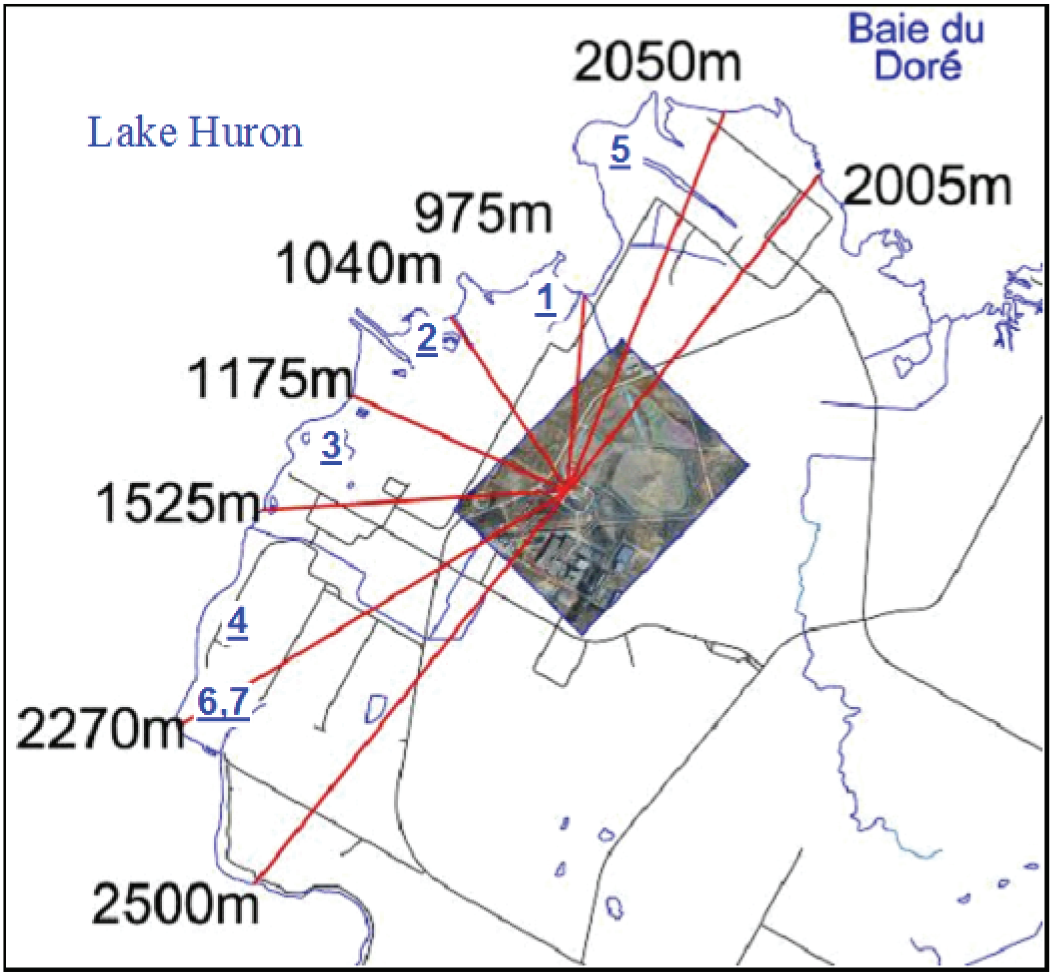

Figure 3.19: DGR Study Area, Proximity to Shoreline, and Approximate Locations of April 15, 2010 Site Visit Photographs (#s 1-7 underlined)

To the west, the Lake Huron water levels at the shoreline vary seasonally and annually: over the past 10 years levels have ranged from 175.7 m to 176.4 m above IGLD 1985. The Lake Huron chart datum is 176.0 m above IGLD 1985. An estimated 1 – 500 year maximum daily mean lake level is 178.4 m above IGLD 1985. Based on these elevations there is therefore a freeboard of at least 2.6 m (181-178.4).

Shoreline protection for the Bruce nuclear site has been designed for mitigation of both potential erosion and wave uprush effects. These protections consisting of rip-rap at a 1V:2H slope have been built on the existing shoreline to an elevation of 179.9 m above IGLD 1985 with structure toe located at an elevation of 176.8 m above IGLD 1985 (Bruce Power 2005). Any roads immediately inland from the shoreline are at elevations of about 181.1 m. Perimeter works have crest widths on the order of 10 m due to their function as perimeter roads. In the event of wave uprush onto these works some water will drain back to the lake or may pool on the road eventually infiltrating the ground and returning to the lake or evaporating.

The site setting relative to Lake Huron is illustrated in Figure 3.20, which shows an aerial view of the Bruce nuclear site with the Bruce B Generating Station in the foreground (Bruce Power 2010). The DGR Site lies inland to the right and east of the winding road located in the upper right portion of the picture. Figure 3.21 shows the Bruce A Generating Station across Baie du Doré viewed from the end of the 6th concession road. The flatness of the shoreline is evident in the two photos.

Figure 3.20: An Aerial View of the Bruce Nuclear Site with the Bruce B Generating Station in the Foreground

Figure 3.21: Picture of the Bruce A Generating Station across Baie du Doré Taken from the End of the 6th Concession Road

Bathymetry for Lake Huron is available from the National Geophysical Data Center (NGDC) of the National Oceanic and Atmospheric Administration (NOAA) Satellite and Information Service (NGDC 2010a). This includes the capability to create a custom grid which is completed in Section 4.3 for the flooding by waves assessment. Lake Huron bathymetry nearshore the Bruce nuclear site is shown in Figure 3.22 (NGDC 2010a).

In general, water depths in the nearshore zone of the lake range from 6 to 20 m, except in Baie du Doré', where depths do not exceed 5 m. Bedrock substrate predominates in the shallow areas of the open shoreline, grading to a mixture of pebble, cobble and boulder at the 7 and 12 m depths. Extensive marsh areas are located along the shore of Baie du Doré.

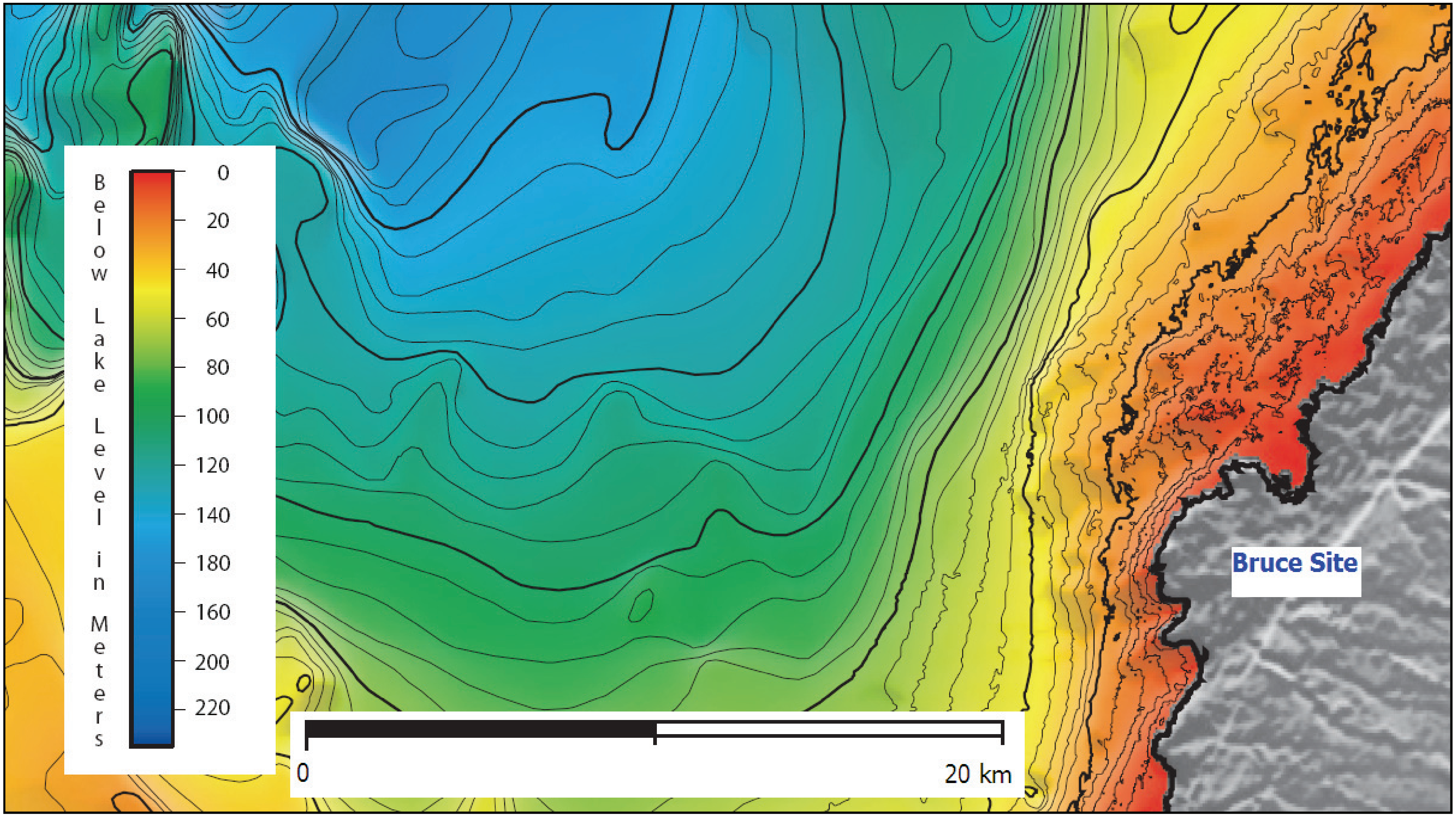

Figure 3.22: Lake Huron Bathymetry, near Bruce Nuclear Site

4. COASTAL FLOOD HAZARD ASSESSMENT

4.1 Extreme Water Levels in Lake Huron

4.1.1 Review of the Historical Record

The foundation for the Great Lakes was laid over millions of years and through several geological eras. The current shape of the basin was formed during the past 10,000 to 20,000 years during the last glaciation. The large weight of the ice sheet depressed the land and large glacial lakes were formed from the meltwaters as the ice retreated. Shifting ice fronts resulted in uplift to the land and changes to the depth, size, and drainage patterns of the lakes during this period. Though uplift has slowed, it is still occurring at different rates over the region (Environment Canada and U.S. EPA 1995), and is a motivation for the establishment of the IGLD 1985 datum for the Great Lakes[9]. It is estimated that the modern water levels and areas of the Great Lakes were attained some 3,500 to 4,000 years ago (NOAA 2004).

Water levels change in response to the water balance for the Great Lakes basin which primarily includes the inputs of upstream inflow, streamflow, and precipitation, and outputs of evaporation, downstream outflow, and diversions out of the lake (Wilcox et al. 2007).

Figure 4.1 shows Lake Huron water levels from 1860 to 2005, a period of 145 years (Wilcox et al. 2007). While water level recording began in the 1840s and systematic records from all lakes commenced in 1860, the current network of multiple gauges on each of the Great Lakes came into operation in 1918 (Figure 4.2). From inspection of this record, multiyear, decadal, and longer fluctuations are evident, though over this period the range of minimum and maximum monthly mean values is relatively small at about 2 m. Extremely high water level peaks have occurred in 1929, 1952, 1973, 1986, and 1997 as well as extremely low troughs in 1926, 1934, 1964, and 2003 (Wilcox et al. 2007). Maximum measured lake levels have been 177.6 m in June 1886 (Figure 4.1) (Wilcox et al. 2007) and 177.5 m in October 1986. In addition to this interannual range in lake levels, there is an annual hydrologic cycle with higher water levels usually occurring in July and lowest water levels generally occurring in February. These seasonal fluctuations, over the period 1918 to 2009, are 38 cm on average and a median of 36 cm. Temporary (in the sense that water is simply forced from one location in the lake to another) lake level changes also occur on time scales of several hours to several days due to storms passing through the region. These result in storm surge or wind setup: high winds blow over the lake surface pushing the water to one shore or another raising the lake level at the shore.

4.1.2 Climate Change and the Future

The historical record, while illustrating a range of conditions encountered, does not readily provide an indication of future lake levels. Great Lakes water levels are routinely projected for periods up to six months in the future. The difficulty and uncertainty in accurately predicting future lake levels increases with time. Presently, while one can reflect that high water levels in the 1980s were an issue in the Great Lakes, resulting in erosion and causing damage to shoreline structures (Sellinger et al. 2008), water level declines since 1973 may be related to evaporation increase, and consistent with many global climate change scenarios.

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[9] "It was recognized that this common datum would have to be periodically revised due to isostatic rebound, sometimes referred to as crustal movement. Isostatic rebound is the gradual rising or "bouncing back" of the earths crust from the weight of the glaciers that covered the Great Lakes-St. Lawrence River region during the last ice age." http://www.lre.usace.army.mil/greatlakes/hh/newsandinformation/iglddatum1985/why/

Warming of the climate systems is unequivocal (Solomon et al. 2007). Consideration of climate change and global warming are anticipated to affect the Great Lakes water budget through changes to runoff of the drainage basin, direct precipitation on the lakes, and evaporation from lake surfaces. Global climate models have been employed to predict changes to the water budget under different scenarios. For the Great Lakes, some projections suggest little change (~10%) in total summer precipitation while an increase (~20-30%) in winter with more rain and less snow is possible (C-CIARN 2005). Other research (e.g., Zhang et al. 2007 reported in Environment Canada 2010) suggests there is no clear change for global precipitation for a broad range of latitudes in North America, including the Great Lakes. Warming of the region itself leads to increased evaporation both from land and water. Whether a possible increase in precipitation or increased evaporation dominates determines the net effect on lake water supply and lake levels.

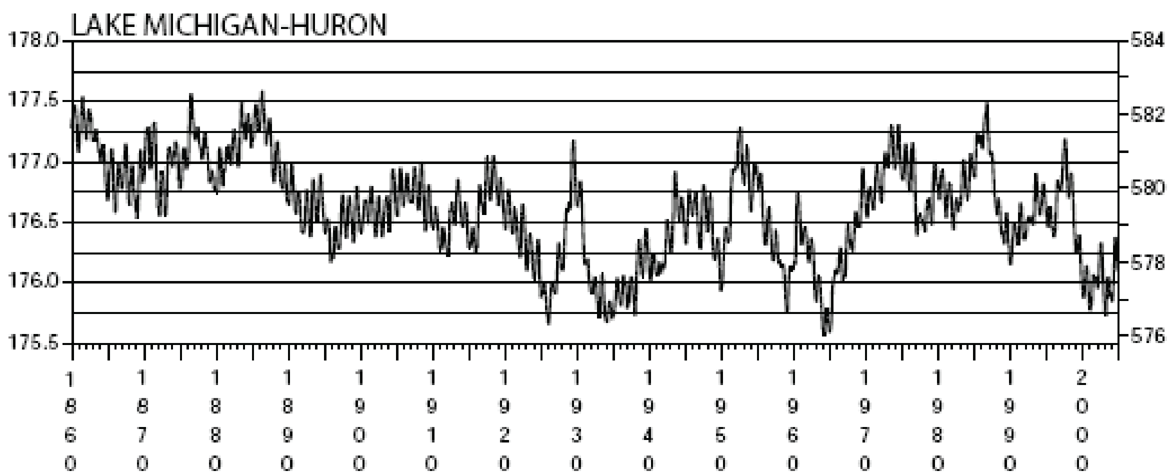

Figure 4.1: Lake Huron Water Levels 1860-2005 (Y-axes Shown in metres and feet IGLD 1985)

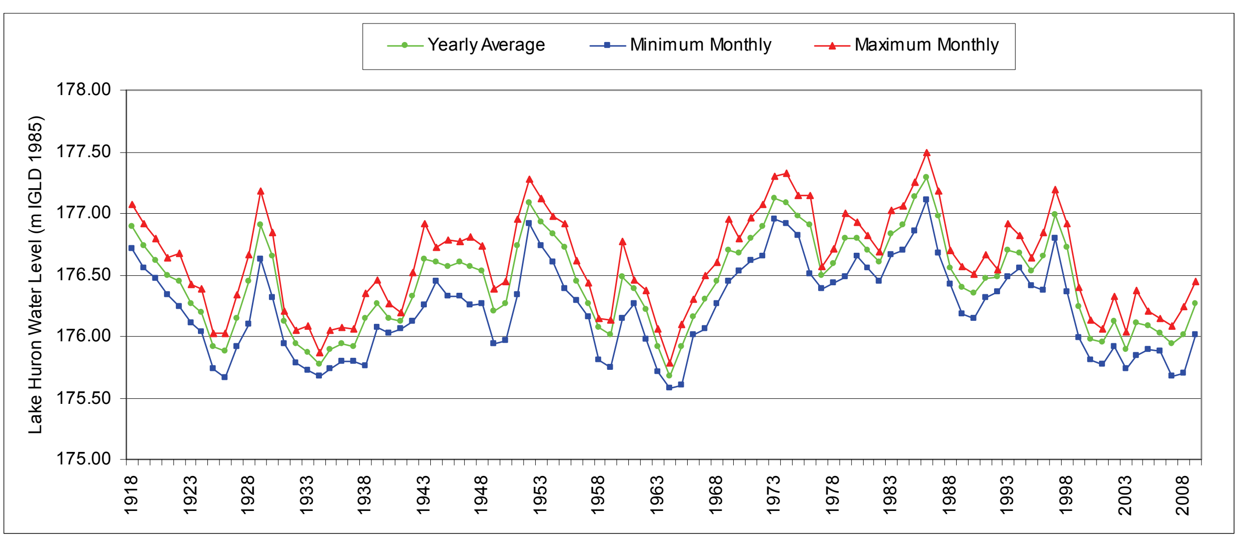

Figure 4.2: Lake Huron Water Levels 1918-2009

A number of modelling efforts have been completed in an attempt to estimate possible future Great Lakes water levels under climate change and several of these are summarized in Table 4.1, with further comments presented below.

Table 4.1: Lake Huron Future Water Level Estimates

#	Model	Lake Level Change	Time Frame	Description	Reference
1	Canadian Centre for Climate Modelling and Analysis (CGCM1)	-1.38 m annual mean level for Lake Huron (below a base level of 176.54 m)	2090	Predicted large drops in lake levels due both to decreases in precipitation and an increase in evaporation.	(Lofgren et al. 2002)
2	UK Met Office's Hadley Centre (HadCM2)	0.35 m annual mean level for Lake Huron (below a base level of 176.54 m)	2090	Predicted a rise in lake level due to increased precipitation and to a lesser degree an increase in air temperature.	(Lofgren et al. 2002)
3	Coupled Hydrosphere-Atmosphere Research Model (CHARM)	Possible increases	2030, 2095 (for Lake Erie)	Based on potential net basin supply increase it is hypothesized that water levels may also increase.	(Lofgren 2003)
4	CGCM2A "hot-dry" CGCM2B "warm-dry", HadCM2A "hot-wet",, HadCM2B "warm-wet"	A decline in Great Lake water levels, particularly the three larger lakes, up to several feet	2090	The findings suggest a warming climate can be expected to bring a decline in Great Lake water levels, particularly the three larger lakes.	(Croley 2003)

Two separate general circulation models employed by the NOAA GLERL yielded two different lake level change scenarios (Lofgren et al. 2002), one predicting a drop of almost five feet (~152 cm), the other predicting an increase of 35 cm (entries 1 and 2 in Table 4.1).

Subsequent work with a different regional dynamical model for the Great Lakes basin predicts the net basin supply will increase which if true would translate into increased lake levels (though by how much is not estimated) (entry 3 in Table 4.1). Lofgren (2003) notes this is in contrast to the above-quoted CGCM1 model prediction but in qualitative agreement with the HadCM2 model predictions (entries 1 and 2 respectively in Table 4.1). A public discussion summary report (Wittman 2008) notes one of the climate models (though not specified which) predicts Lake Michigan-Huron water levels will rise 18 inches (~46 cm) above the historical average.

In an attempt to determine the effects of the full ranges of projected minimum and maximum temperatures and high and low precipitation amounts for hydrological analysis, GLERL used three different general circulation models to simulate four future climate scenarios (entry 4 in Table 4.1). Under each scenario the net basin water supply to each lake will generally be less than the historical annual average for all the Great Lakes (Croley 2003, NOAA 2004). Only the "warm-wet" scenario shows a higher net basin supply during the winter and part of the spring than in the past. Projected higher temperatures lead to greater evaporation and less runoff. Lake temperatures rise and peak earlier in the year and resident heat in the lakes increase throughout the year. This leads to reduced ice formation and increased evaporation. Under a scenario of greater evaporation due to generally warmer temperatures and less winter ice cover Great Lakes water levels are expected to decline several feet. The findings suggest a warming climate can be expected to bring a decline in Great Lake water levels, particularly the three larger lakes. The extent of the decline is believed to largely depend on whether precipitation increases significantly and whether temperature increases can be measurably minimized, i.e., through reductions in greenhouse gas emissions.

This summary indicates that future Great Lakes water levels are uncertain, though in this survey there is a preponderance of predicted decreases in lake levels versus lake level increases. The predicted ranges are on the order of a 0.5 m rise to a 1.5 m fall. Independent of future annual mean lake levels, whatever their value, future water level oscillation will still occur about that mean.

4.1.3 Extreme Lake Levels at the Bruce Nuclear Site

For an assessment of potential lake flooding, it is the maximum or extreme water levels that are of interest. As evident through presentation above of the historical record and possible future conditions, the water levels for the Great Lakes are not constant, there is no definite trend either up or down, nor are they readily predicted for periods beyond several months.

Lake Huron extreme water level estimates have been made; however, as reported in the Bruce New Nuclear Hydrology and Water Quality TSD (GOLDER 2008). These are estimates of future lake level conditions that can be assumed for an assessment of potential lake flooding. A Gumbel analysis of historical water level measurements from the water level station at Goderich was completed (GOLDER 2008). The estimates include:

- 100-year return period values of:
  - A maximum daily mean water level of 178.0 m above IGLD 1985; and
  - A maximum instantaneous water level value of 178.3 m above IGLD 1985.
- 500-year return period values of:
  - A maximum daily mean water level of 178.4 m above IGLD 1985; and
  - A maximum instantaneous water level value of 178.6 m above IGLD 1985.

The 500-year return period is appropriate for consideration. The daily mean, rather than an instantaneous, water level value is also appropriate for considering the lake since for this time scale possible phenomena such as seiche or surge which generally occur over time periods less than 24 hours will not appear in the daily record. Therefore, the 500-year maximum daily mean water level value of 178.4 m is the candidate extreme lake level value chosen for the investigation of potential lake flooding. This consideration will include, in addition to lake level, seiche and surge and wave flooding as presented in Sections 4.2 and 4.3 respectively.

4.2 Flooding by Storm Surge and Seiche

Given the location of the site on the shore of Lake Huron, potential flooding by storm surge and seiche is taken into consideration in the flood analysis.

4.2.1 Storm Surge and Seiche Model

A numerical model of the hydrodynamics of Lake Huron was developed to assess the potential for generation of surge and seiche in response to extreme severe weather systems tracking through the region. The software is HYDRO2D (AMEC 2010). Further information about the qualification of HYDRO2D and other computing programs used in this work can be found in Appendix A.

The model was implemented on a bathymetric grid of Lake Huron with a 1 nautical mile (1.852 km) resolution. The bathymetry was obtained from the National Oceanic and Atmospheric Administration (NOAA) Digital Geophysical Data Center (NGDC 2010a). Data were extracted at 1 arc-minute resolution, projected in UTM zone 17, and re-sampled on a rectangular grid with 1 nautical mile (1.852 km) resolution. The resulting bathymetric grid is shown in Figure 4.3.

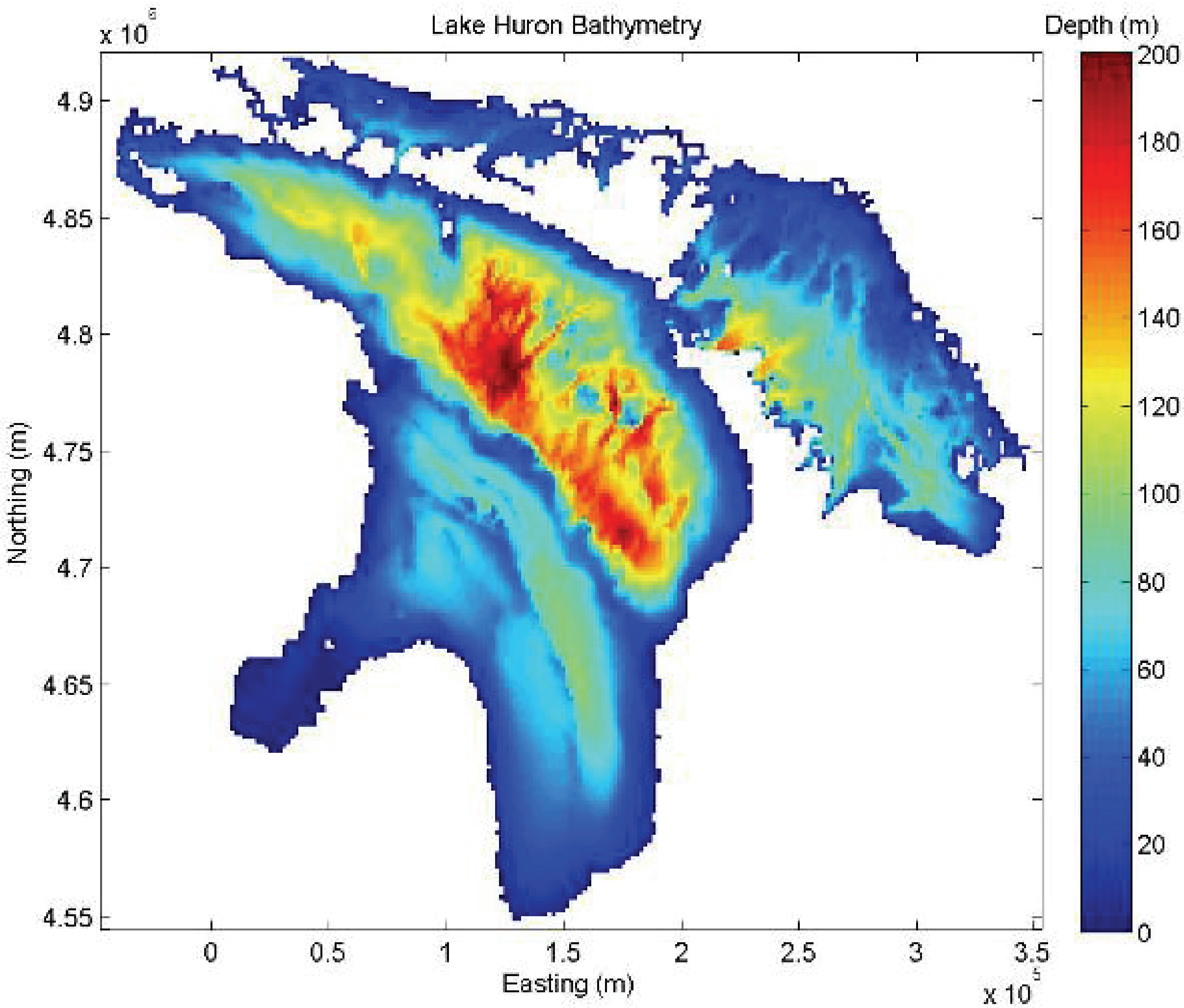

Figure 4.3: Lake Huron Bathymetry

4.2.2 The Hydrodynamic Model

The hydrodynamic model, HYDRO2D, represents the depth-averaged (two dimensional) currents and variations in water level that result from wind and atmospheric pressure forcing. It is based on the depth-averaged momentum and continuity equations (with usual Boussinesq hydrostatic and incompressibility approximations). The model includes the non-linear advection term, as well as the Coriolis acceleration and has standard quadratic bottom friction and second order lateral diffusion of momentum. For the assessment of storm effects, the forcing terms are the atmospheric pressure gradient and the wind stress.

Wind stress is represented by a quadratic drag with a drag coefficient that varies as a function of the wind speed (constant drag for wind speed less than 7.5 m/s and increasing linearly with stronger winds) following the formulation by Wu (1980).

4.2.3 Representation of Storm Atmospheric Pressure and Wind Fields

Idealized atmospheric pressure and wind fields are used to represent the main types of severe storms. Low pressure systems are represented by a Gaussian pressure field with a slightly reduced radius in order to account for the asymmetry of the pressure field in actual storms that exhibit steeper pressure gradients (isobars closer) near the centre on the leading front. The wind field of the storm is determined by scaling down the geostrophic winds associated with the atmospheric pressure field (wind parallel to the isobars, corresponding to a balance between pressure gradient and Coriolis acceleration) to match the actual characteristic maximum wind speed of the storm measured at a typical height of 10 m. The effects of friction on the wind directions are accounted for by making the wind veer towards the interior of the storm by an angle between 0° to 40° (accordingly to various observations for unstable or stable conditions). In the model, storms follow straight tracks and travel at a constant speed. The model was simulated for a range of track directions corresponding to each type of storm and with the center of the storm hitting Lake Huron at various locations from west to east along its zonal mid section.

Characteristics of the storms are defined by the following parameters:

- Low pressure at the centre of the storm;
- High pressure surrounding the storm;
- Radius of the storm (scale factor of the Gaussian atmospheric pressure field);
- Maximum wind speed;
- Angle by which the wind veers towards the centre of the storm;
- Storm track direction (direction from which the storm comes);
- Speed at which the storm travels; and
- Section of the Lake over which the centre of the storm passes.

4.2.4 Types of Surge-Producing Storms

The most severe types of weather systems that can affect the region of Lake Huron are summarized below.

- Post Tropical Storms: a good example of a post tropical storm with very severe wind conditions for Lake Huron is Hurricane Hazel (1954). Most other post tropical storms arrive in the area from the Gulf of Mexico and although they may still produce very heavy precipitation, winds have significantly weakened. Hazel landed on the Atlantic coast and was reinforced on its way by a low pressure system to the southeast of Lake Ontario. Therefore, Hazel still had very strong winds. A storm like Hazel would typically approach

Lake Huron from between the southeast and south. A Hazel-like post tropical storm with extremely severe characteristics could have sustained winds up to 100 km/h and a pressure drop as low as 950 mbar[10].

- Alberta Clippers: they are compact, fast-moving, winter storms with sustained winds up to about 80 km/h and characteristic pressure drop of about 970 mbar. They would typically track from between northwest to west-southwest.
- Colorado Lows: they are less compact than the Alberta Clippers but have otherwise similar characteristics and would track from the southwest or south-southwest.
- Gulf lows: a good example of a very severe Gulf low is the Great Blizzard of 1978. The pressure dropped to the extremely low value of 958 mbar. Characteristic severe sustained winds were up to about 100 km/h.

4.2.5 Sensitivity Analysis

The model was run for a large number of combinations of the parameters representing the characteristics of the idealized storms. Analysis of the results provides good insight on the response of Lake Huron to various weather systems with different characteristics and allows determination of which storms, typical of the region, are the most likely to result in significant surge and possible subsequent seiche. Deeper depressions and stronger winds produce a stronger response in the model. A brief discussion of the sensitivity of the model to the other parameters follows.

- Radius of the storm: Lake Huron is about 400 km long from north western tip (Mackinac Straits) to southern tip (Sarnia/Port Huron) and has a width of about 150 km at its widest zonal mid section. So it can be expected that weather systems with a similar scale would result in the strongest dynamic response. It was found that storms represented by a Gaussian pressure field with a scale factor of 300 km or 200 km produced the largest surge and seiche. As mentioned above, for the idealized Gaussian pressure field, the scale factor needs to be smaller than the actual radius of the storm to present the steep pressure gradient usually found on the leading edge. Small scaling factors between 200 km and 300 km are representative of the most compact weather systems in the region such as Alberta Clippers or post tropical storm Hazel.
- Tendency for surface winds to veer inside the storm: the model was run with wind fields parallel to the isobars or veering towards the centre of the storm by 20° and 40°. Results indicate that the more the wind direction veers towards the centre of the storm, the larger the amplitude of the surge.
- Storm track direction: tracks running along the main axis of Lake Huron (from the northwest) were found to have the most impact overall in terms of surge and seiche generation.
- Speed at which the storm travels: the fastest-moving storms were found to produce the largest surge and seiche. The higher travelling speeds are getting closer to the speed of propagation of the shallow water long waves, so that both the forced response and the free response travel at similar speeds. This creates conditions for resonance in the Lake which results in surge and subsequent seiche of larger amplitude. Post tropical storm Hazel was travelling at about 80 km/h. Alberta Clippers are typically fast moving storms with speeds of up to 100 km/h.
- Section of the Lake hit by the centre of the storm: the amplitude of the response to various tracks was found to be highly variable for different parts of Lake Huron. As expected, the north western and southern tips saw the largest surge while the central regions saw relatively smaller increase/decrease in water level. As was also expected, Saginaw Bay exhibited large surge and could sustain its own seiche forced at its mouth by the response of the main body of the Lake. Georgian Bay and North Channel also exhibited large surge and

[10] 1 mbar = 1 hPa

seiche virtually completely decoupled from the Lake. At Bruce nuclear site, highest water levels were attained by the surge as a result of storms from the west/northwest sector.

4.2.6 Characteristics of Modeled Storms

The parameters used to represent the idealized storms corresponding to the types of surge producing storms are summarized in Table 4.2.

Table 4.2: Surge Producing Storm Descriptions

	Post Tropical Storm (*Hurricane Hazel 1954*)	**Alberta Clipper**	**Colorado Low**	**Gulf Low (*Great Blizzard 1978*)**
High Pressure	1025 mbar	1025 mbar	1025 mbar	1025 mbar
Low Pressure	950 mbar	970 mbar	950 mbar	950 mbar
Radius (scale factor)	300 km	200 km	300 km	300 km
Maximum Wind Speed	100 km/h	80 km/h	80 km/h	100 km/h
Track Direction (from)	SE, SSE, S	NW, WNW, W, WSW	SW, SSW	SW, SSW, S
Storm Velocity	80 km/h	100 km/h	100 km/h	60 km/h

For all storms, wind was made to veer towards the centre of the storm by an angle of 40° from the tangent to the isobars. For each storm type and track directions except the west, nine different tracks were considered with the centre of the storm crossing at nine different locations from west to east along the zonal mid-section of the Lake. For an Alberta Clipper from the west, nine tracks were considered at nine latitudes between the northern and southern tips of the Lake.

4.2.7 Results

The response of Lake Huron to a given storm was simulated for a period of 24 hours in each run, allowing for development of the surge forced by the storm as it approaches the region and tracks across the Lake, and subsequent free response in the form of seiche as the storm leaves the region. Highest water levels attained at Bruce during each simulation are presented in Table 4.3.

Overall, the highest levels at Bruce are attained at the peak of the surge during storms that track close to the site. In these cases, the subsequent seiche in Lake Huron produces lower levels at the site than surge levels. Only in a few cases where the center of the storm does not come close to Bruce, and therefore cannot produce a significant surge at the site, is the highest level occurring during subsequent seiche and is quite a bit lower than the maximum surge level. This is consistent with the fact that Bruce is in the central region of the Lake where seiche levels are expected to be much smaller than the levels occurring at the extremities of the Lake, or in Saginaw Bay.

Table 4.3: Results of Surge and Seiche Level Predictions

from Extremely Severe Post Tropical Storm									
Tracking from	Position of Centre of Storm over zonal mid section of Lake Huron West				Centre				East
SE	0.35 m	0.41 m	0.43 m	0.42 m	0.39 m	0.45 m	0.46 m	0.41 m	0.29 m
SSE	0.26 m	0.36 m	0.43 m	0.38 m	0.47 m	0.59 m	0.56 m	0.42 m	0.25 m
S	0.18 m	0.26 m	0.31 m	0.31 m	0.56 m	0.73 m	0.73 m	0.53 m	0.30 m
from Extremely Severe Alberta Clipper									
Tracking from	Position of Centre of Storm over zonal mid section of Lake Huron West				Centre				East
WSW	0.49 m	0.57 m	0.66 m	0.73 m	0.78 m	0.81 m	0.80 m	0.76 m	0.66 m
WNW	0.64 m	0.85 m	1.04 m	1.18 m	1.26 m	1.27 m	1.20 m	1.06 m	0.87 m
NW	0.21 m	0.33 m	0.62 m	0.97 m	1.20 m	1.18 m	0.93 m	0.58 m	0.27 m
	Position of Centre of Storm over meridional mid section of Lake Huron North				Centre				South
W	0.23 m	0.42 m	0.63 m	0.86 m	1.04 m	0.92 m	0.52 m	0.20 m	0.16 m
from Extremely Severe Colorado Low									
Tracking from	Position of Centre of Storm over zonal mid section of Lake Huron West				Centre				East
SSW	0.14 m	0.15 m	0.20 m	0.31 m	0.56 m	0.72 m	0.72 m	0.59 m	0.40 m
SW	0.12 m	0.15 m	0.30 m	0.48 m	0.67 m	0.80 m	0.84 m	0.76 m	0.62 m
from Extremely Severe Gulf Low									
Tracking from	Position of Centre of Storm over zonal mid section of Lake Huron West				Centre				East
S	0.10 m	0.17 m	0.22 m	0.27 m	0.54 m	0.71 m	0.73 m	0.55 m	0.30 m
SSW	0.08 m	0.12 m	0.14 m	0.20 m	0.52 m	0.75 m	0.81 m	0.71 m	0.49 m
SW	0.05 m	0.11 m	0.11 m	0.27 m	0.48 m	0.67 m	0.78 m	0.77 m	0.67 m

The maximum water level at the Bruce nuclear site is 1.3 m during a surge generated by an Alberta Clipper from the west-northwest. This compact type of storm travelling over the north western part of the Lake towards the Bruce nuclear site is the most efficient for surge development along the shore in the region around the Bruce nuclear site. The water level anomaly over Lake Huron at the time of the peak surge at the Bruce nuclear site during this Alberta Clipper is presented in Figure 4.4.

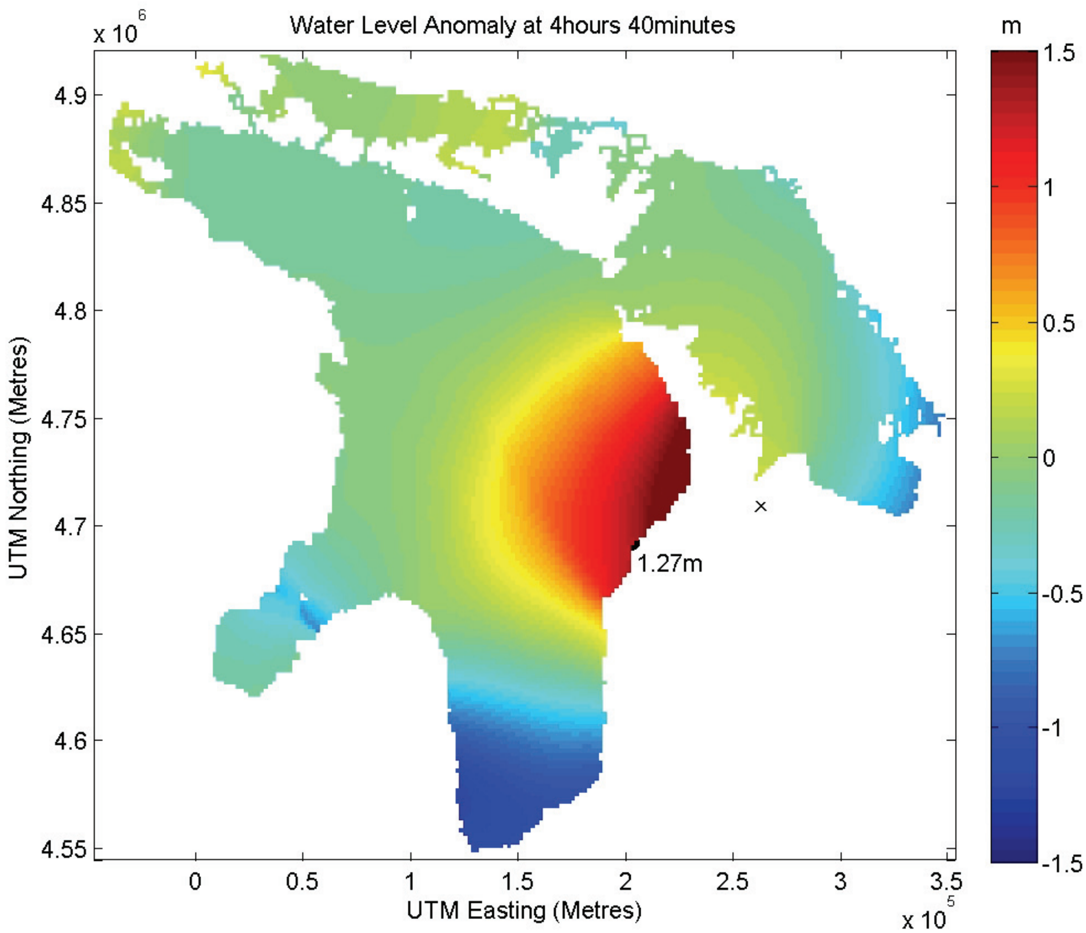

Figure 4.4: Maximum Surge at Southern End of Lake Huron

As noted previously, an example of sudden and large changes in lake water levels associated with passage of a summer storm occurred in July 1995. During this event, a dramatic seiche occurred in Lake Huron the evening of July 13th. In the span of about one and a half hours, water level measurements at Goderich rose 0.53 m from 176.63 m to 177.15 m above IGLD 1985, and then precipitously fell 1.08 m (or to 0.56 m below the mean) to 176.07 m before returning to near normal. Smaller seiches up to magnitude about 0.3 m were also subsequently observed, true to the seiche physical mechanism. At Lakeport, a longer period and somewhat larger amplitude seiche was observed. In the span of about five hours, lake levels rose 0.66 m from 176.65 m to 177.22 m, and then precipitously fell 1.40 m (or to 0.81 m below the mean) to 175.82 m before returning to near normal.

4.3 Flooding by Waves

Given the location of the Bruce nuclear site (and DGR area located immediately inland) on the shore of Lake Huron, Ontario, wind generated water waves (surface gravity waves) are taken into consideration in this assessment of potential lake flooding.

Waves are formed by a complex process of energy transfer from wind moving across a smooth water surface, through wind turbulence creating small waves or ripples and then from surface ripples to larger waves. This energy is carried by waves to the nearshore zone and serves as the primary energy source for shoreline changes such as erosion, damage to shoreline structures, formation of depositional beach features and littoral transport.

To describe the flooding potential from waves, the SWAN (Simulating WAves Nearshore) model was used to propagate extreme wave conditions from a selected offshore Wave Information Studies (WIS) node to the shoreline, while the SPLASH software was used for the wave uprush calculations. The descriptions of the software are provided in Section 4.3.2.

First, a description of the shoreline characteristics and topography as one approaches the DGR area from the lake is presented in Section 4.3.1.

4.3.1 Shoreline Characteristics

The ground surface elevation on the Bruce nuclear site generally rises over distances up to 100 m from the lake to about elevation 179 m. This is followed by a flatter approach to the DGR project site, which is about 975 to 2500 m inland, where elevations are in the range of 181 to 187 m above IGLD 1985.

The DGR area and its proximity to the lake are illustrated in Figure 3.19. For additional orientation, Figure 4.5 to Figure 4.11 show photographs taken at select shoreline locations (locations are noted in Figure 3.19) during the Project site visit. These photographs illustrate the flat nature of the shoreline.

Figure 4.5: Shoreline View Location 1

Figure 4.6: Shoreline View Location 2

Figure 4.7: Shoreline View Location 3

Figure 4.8: Shoreline View Location 4

Figure 4.9: Shoreline View Location 5

Figure 4.10: Shoreline View Location 6

Figure 4.11: Shoreline View Location 7

The Baie du Dore shoreline material is a mix of sand and cobble with bedrock not far below the surface. At the north end of the site the shoreline is a mix of sand, cobble and boulders (around location 5). This continues to about midway between locations 1 and 2. Again, it is likely bedrock is close to the surface in this zone. Most of the area from locations 2 to 4 is exposed bedrock. Farther south of this is armoured rip-rap at a 1V:2H slope built on the existing shoreline to an elevation of 179.9 m above IGLD 1985 with structure toe located at an elevation of 176.8 m above IGLD 1985 (Bruce Power 2005).

The Lake Huron mean water level on the site visit 15 April 2010 was 176.13 m above IGLD 1985[11]; at Goderich it was 176.112 m above IGLD 1985. During the month of April 2010 the daily mean water level varied from 176.053 m on April 2 to 176.269 m on April 17[12]. This level is therefore about 40 cm below the long-term (1918-2009) Lake Huron average of 176.43 m and 2.29 m below the 1-500 year value of 178.4 m.

A north to south vertical cross-section of the site topography from the lake shoreline near MacPherson Bay, and site visit photo location 1 (Figure 4.5) to the southwestern boundary of the DGR operational area[13] (approximately at elevation 185.5 to 187.5 mASL) is shown in Figure 4.12. This was derived from inspection of the site LIDAR data set noting the elevation and horizontal distance at every 1 m contour. The profile rises from 176 m at the lake to about 187 m in the DGR area. The vertical scale in the figure is exaggerated given the gentle slope (~ 1V:86H).

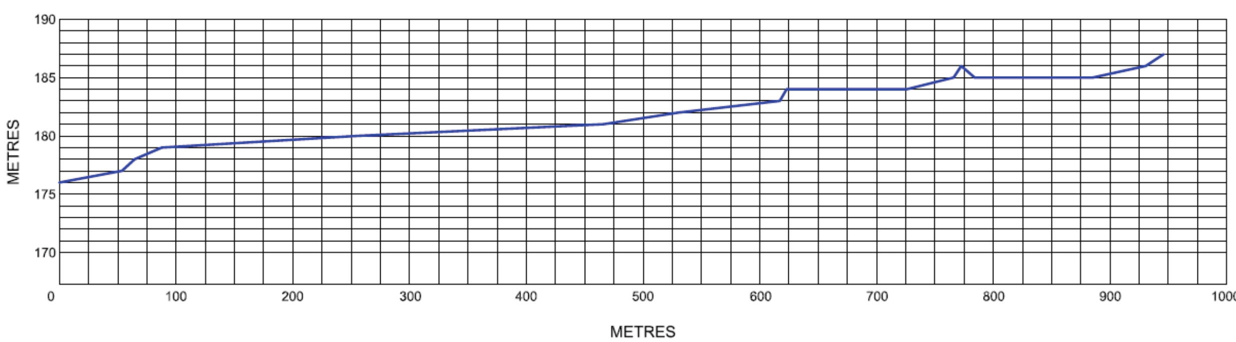

Figure 4.12: Cross-section View from Lake Shoreline, MacPherson Bay, to DGR Operational Area. Elevation in Metres above IGLD 1985

Given this location represents the shortest distance from the lake, and from inspection of site topographic maps (e.g., Figure 4.5.2-1 of the Bruce New Nuclear Hydrology and Water Quality TSD (GOLDER 2008)), the profile is deemed representative of the lowest slope approaching the DGR from the lake, and thus a suitable shoreline slope for estimation of wave uprush.

4.3.2 Data and Models

A Lake Huron wind and wave hindcast, developed by WIS of the Office, Chief of Engineers, U.S. Army Corps of Engineers (USACE) (Reinhard et al. 1991) was selected to enable the assessment of wave flooding potential at the Bruce nuclear site. The WIS model grid consists

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[11] http://www.lre.usace.army.mil/hh/GreatLakesWaterLevels/GLWL-1MonthAgo-Meters.pdf (accessed May 10, 2010)

[12] http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/twl-mne/inventory-inventaire/data-donnees-eng.asp?user=isdm-gdsi&region=CA&tst=1&no=11860&ref=maps-cartes (accessed May 10, 2010)

[13] UTM coordinates X: 453369 m, Y: 4908278 m

of a 10 nautical mile (about 18 km) grid spanning 49 locations about the Lake Huron shoreline. The hindcast consists of three hourly significant wave height, peak wave period, mean wave direction, and wind speed, for 32 years (1956 to 1987). Deep water was assumed across the entire grid; therefore, no bathymetry was input. The winds were interpolated over the grid at 3-hour intervals to force a spectral wave model and verifications were made using long-term deployment NOAA buoys. The wave model included the time-dependent wave action balance equation, wave growth based on the combined Phillips and Miles mechanism, weak nonlinear wave-wave interaction, equilibrium JONSWAP and Kitaigorodskii spectra and linear refraction, as well as shoaling and dissipation terms.

The SWAN wave model was developed by Holthuijsen et al. (2000) and utilizes a finite difference scheme to compute random, short-crested, wind-generated waves and allows for spectral wave input at specified boundaries. The action density spectrum (equal to the energy spectrum divided by the relative frequency) is used since it is a quantity that is conserved in the presence of currents. SWAN incorporates physical processes such as wave propagation, wave generation by wind, white-capping, shoaling, wave breaking, bottom friction, reflection, subsea obstacles, wave set-up and wave-wave interactions in its computations. SWAN computes the wave field and other wave parameters over a specified range of geographical space, time, wave frequencies and directions. The model inputs include the NOAA gridded bathymetry and topography (NGDC 2010a), stillwater and surge levels, and the WIS wind and wave hindcast.

SPLASH (Atria 1997, OMNR 2001) has been designed as a software aid to calculations of wave uprush and wave overtopping on shoreline beaches and structures. SPLASH is capable of using several different methodologies to calculate the wave uprush and overtopping for any given set of input parameters. Calculations are performed by varying the wave parameters (height and period) and the structure geometry and characteristics of the beach or wall (slope, depth, surface reduction factor, lake bottom slope).

4.3.3 Wave Hindcast Extreme Analysis

Extreme wave estimates were compiled using the 32 year (1956 to 1987) WIS node #H0043 data record as shown in Figure 4.13.

For each year of the node, the maximum value of significant wave height, Hs, was selected. A Gumbel cumulative probability distribution was fitted to the 32 points using the maximum likelihood algorithm (Gumbel 1958). Using the fitted distribution, Hs values for selected return periods from one to 100 years have been estimated. The associated peak wave period, Tp, is the period corresponding to each maximum Hs selected.

These results are presented in Table 4.4. Estimated 100-year maximum wave heights range from 9.1 m to 10.1 m from west to east of the site.

Table 4.4: WIS Node #H0043 Significant Wave Height (Hs) Extremal Analysis

	SW		NW		Omni-directional	
	Hs (m)	Tp (s)	Hs (m)	Tp (s)	Hs (m)	Tp (s)
10-year	6.7	10.2	7.4	11.2	7.7	11.2
50-year	8.4	11.5	9.2	12.7	9.4	12.6
100-year	9.1	12	9.9	13.3	10.1	13.2

Notes:

Maximum Hs in the dataset: 9.2 m, Tp associated: 13 s, wind speed associated: 27 m/s

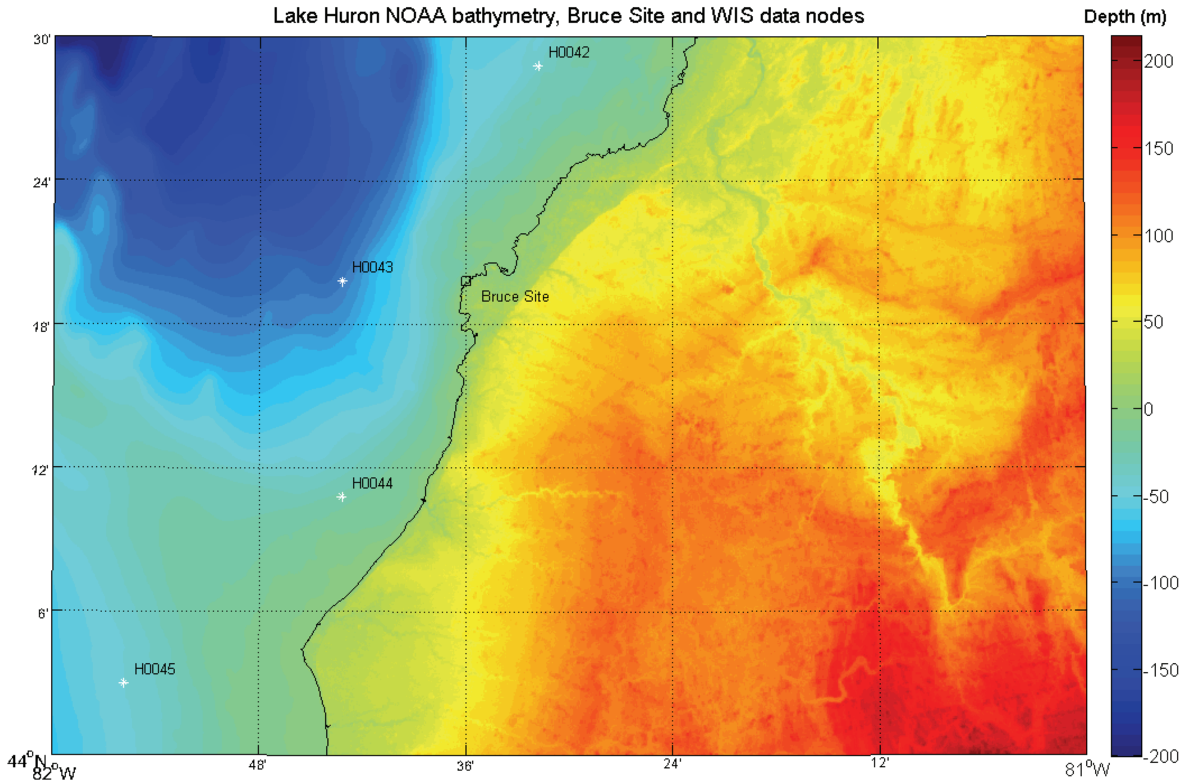


Figure 4.13: WIS Node locations, with Local Bathymetry and Topography, Referred from IGLD 1985 Chart Datum (0 = 176 m)

Omni-directional extremes are higher than directional extremes from the NW or SW. The difference between directional (NW and SW) and omni-directional extreme estimates is up to a metre for the SW direction, and 0.2 m for the NW direction.

Based on these results, it is appropriate to use the WIS #H0043 100-year Hs of 10.1 m with period Tp of 13.2 s propagating from the NW (315° N) as input to the wave propagation and uprush models; two steps which are described in Sections 4.3.4 and 4.3.5 respectively.

4.3.4 Nearshore Wave Propagation Modeling

Two scenarios of water levels were taken into account with the results of the extreme wave analysis (10.1 m Hs, 13.2 s Tp wave) to perform the the nearshore wave propagation modeling:

- A 500-year return still lake water level equal to 178.4 m above IGLD 1985; and
- A 500-year return still lake water level plus an estimated maximum storm surge (1.3 m) equal to 179.7 m above IGLD 1985.

For each of these two scenarios, SWAN was run using the 3-arc second bathymetry provided by NOAA (NGDC 2010a) and forced over its north, western and southern boundaries by the extreme wave conditions determined in the previous section, that is by a significant wave height (Hs) of 10.1 m with a peak period (Tp) of 13.2 s and coming from the northwest (315° N). Wind speed input of 40 m/s from the northwest (315° N) was included in the simulation, as tests indicated that there is sufficient fetch for the wind to contribute to the significant wave height observed along the shore.

The computational grid was created so that the western boundary was located at the longitude of the WIS #H0043 node and all the Bruce Nuclear site shoreline could be resolved (Figure 4.14). For additional orientation for the reader, the figures show as “DGR Area” the surface boundaries of the DGR surface facilities, north of the railway track.

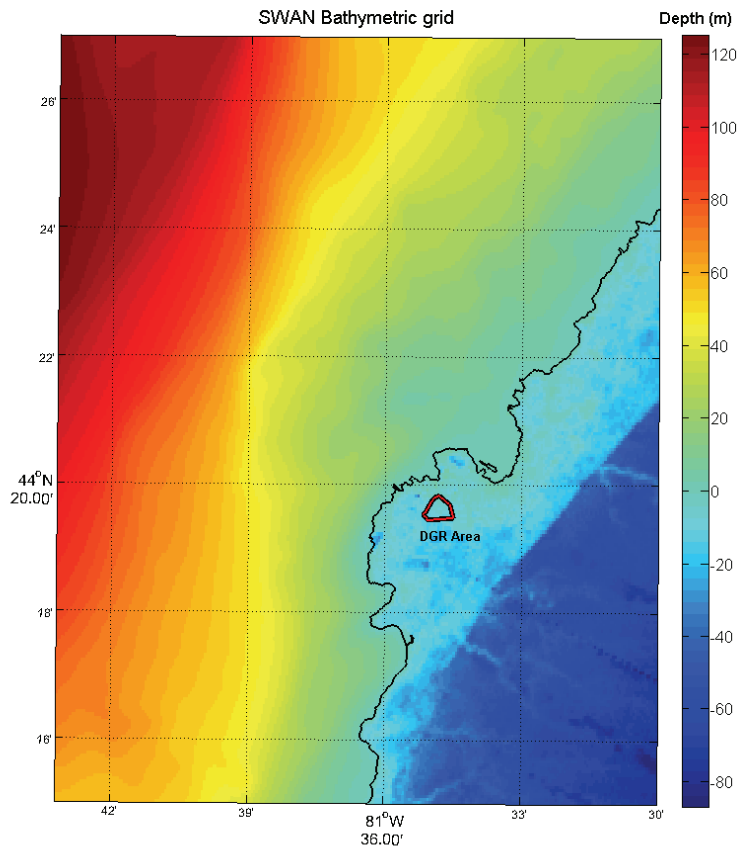


Figure 4.14: SWAN Bathymetric and Computational Grid, Bathymetry from NOAA (Negative Depth Represents Land above the Water Level)

4.3.4.1 500-Year Still Lake Water Level

Wave height and direction propagation results of this scenario are presented in Figure 4.15 and the wave induced water level setup is shown in Figure 4.16.

The significant wave height Hs at approximately 100 m from the shoreline (defined at 176 m, IGLD 1985) at the Bruce nuclear site was also extracted (Figure 4.17) for later application in the wave uprush estimation. The wave height values are conservatively selected from these data to reflect the maximum observed values near the Site. The corresponding wave setup along the shoreline at the Bruce nuclear site is also presented in Figure 4.17.

Based on these results, it is appropriate to use a value for Hs of 5.5 m with the peak period equal to 13.2 s as input for the wave uprush calculations. This is a nearshore value in contrast to the value of 10.1 m from offshore.

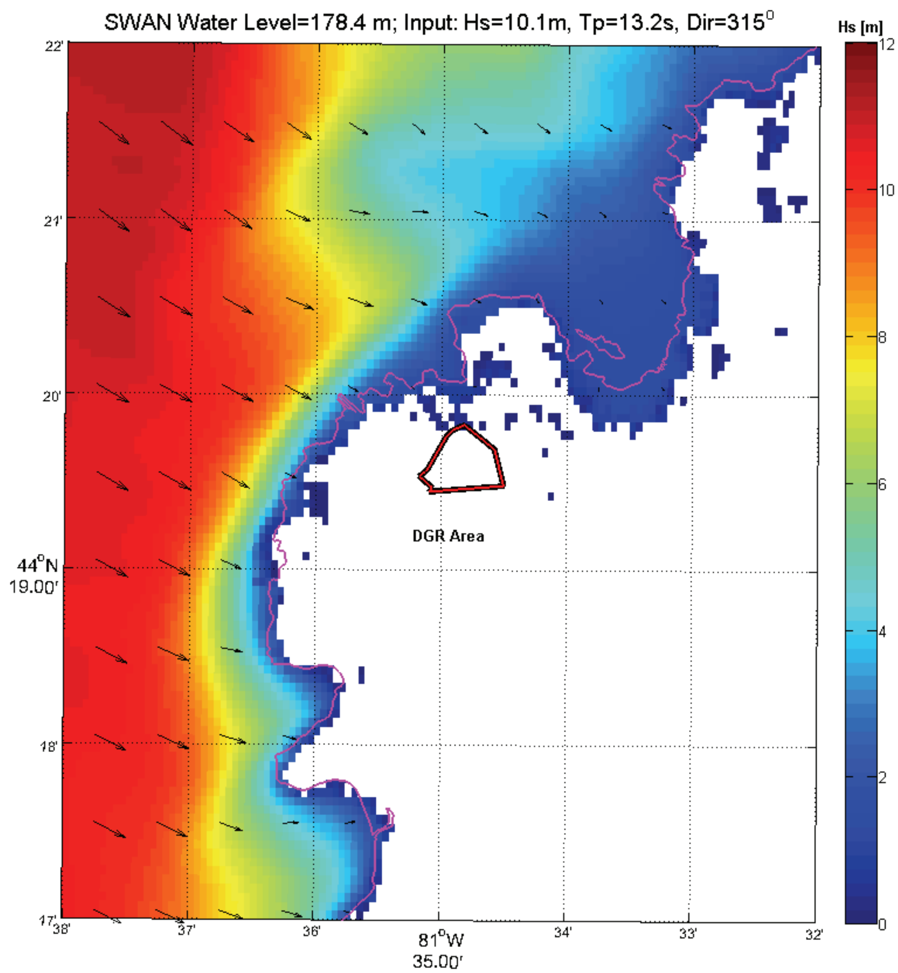


Figure 4.15: SWAN Wave Height and Direction Propagation Result over Extreme Still Lake Water Level of 178.4 m above IGLD 1985

There are a few conclusions to note regarding the results from the SWAN simulations. In Figure 4.15 and Figure 4.16, the coastline defined at 176 m above IGLD 1985 is presented as a reference to the current mean lake water level, while the areas in white represent the dry areas in the extreme scenario considered here. Thus, when the 500-year still lake water level and the water level setup due to waves (up to ~0.475 m, Figure 4.17) are included, the SWAN model indicates some level of flooding along the shoreline of the Bruce nuclear site, with the most severe levels reaching the northern portion of the DGR Area, though not the operational area, from the direction of MacPherson Bay. Since the topography of the Bruce nuclear site above the mean lake water level is relatively crude (from the NOAA bathymetry compared with more recent high resolution LIDAR elevation measurements) and does not include man-made structures, these results are to be taken only as a general indication of the areas along the shoreline that are exposed to risk of flooding. Following these results, the North-South approach from MacPherson Bay to the DGR Area was chosen for wave uprush calculations, in order to estimate the maximum extreme water level at the site.

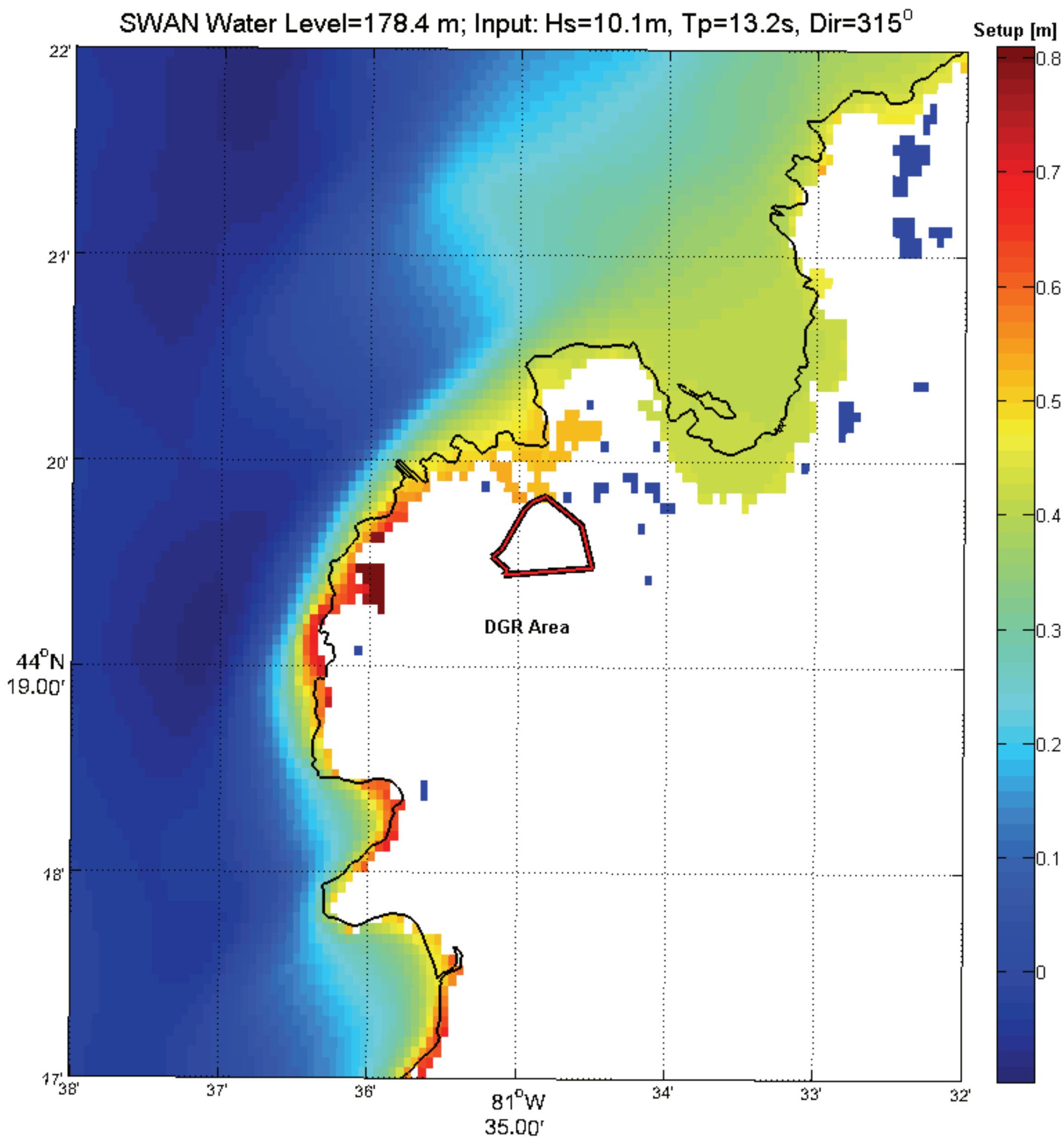


Figure 4.16: SWAN Wave Setup Result over Extreme Still Lake Water Level of 178.4 m above IGLD 1985

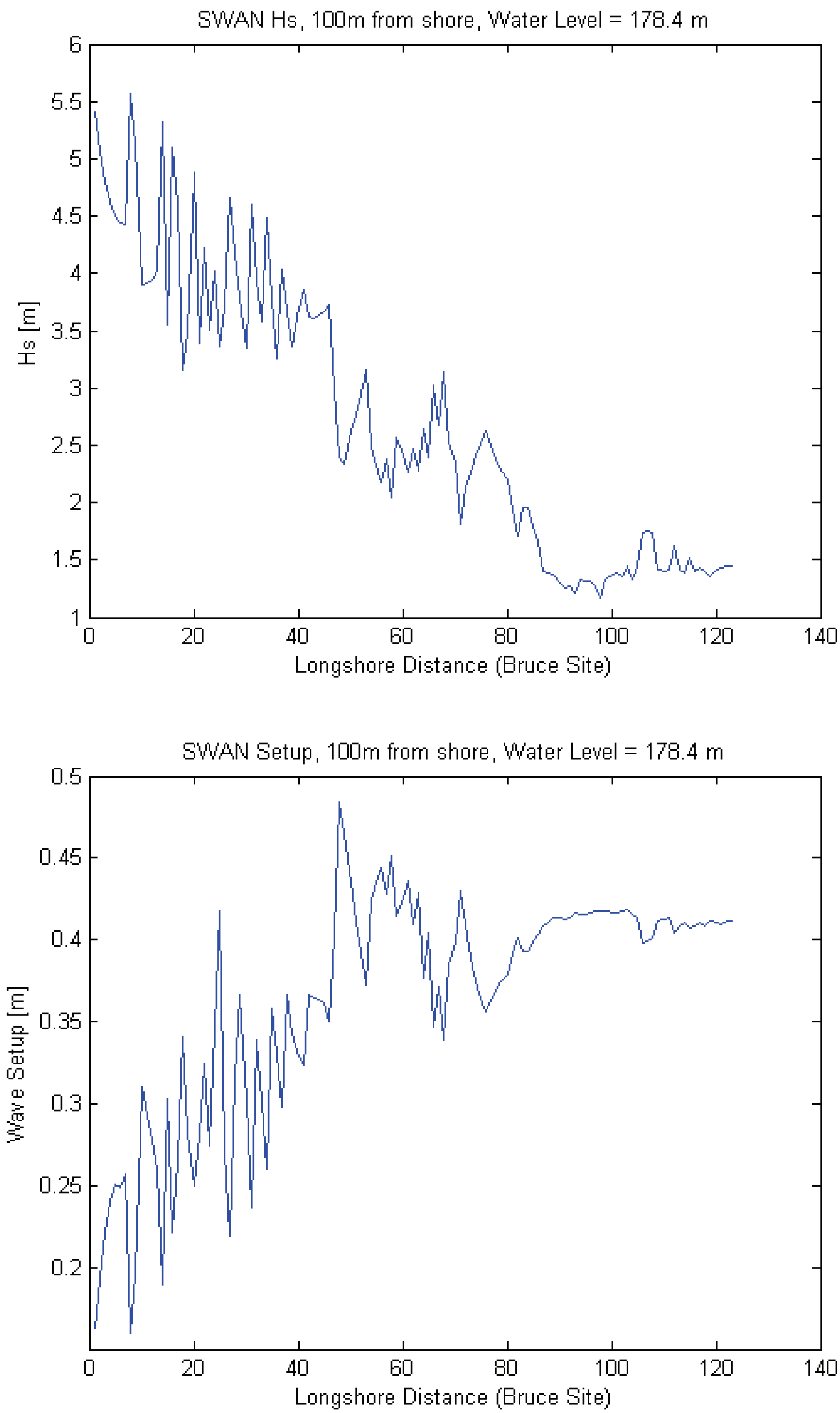


Figure 4.17: Significant Wave Height (Hs) and Wave Setup at 100 m from the Shore, from SWAN Simulation Results over Extreme Still Lake Water Level

4.3.4.2 500-Year Still Lake Water Level Plus Surge

Wave height and direction propagation results of this scenario are presented in Figure 4.18 and the wave induced water level setup is shown in Figure 4.19.

The significant wave height Hs at approximately 100 m from the shoreline at the Bruce nuclear site (defined at 176 m, IGLD 1985) was also extracted (Figure 4.20) for later application in the wave uprush estimation. The wave height values are conservatively selected from these data to reflect the maximum observed values near the Site. The corresponding wave setup along the shoreline at the Bruce nuclear site is also presented in Figure 4.20.

Based on these results, it is appropriate to use a value for Hs of 6 m with the peak period equal to 13.2 s as input for the wave uprush calculations.

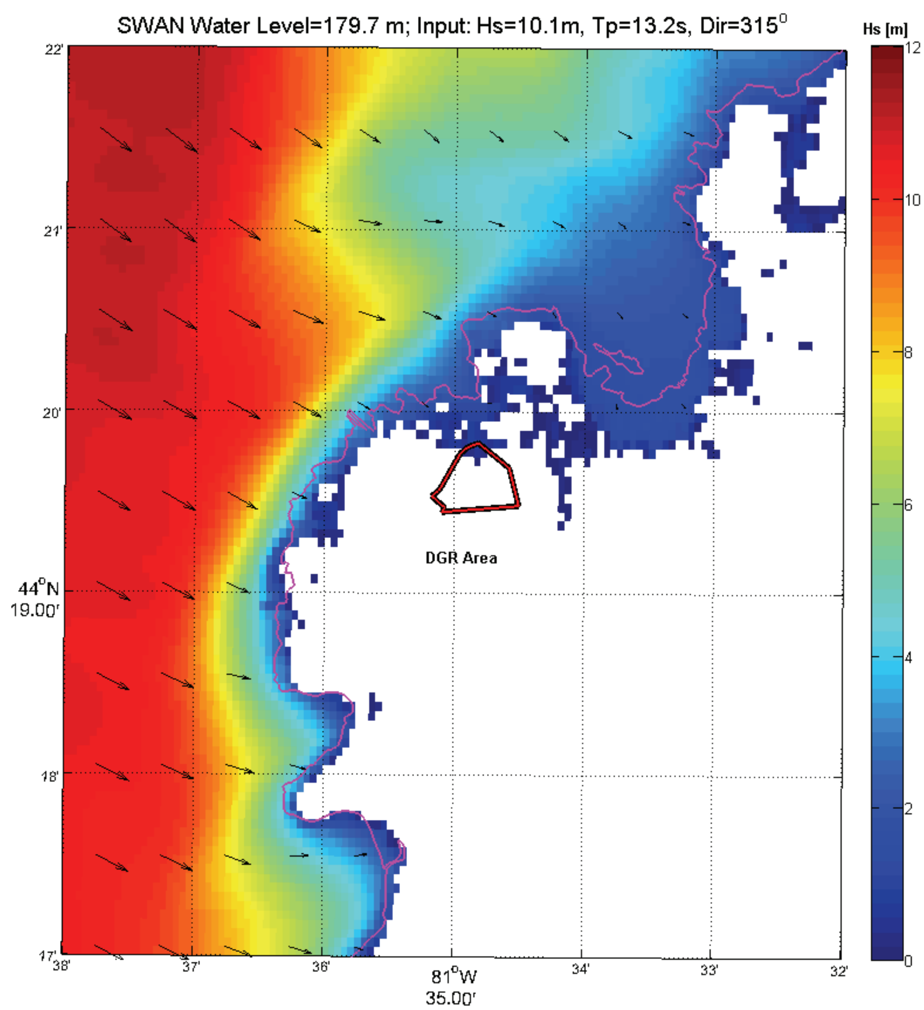


Figure 4.18: SWAN Wave Height and Direction Propagation Result over Extreme Still Lake Water Level, including Storm Surge, of 179.7 m above IGLD 1985

There are a few conclusions to note regarding the results from the SWAN simulations. In Figure 4.18 and Figure 4.19, the coastline (defined at 176 m, IGLD 1985) is presented as a reference to the current mean lake water level, while the areas in white represent the dry areas in the extreme scenario considered here. Thus, when the 500 year still lake water level and the water level setup due to waves (up to ~0.4 m, Figure 4.20) are included, the SWAN model indicates some level of flooding along the shoreline of the Bruce nuclear site, with the most severe levels reaching the northern portion of the DGR Area, though not the operational area, from the direction of MacPherson Bay. Since the topography of the Bruce nuclear site above the mean lake water level is relatively crude (from the NOAA bathymetry compared with more recent high resolution LIDAR elevation measurements) and does not include man-made structures, these results are to be taken only as a general indication of the areas along the shoreline that are exposed to risk of flooding. Following these results, the North-South approach from MacPherson Bay to the DGR Area was chosen for wave uprush calculations, in order to estimate the maximum extreme water level at the site.

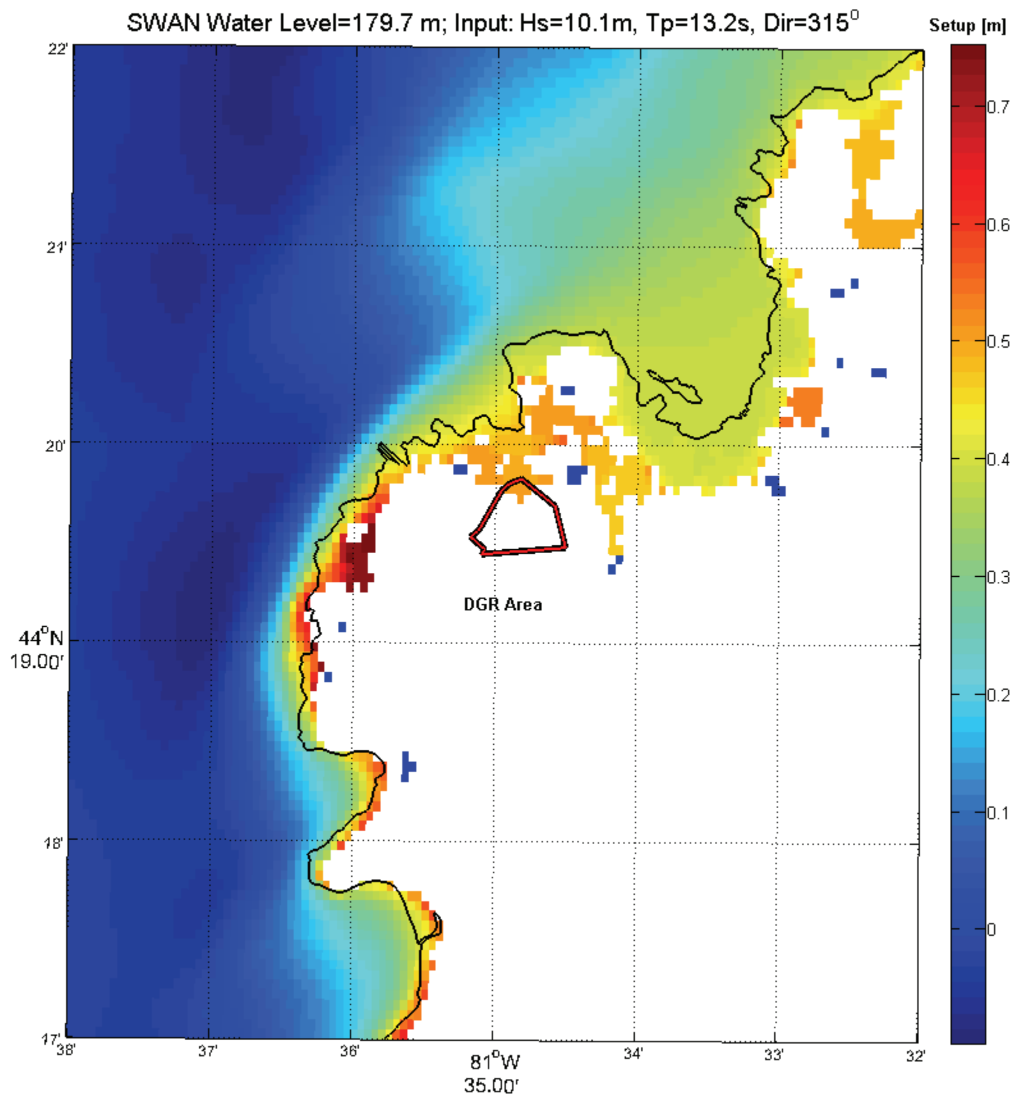


Figure 4.19: SWAN Wave Setup Result over Extreme Still Lake Water Level, Including Storm Surge, of 179.7 m above IGLD 1985

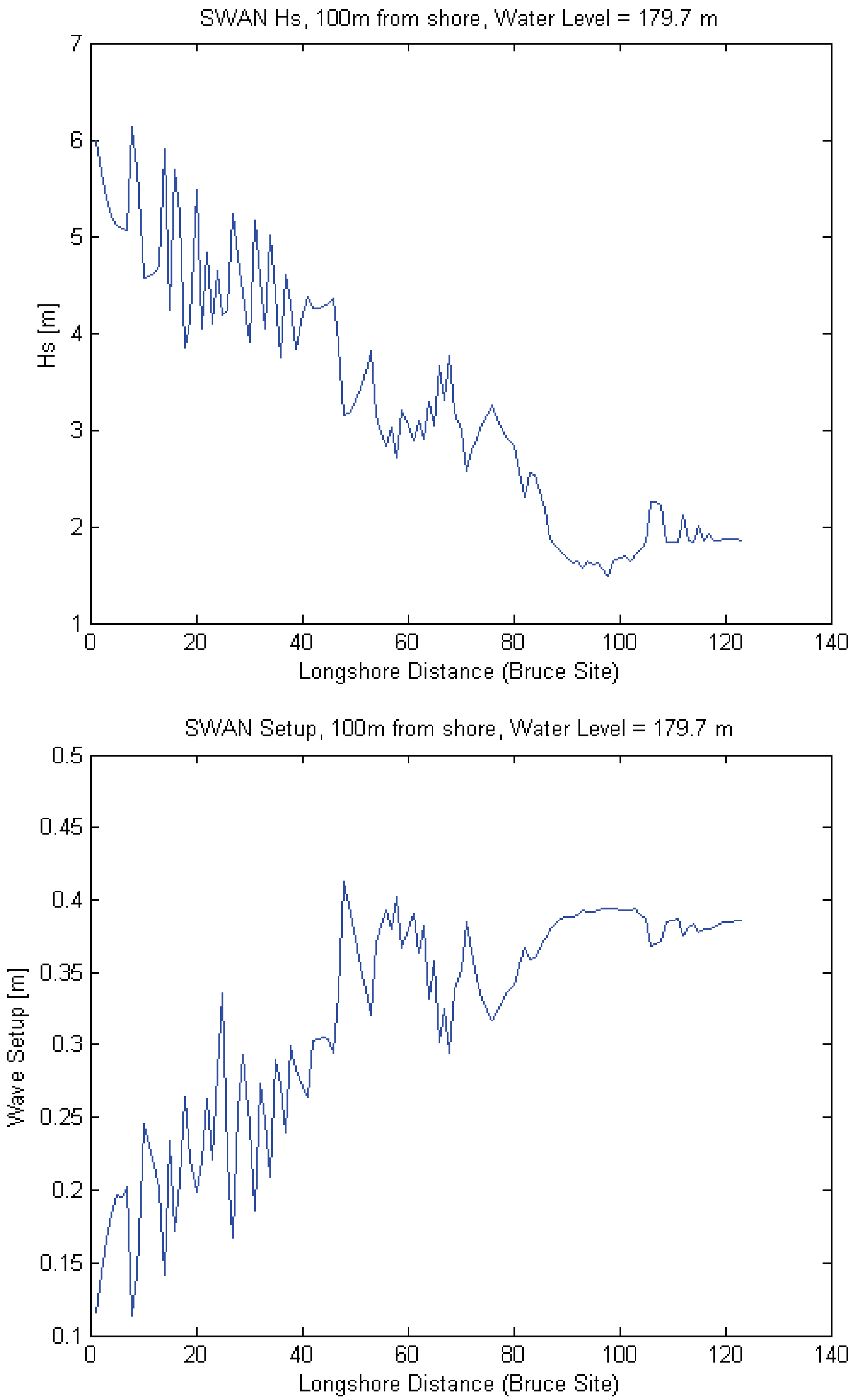


Figure 4.20: Significant Wave Height (Hs) and Wave Setup at 100 m from the Shore, from SWAN Simulation Results over Extreme Still lake Water Level, Including Storm Surge

4.3.5 Wave Uprush Estimates

The characteristics used to describe wave uprush are shown in Figure 4.21 (OMNR 2001). The primary controlling parameters for wave uprush include (OMNR 2001):

- Stillwater level;
- The incident wave climate;
- The beach or protection work slope;
- The lake bottom slope;
- The water depth at toe of the protection work's slope or beach slope; and
- Surface roughness and protection work permeability.

Other factors, such as the local bathymetry (e.g., offshore bars and composite slopes), berms in front of protection works and oblique wave attack may also change the magnitude of the wave uprush/runup. Ice cover of the shore can also influence the wave uprush by masking a rough permeable slope making it smooth and impermeable, and/or by limiting the depth of water by the presence of an ice foot, thereby limiting the wave action (OMNR 2001).

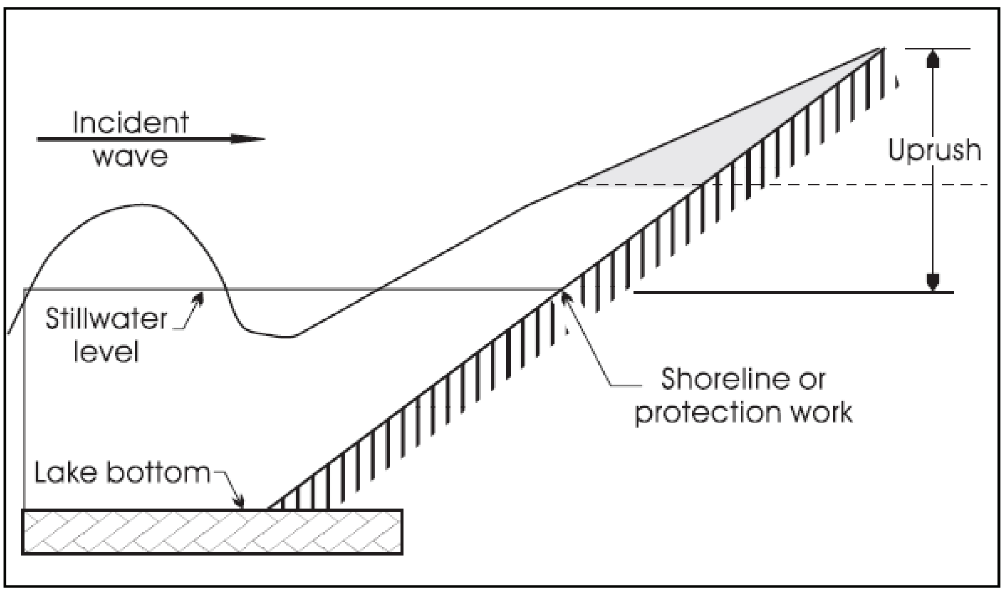
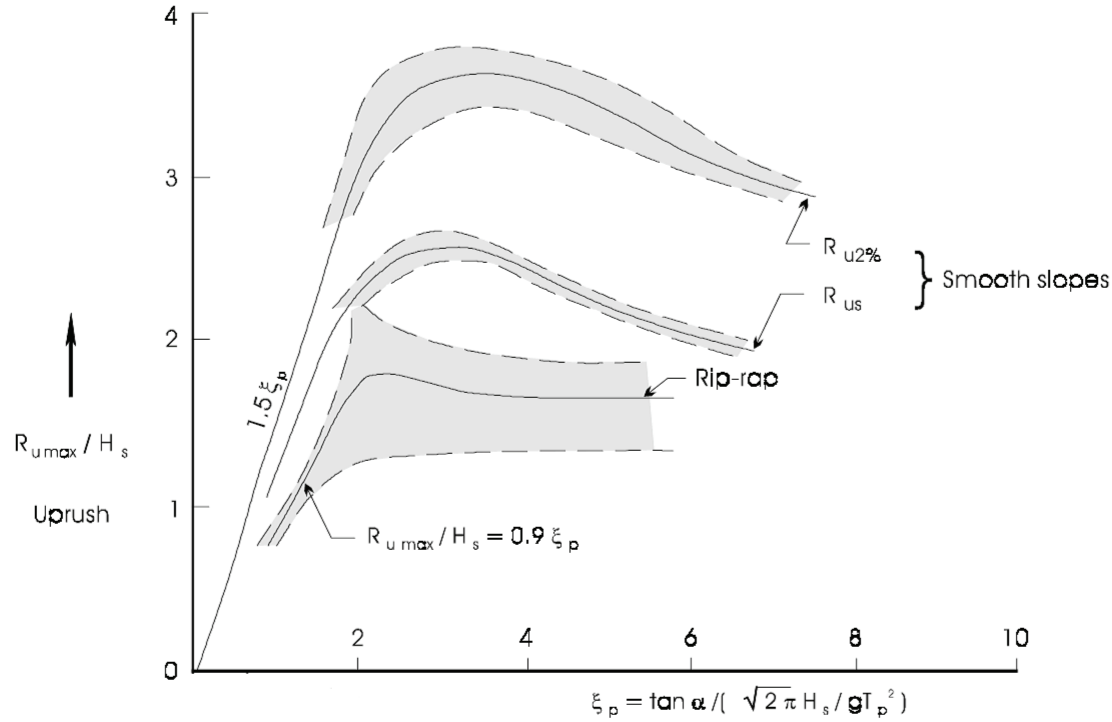


Figure 4.21: Characteristics of Wave Uprush for a Wave Breaking on a Slope

A range of uprush values arise for different significant wave height and structure slope combinations as illustrated in Figure 4.22 (Pilarczyk 1990). The y-axis of the graph presents the ratio of wave uprush value to significant wave height. The x-axis presents ξ, the Iribarren number, calculated as a function of significant wave height, peak wave period, and shoreline structure slope. The figure illustrates the relationships between these parameters, and their effect on wave uprush, for both smooth slopes and rip-rap (rock or other material used to protect shorelines from erosion). Several fitted curves are annotated. One can readily note, for example, the greater uprush for smooth surfaces; that peak uprush occurs for the range of ξ between 2 and 4; and there are regions of the curves where the uprush:significant wave height is sensitive to small changes in ξ. It is therefore critical to estimate these parameters as accurately as possible and recognize the inherent difficulty in making a prediction.



Notes: Ru2% is the 2% exceedence uprush value; Rus is the ‘significant’ (based on the significant wave height, Hs) uprush value; ξ is the Iribarren Number calculated from Hs, peak wave period, Tp, and structure slope, tan α

Figure 4.22: Uprush Functions for Irregular Waves

It is noted that there is a degree of uncertainty in the predicted uprush levels using these types of empirical equations. These equations try to correlate and simplify very complex phenomena using a limited number of parameters (e.g., basic wave height and period, shoreline slope). The scatter from which each of the empirical equations were derived are generally large and hence the resulting uncertainties. These uncertainties generally relate to factors such as:

- A need to assume regular waves as opposed to irregular waves;
- Use of a simplified shoreline profile; and
- Use of typically very simplified physical conditions in the experiments from which the relationships were derived.

While the scenario conditions considered here are comparable with the experiments associated with these empirical methods discussed, the numbers presented below should be considered as providing order of magnitude estimates only (Atria 1997).

In this section, two water level conditions were considered as input to the uprush calculations: 178.4 m and 179.7 m above IGLD 1985, together with the corresponding significant wave height results from Section 4.3.4.

The North-South approach from MacPherson Bay to the DGR Area was chosen as the area with the highest risk of flooding due to the combined effect of the 500 year lake water level and wave setup. Given the ‘structure’ or overland configuration/profile derived from LIDAR data, the very low slope (approximately 1V:90H) and wave climate under consideration, the method by Mase (1989) was chosen as the most appropriate for uprush calculations. This method is based on an extensive series of laboratory tests to study the uprush of irregular waves on gentle, impermeable slopes ranging from 1:5 to 1:30, and is considered “accepted” for determining flooding hazards in the Great Lakes (Atria 1997). The significant wave height and period extracted at a distance approximately 100 m from the mean lake water level (176 m, IGLD 1985) were used.

Using the Mase (1989) method, several uprush estimates, such as the average, significant and top 2% can be made. For this study, the top 2% value (that is, on average, 2% of all uprush values will exceed this level) was used. For the purpose of design, the uprush of 2% exceedance is commonly used in the Netherlands (e.g. Pilarczyk 1990). In addition, since the selected slope surface is a mix between sand and cobble, two different reduction factors corresponding to each surface material were considered. It is noted that since the SPLASH software implementation of the Mase, 1989 method does not provide for the 2% exceedance value (it provides the significant uprush value only), the direct equation and coefficients presented in (Atria 1997) were used:

$$\frac{R_2}{H_s} = 1.86\,\xi^{0.71}$$

where R_2 is the wave uprush value exceeded by 2% of the waves , the Iribarren number is given by $\xi = \tan\theta/(Hs/Lo)^{1/2}$, θ is the angle of the front slope of the structure or shoreline above the horizontal, Hs is the significant wave height, and Lo is the estimated wavelength.

The results of the uprush calculations for the two extreme water levels (with and without storm surge) are given in Table 4.5 and Table 4.6 respectively.

Table 4.5: Wave Uprush Estimates, Lake Water Level = 178.4 m above IGLD 1985

Water Level = 178.4 m **Inputs:** beach type structure, structure slope = 1:90; incident wave height = 5.5 m; period = 13.2 s; calculated Iribarren Number = 0.0781		
Method	**r coefficient[14]**	**Uprush Estimate**
Mase, 1989	0.6 0.9	1.00 m 1.51 m

Table 4.6: Wave Uprush Estimates, Lake Water Level = 179.7 m above IGLD 1985

Water Level = 179.7 m **Inputs:** beach type structure, structure slope = 1:90; incident wave height = 6 m; period = 13.2 s; calculated Iribarren Number = 0.0748		
Method	**r coefficient**	**Uprush Estimate**
Mase 1989	0.6 0.9	1.06 m 1.60 m

[14] Wave uprush on rough slopes is less than uprush on smooth slopes. This concept leads to the development of a ‘so called’ reduction factor r. This reduction factor was then applied to the uprush formulas developed for smooth slopes in order to obtain an uprush value for the comparable rough slope. By default, values of 0.9 and 0.6 were used to represent ‘sand surface’ and ‘cobble surface’, respectively.

The maximum uprush estimates for the two scenarios are 1.51 m and 1.6 m, respectively, conservatively considering a sandy slope. Since the surface material is mixed sand and cobble, it is expected that the maximum realized values should fall between the values calculated for each surface in each scenario.

It is recommended that these values are considered in addition to the values of 500-year maximum water levels, the storm surge and seiche levels and the wave setup levels in any detailed analysis of flooding impact on the infrastructure in the area.

In terms of considering potential maximum inundation or horizontal extent, the extreme prediction of 181.8 m (176 m chart datum + 2.4 m 500-year lake level offset +1.3 m storm surge + 0.475 m wave setup +1.6 m uprush), along the north-south section considered, translates to a distance of approximately 500 to 550 m inland.

4.3.6 Summary of Potential Lake Flooding due to Storm Surge, Seiche, and Wave Uprush

The assessment for potential lake flooding considered high water level, storm surge, seiche, wind wave, and wave uprush that could affect the DGR operational area inland of the Lake Huron shoreline. As reported in the previous section, the 181.8 m flood level prediction is the sum of a number of extreme or maximum conditions which would behave on different time scales, thereby ‘mitigating’ the flood level duration and magnitude. For example, the 500-year lake level offset of 178.4 m above IGLD 1985, 2.4 m above chart datum, would likely last for time scales of days to weeks. The predicted maximum storm surge of 1.3 m resulting from a passing severe Alberta Clipper storm would likely last for time scales of minutes to one or several hours. The wave flooding modelling showed significant wave height amounts of up to 6 m just 100 m from the shoreline. This translated into some ‘wetting’ of the northern tip of DGR area with wave heights close to zero and wave setups; however, predicted to be as high as about 48 cm for locations near the DGR stormwater management (SWM) pond but distant from the operational area to the southwest. Finally, a wave uprush of an additional 1.6 m was estimated. This is a prediction of a top 2% uprush estimate value, so during the several hours that waves were most severe, about 2% of the time the uprush would be this large. In reality, the amount of uprush would vary with the range of wave heights seen during the storm. The uprush would oscillate between greater and lesser values, e.g., while a 6 m wave might produce a 1.6 m uprush, a 3 m wave might produce a 0.7 m uprush. The wave periods are on the order of 10 s. Such extreme wave setups and uprush as this would likely last, albeit with the noted rise and fall behaviour, for the storm duration for which the largest waves are produced, perhaps one to several hours. This discussion provides an indication of possible shoreline flooding events, again, as noted, estimated to occur within approximately 500 to 550 m inland, well-removed from the DGR operational area.

4.4 Flooding by Tsunamis

Tsunamis are long period gravity waves generated by seismic disturbances of the sea bottom or shore, or landslides resulting in a sudden displacement of the water surface with the resulting wave energy spreading outwards across the ocean or lake at high speed. Tsunami occurrences in Canada are rare, with the Pacific Coast at greatest risk due to the high occurrence of earthquake and landslide activity. Their occurrence can result in major damage and loss of life. An additional consideration is the potential for a tsunami to occur as a series of waves (rather than a single wave) with associated increased impact from cumulative damage or flooding effects.

For consideration of the possible risk of tsunamis flooding for the Bruce nuclear site, a high level tsunami hazard assessment is presented. This is based on the approach presented by the U.S.

Nuclear Regulatory Commission 2008 NUREG/CR-6966 PNNL-17397 report (U.S. NRC 2009). This includes the following primary steps:

1. Assess whether the Bruce nuclear site is subject to tsunamis;
2. Assess whether the plant site (or DGR Area) is affected by tsunamis; and
3. Determine the hazards posed to safety of the plant (or DGR Area) by tsunamis.

The results of the assessment are presented below.

4.4.1 Regional Screening Test

Resources to assist with this first step include the Natural Hazards Database at the U.S. National Geophysical Data Center (NGDC), review of relevant literature including any geomorphic, shore protection, and nearshore classifications.

The NGDC and World Data Center (WDC) for Geophysics and Marine Geology have established a Historical Tsunami Database consisting of “two related files containing information on tsunami events from 2000 B.C. to the present in the Atlantic, Indian, and Pacific Oceans; and the Mediterranean and Caribbean Seas” (NGDC 2010b). The Tsunami Source Event data file has the information on tsunami source location, date, and time, event magnitude, maximum water height, total number of deaths, injuries and damage for the event; and the Tsunami Runup data file has the information on locations where tsunami effects occurred: arrival date and time, travel time, maximum water heights, horizontal inundation distances, deaths, injuries, and damage for specific locations[15]. Entries for Ontario and the states bordering the Great Lakes were examined.

There are runup entries for May 6, 1952 in Lexington, Harbor Beach, and Port Huron, Michigan. A wave runup height[16] of 1.52 m was reported (from Lexington, about half way between Sarnia and Harbor Beach on the southwestern shore of Lake Huron). This entry is flagged as a seiche or meteorological origin rather than a tsunami.

There is an entry for the Detroit River, inland of Lake Huron, September 19, 1884 “a wave or ‘ground swell’ was reported. The exact location is not known, nor is the source. The event validity of a tsunami is tagged as questionable.

There are doubtful runup entries (again these are flagged as a seiche or meteorological origin rather than a tsunami) for Illinois and Indiana including those for the June 26, 1954 Seiche event with runup height up to 3 m[17] and also for Green Bay, Wisconsin in 1895[18].

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15 The two ASCII tab-delimited event files can be readily downloaded.

16 The maximum elevation the wave reaches at the maximum inundation, though as stated in the database Data Reliability note titled *Uncertainties in the Significant Earthquake and Tsunami Databases* “it is not always clear which reference level was used”.

17 “1954, June 26. At least eight persons drowned when a wave struck nearly twenty-five miles of Chicago’s Lake Michigan shoreline. The wave swept over an eight foot sea wall at Loyola University close to Chicago’s northern boundary, but caused no damage. Normally it was widely believed that a seiche in this area would never exceed a 4-or 5-foot rise or fall in the water level. While such seiches result from squall lines that contain significant pressure changes and occur each year in the Great Lakes, this 1954 event was at least twice as large as any that had occurred up to that time. Seiche related deaths have also occurred in other events. The 1954 event may have had a under-water landslide in connection with the event that augmented the wave. (New York Times 1954, Chicago Tribune 1985) Validity 1 (very doubtful tsunami).” (Lockridge et al. 2002).

18 “1895, October 31. The Charleston, Missouri Earthquake (6.2 ml) caused extensive damage to schools, churches, homes and commercial buildings in Charleston. This was the largest earthquake to occur in the central Mississippi River valley since the 1811-12 series in the area of New Madrid, Missouri. A slight earthquake shock was felt at Green Bay, Wisconsin (Lake Michigan). There was a slight tidal manifestation on the bay. (Street, Couch, Konkler, 1986, Stover and Coffman 1993).” (Lockridge et al. 2002). The NGDC database reports a validity code of 0 “event that only caused a seiche or disturbance in an inland river”.

No tsunami runup events are reported in the database for Canada.

There are no tsunami source events for the states or provinces bordering the Great Lakes. The nearest entry for Canada is for a location well out into the Gulf of St. Lawrence west of Newfoundland.

Since tsunamis may be of seismic origin, a review of the earthquake risk for the region is appropriate. The literature suggests that it requires an earthquake of the order of Magnitude 6.5 to initiate a tsunami (González et al. 2007) and this would need to rupture the lakebed over a distance of several kilometres with a vertical offset on the order of 1 m.

The geological stability of the Great Lakes region is illustrated in Figure 4.23 (NRCAN 2010b), where the largest measured seismic activity results in only small earthquakes typically of Magnitude 3 or 4 (Figure 4.24) (NRCAN 2010a) less than the pre-requisite Magnitude 6.5 or greater. A more recent (and similar) indication of seismicity in the Bruce region is provided in Figure 4.25 (INTERA 2011). These low earthquake magnitudes in the vicinity of Lake Huron indicate a seismically-induced tsunami is an improbable event.

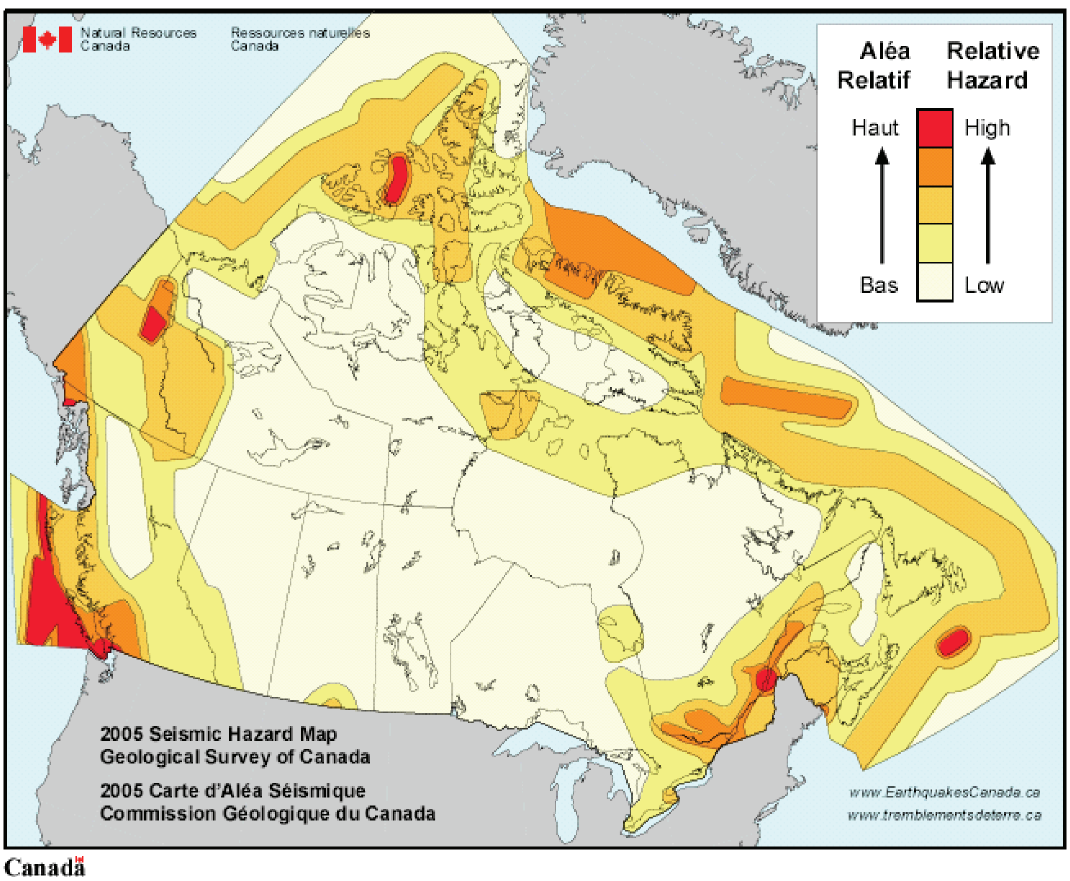

Figure 4.23: Simplified Seismic Hazard Map for Canada

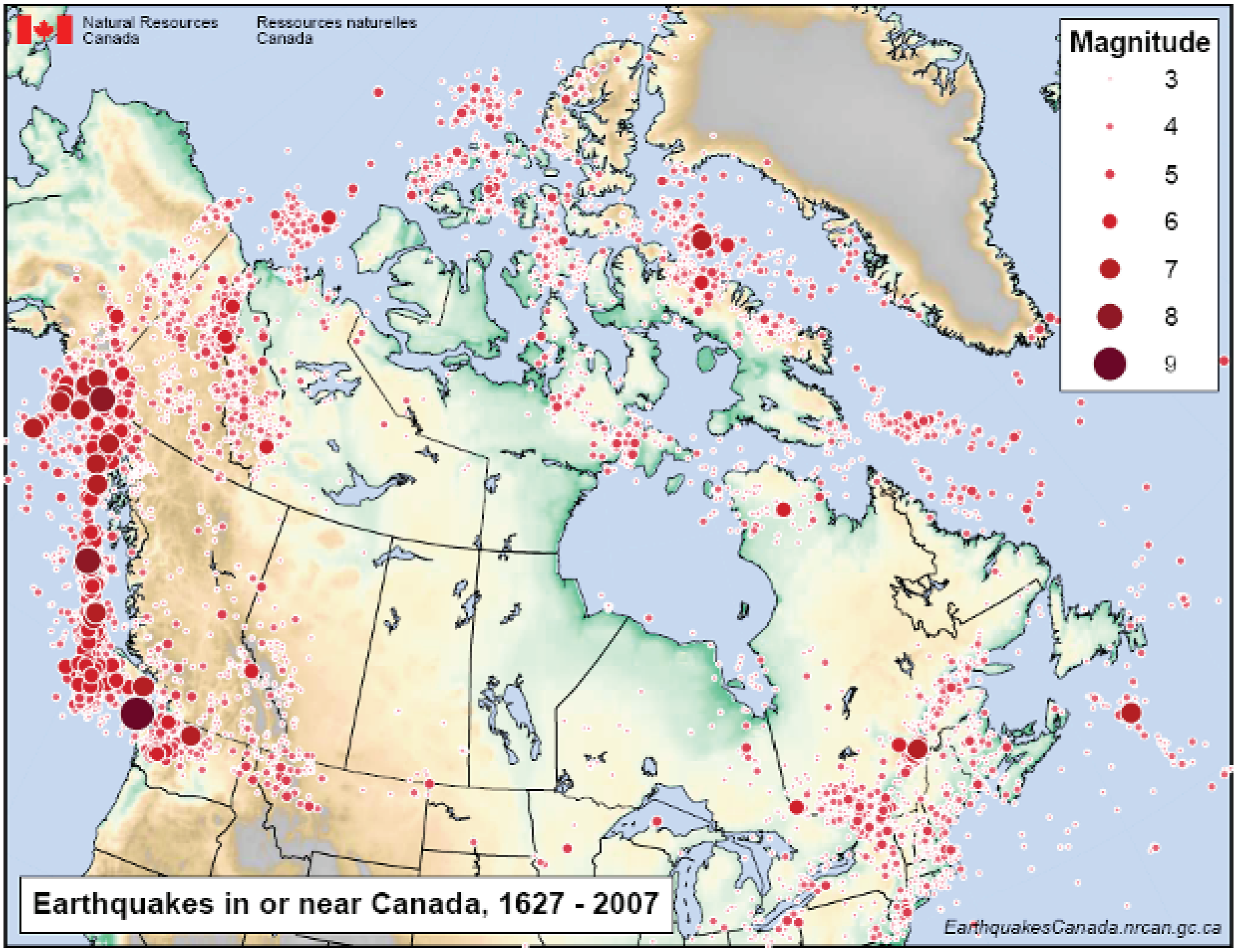

Figure 4.24: Earthquakes in or near Canada, 1627-2007

Landslides are also a potential mechanism for tsunami generation, though tsunamis generated by landslide usually do not travel as far as those generated by an earthquake. The shoreline region around Lake Huron is classified primarily as being susceptible to light erosion, and some areas of moderate erosion along a 50-60 km stretch from south of Point Clark, past Goderich, south to Grand Bend, Ontario. In small stretches (less than 50 km) there is a susceptibility to severe erosion near Sarnia and the southern end of Lake Huron, near the northwestern shore of Saginaw Bay, and near the Georgian Highlands of Georgian Bay (OMNR 2001).

A review of the on-line Natural Resources Canada landslides hazard map indicates no landslides along or near the Canadian shores of Lake Huron (NRCAN 2010c). This should not be taken to mean there are no landslides, rather the risk is low.

(Circles around Bruce represent 50 km and 150 km radius.)

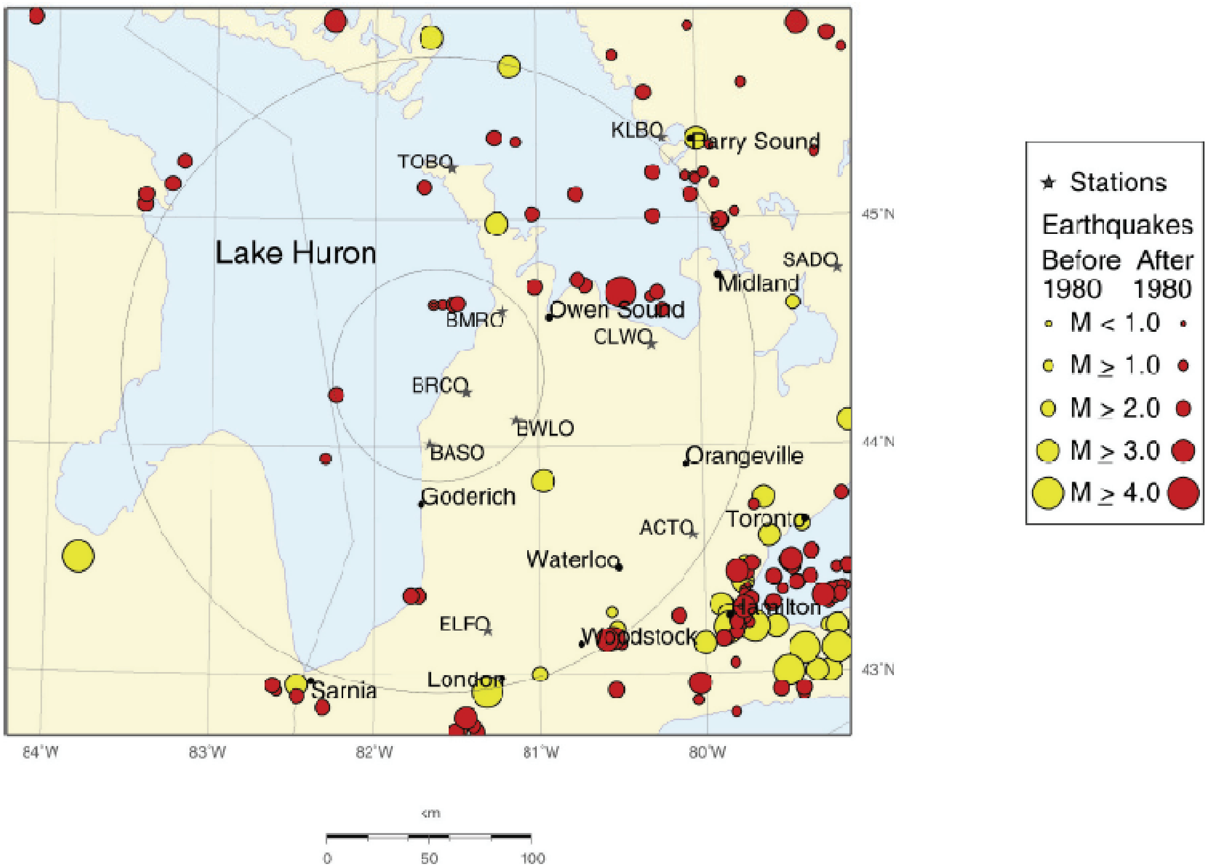

Figure 4.25: Seismicity in the Bruce Region to December 2008

The shores of Lake Huron are less than 200 mASL, i.e., less than 25 m above the lake level. These are not high slopes compared with lake locations in British Columbia for example where large landslides have taken place resulting in tsunami generation[19,20].

The conclusion of the regional screening, which included review of the historical record and potential (earthquake and landslide) tsunamigenic sources, is that the Bruce nuclear site is not subject to tsunamis.

4.4.2 Conclusion of Tsunami Hazard Assessment

As noted in (U.S. NRC 2009), "if the first step (step 1. above) of the regional screening identifies that the site region is not subject to tsunamis, no further analysis for tsunami hazards is required". Based on the results of regional screening test, it can be concluded that the DGR area is not affected by tsunamis.

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[19] In December 2007, "a massive landslide deposited approximately half a million cubic metres of rock and sediment into Chehalis Lake. The force of the material entering the lake generated a wave estimated to be 50 feet in height in some places." http://www.for.gov.bc.ca/DCK/Topics/Chehalis_Lake/Chehalis_Lake_Index.html

[20] "it appeared 600 vertical metres of rock and trees slid down the mountainside, washed into the lake and triggered a giant wave." http://www.cbc.ca/canada/british-columbia/story/2007/12/08/avalanche.html

5. SURFACE FLOOD HAZARD ASSESSMENT

The surface flood hazard assessment for the DGR site focuses on two aspects, namely:

- Riverine Flood Hazards; and
- Flood Hazard due to Direct Rainfall on the DGR site.

The assessment of each of these flood hazards is described in detail in the following sections. Please note that any potential impacts described herein relate to only flood hazards.

5.1 Definition of Probable Maximum Precipitation

There is a finite limit on the atmosphere's ability to produce rain at any given location due to climate, topography and atmospheric moisture limits. The concept of a finite limit for precipitation from a single storm event is called the Probable Maximum Precipitation (PMP). The exceedance probability of the PMP by its nature is almost zero (i.e., it is an improbable event). In practice, the PMP exceedance probability and estimated return periods are in the range of 1 in 10,000 years to 1 in 1,000,000 years.

The World Meteorological Organization (WMO) defines the PMP as "the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year, with no allowance made for long-term climatic trends" (WMO 1986). Although not definitive, internet searches, completed for this project for the purposes of reviewing PMP definitions, found that most sources dated after 1986 referred to the WMO 1986 definition. Sources dated earlier than 1986 offered definitions that embody similar elements as those used in the WMO 1986 definition.

The Ontario Ministry of Natural Resources uses a more simplified definition of PMP as "the largest precipitation event that can be reasonably expected to occur over a selected basin" (OMNR 2002).

Two basic methodologies are available for PMP estimation; meteorological and statistical.

- Meteorological approaches as outlined in (WMO 1986) use estimates of atmospheric moisture, moisture maximization, wind maximization, storm transposition, transposition adjustments, etc. as the basis for PMP estimation.
- Statistical approaches (an example is the Hershfield Method) can be used wherever sufficient precipitation data are available. Statistical estimation techniques are generally applicable to smaller watersheds up to 1000 km^2 in area. These approaches are useful when data to support meteorological approaches are not available.

In some jurisdictions (including Ontario and the United States) regional mapped PMP estimates are also available, typically based on meteorological methodologies, offering an alternative to site specific analyses.

Additional considerations of storm size and season are relevant in regard to the WMO PMP definition.

Storm size for hydrological application of PMP values is outlined in HMR-52 (NWS 1982). For this study, the subject watersheds are small and generally fit within the primary storm ellipse covering an area of 10 square miles. As such, no areal reduction factors will apply for hydrologic modeling.

Dam safety guidelines outline a number of PMPs, including summer PMP and winter PMP based on Probable Maximum Snow Accumulation (PMSA). Regional PMP estimates generally use summer time rainfall events as the basis for analysis. Experience suggests that winter PMP typically govern in more northerly areas and in larger watersheds. HMR-53 (NWS 1980) demonstrates the predominance of occurrence of extreme weather for the Great Lakes region during the summer months. Therefore, the “design” time of year for this study is the summer.

5.1.1 Province of Ontario Regulatory PMP Definition

A regulatory PMP definition is available for the Province of Ontario in the “Lakes and Rivers Improvement Act Technical Guidelines” (LRIA) (OMNR 2004). PMP rainfall totals, applicable to the Bruce DGR site, are presented in Table A.4 of the LRIA Appendix A (OMNR 2004) and reproduced as Table 5.1.

Table 5.1: Probable Maximum Precipitation Estimates

Storm Duration (hours)	Total Rainfall (mm)
48	460
36	445
24	440
12	420
6	405

The LRIA (OMNR 2004) also indicates that, for watershed areas less than 500 square miles (about 1300 km^2), a 6 or 12 hour PMP duration is normally used for flood risk assessment as these usually produce the highest peak flood flow. The associated 6 hour and 12 hour rainfall distributions are presented in Table A.2 of the LRIA Appendix A (OMNR 2004) and reproduced as Table 5.2.

The LRIA (OMNR 2004) represents the current standard in the Province of Ontario for the definition of PMP rainfall depths in areas where a site specific evaluation is not available, not possible or not warranted.

Draft information providing updated estimates of PMP for the Province of Ontario is available in the “PMP for Ontario” (OMNR 2006) report. This study concluded, based on a review of existing information, that the current PMP estimates are outdated. The following conclusions are documented in (OMNR 2006).

- The original PMP estimates by Bruce (1961) have been widely used in Ontario and adopted by OMNR, but are now considered to be out of date since additional data is available for updating PMP estimates.
- OPG studies contain a significant data base of historical storms, which, together with additional recent storms can be utilized to update the PMP estimates for the Province.
- Preliminary PMP storm maximization based on the June 2002 49th parallel storm resulted in significantly higher PMP values (in comparison to OPG estimates) in Northwestern Ontario. The observed rainfall for the event was found to exceed OPG PMP estimates at several watershed locations. These comparisons tend to indicate that PMP may be underestimated at some locations by the OPG studies and require updating.

Table 5.2: PMP Rainfall Distributions

Time (hours)	Incremental Rainfall Totals (%)	
	PMP – 6 hr	PMP – 12 hr
1	8	2
2	9	3
3	11	3
4	49	4
5	15	6
6	8	51
7		15
8		4
9		4
10		3
11		3
12		2

Based on the summary mapping provided in Appendix G of (OMNR 2006), the PMP rainfall totals provided in Table 5.3 were estimated.

Table 5.3: Probable Maximum Precipitation Estimates

Storm Duration (hours)	Total Rainfall (mm)	Abstracted from (OMNR 2006) Appendix G	Change from Current PMP Definition
72	630	Figure G.1	n/a
48	637	Figure G.2	+38%
24	596	Figure G.3	+35%
12	570	Figure G.4	+36%
6	550	Figure G.5	+36%

Notes:
a rainfall total was not available for the 36 hour PMP event in this reference.

Even though the catalyst for the review of PMP definitions for the Province was a conclusion that current estimates are outdated, the revised estimates as detailed in the ‘PMP for Ontario’ report (OMNR 2006) remain draft and have not replaced for the current PMP estimates presented in the LRIA (OMNR 2004).

5.1.2 Site Specific PMP Estimation

As noted previously, meteorological approaches to PMP determination use estimates of atmospheric moisture, moisture maximization, wind maximization, storm transposition, transposition adjustments, etc. as the foundation data. The data to support a DGR Site specific PMP analysis based on meteorological approaches is not readily available. As such, a statistical PMP estimation approach was used.

The Hershfield Approach is not the only statistical method available for PMP estimation, but it is the most widely accepted (WMO 1986). The Hershfield Method uses the equation:

$$X_T = X_n + K \times S_n$$

where:

X_T = total rainfall depth during the 24 hour PMP

X_n = Average annual maximum 24 hour rainfall for the period of record

K = Hershfield Co-efficient

S_n = Standard deviation of the annual maximum 24 hour rainfall series

PMP estimates based on rainfall data for the Kincardine station (no. 6124127) were obtained from Environment Canada (see Appendix B). These estimates are based on the Hershfield Method and are summarized in Table 5.4 (Environment Canada 2010c).

Table 5.4: Probable Maximum Precipitation Estimates

Storm Duration (hours)	Total Rainfall (mm)
72	313.2
48	331.9
36	n/a
24	328
12	n/a
6	n/a

Overall, these values seem low when compared to PMP estimates from the other sources. This method of analysis is particularly sensitive to the completeness and accuracy of the underlying rainfall dataset. This may account for the PMP estimates generated from this method being lower than anticipated.

5.1.3 US National Weather Service PMP Estimates

The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) has provided PMP guidance and studies since the late 1940s (NOAA 2009). The NWS produced a number of Hydrometeorological Reports (HMRs) between 1963 and 1981 focused on estimation of PMP for the United States. The HMR series is the standard source for PMP values across the United States (Tomlinson et al. 2009). HMR-51 (NWS 1978) includes the region of the United States around the Great Lakes. The regional PMP estimates provided in

HMR-51 can be used, through extrapolation, to estimate PMP in Ontario. An example of an HMR-51 PMP map is illustrated in Figure 5.1 (NWS 1978).

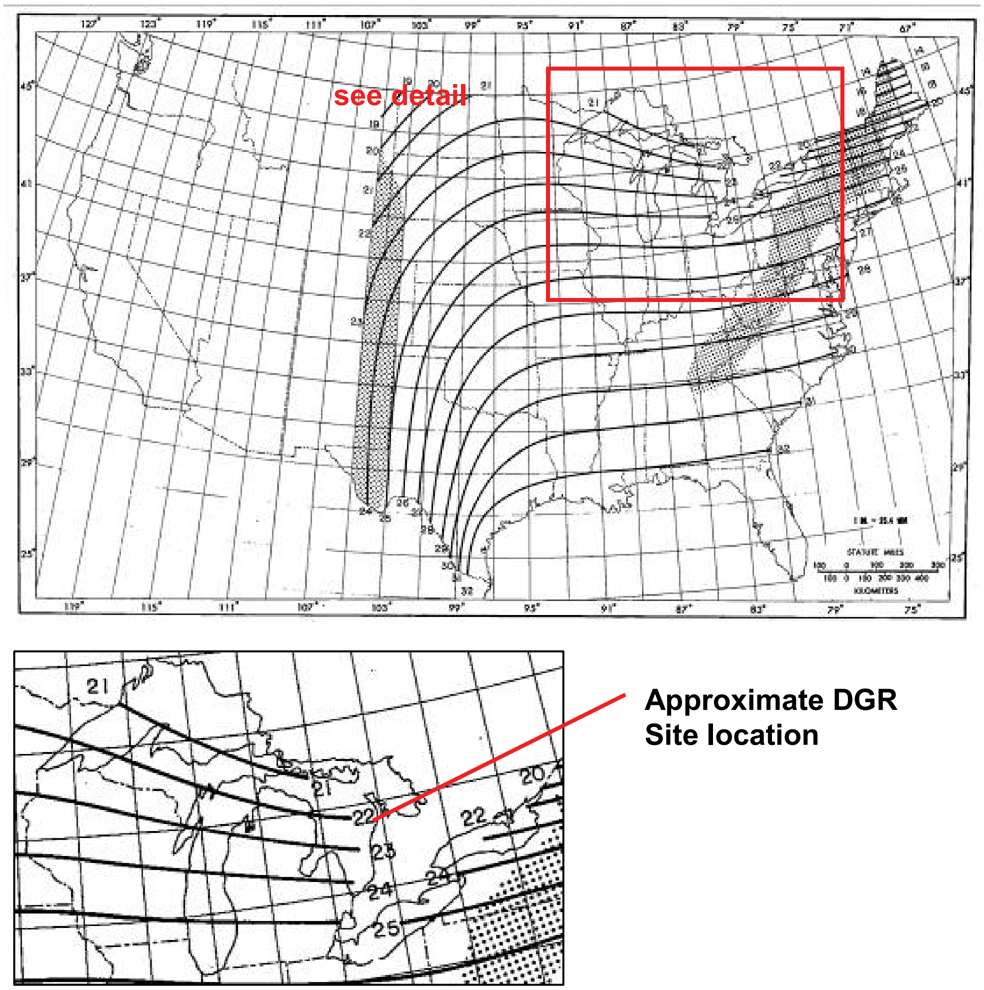

Figure 5.1: Probable Maximum Precipitation Amounts (inches) for the 6 hr PMP for Watershed Areas up to 10 Square Miles

Table 5.5 summarizes PMP estimates for the DGR Site based on NWS documentation and statistical methods.

The revised PMP estimates for Ontario report (OMNR 2006) documents a comparison with the HMR-51 PMP estimates and concludes that the (OMNR 2006) estimates are slightly under HMR-51 values for small watersheds and slightly over HMR-51 values for larger watersheds. It was concluded that the revised Ontario PMP estimates were generally within 10-15% of the HMR-51 estimates (OMNR 2006). As indicated in Table 5.6, the difference between the two DGR Site estimates is in the range 4% to about 30% over the range of storm durations. The trend is comparative with PMP estimates within the 15% suggested range for the 6 and 12 hour durations, with deviations outside of the suggested range for durations of 24 hours and higher.

Table 5.5: Probable Maximum Precipitation Estimates

Storm Duration	Total Rainfall (mm) NWS, 1978 NWS, 1982[1] Statistical[2]
72 hours	818
48 hours	773
36 hours	N/A
24 hours	711
12 hours	660
6 hours	572
3 hours	515
2 hours	476
1 hour	395
30 minutes	305
15 minutes	215
5 minutes	135

Notes:

1. PMP estimates for durations less than 6 hours were established using the procedures outlined in (NWS 1982). A similar procedure is not available for the Ontario PMP definitions.
2. PMP estimates for the other durations (i.e., NWS 1978 and NWS 1982) were used as the basis for graphical interpolation to estimate PMP for 2 and 3 hour duration events.

Table 5.6: Comparison of HMR-51 and OMNR (2006) PMP Estimates

Storm Duration (hours)	Total Rainfall by Source (mm)		
	OMNR 2006	NWS 1978	Difference
72	630	818	29.8%
48	637	773	21.4%
36	n/a	n/a	n/a
24	596	711	19.3%
12	570	660	15.8%
6	550	572	4.0%

The HMRs provide generalized rainfall values that are not basin-specific and tend to represent the largest PMP values across broad regions. Site-specific PMP studies incorporate basin characteristics that are specific to the topography and local climate of the watershed being studied. A 1993 Michigan-Wisconsin study, for example, produced significant reductions in PMP with the greatest reduction relative to HMR 51, around 20%, for storm durations up to 12 hours and drainage areas up to 500 square miles (Tomlinson et al. 2009). If similar reductions could be expected at the DGR Site then the HMR 51 and (OMNR 2006) estimates would be very comparable across all durations.

HMR-53 (NWS 1980) provides seasonal PMP estimates for the region of the United States around the Great Lakes. These are summarized in Table 5.7. The trend is consistent across the durations with the greatest PMP estimates occurring in the mid to late summer months. This information supports the recommendation to use a summer time frame as the design season for this flood risk assessment.

Table 5.7: Approximate Seasonal PMP Estimates

Month	Total Rainfall by Duration (mm)		
	6 hr	24 hr	72 hr
January[1]	112	152	229
February[1]	112	152	229
March	130	203	279
April	178	279	356
May	279	457	533
June	508	610	711
July[2]	572	686	818
August[2]	572	686	818
September	508	711	787
October	356	457	559
November	203	305	406
December	140	229	279

Notes:

1. One map/estimate provided for January/February
2. One map/estimate provided for July/August

5.1.4 PMP Estimates Summary

The estimates of PMP are summarized in Table 5.8 for the various sources reviewed for this assessment.

The Hershfield Method provides the lowest PMP estimate for the available durations. A number of comments are relevant with regard to this PMP estimate, namely:

- Hershfield (1961) indicated that this method should provide an upper bound PMP estimate. It is clearly not the case for this Site given the other estimates available; and

- As indicated in Table 5.9, several well documented rainfall events in Ontario have occurred with total rainfall very near to or exceeding the Hershfield Method PMP estimate. As a theoretical maximum rainfall total for a given location, the PMP estimate should not be exceeded.

For the reasons noted above the PMP estimate computed by the Hershfield Method will not be included in further analysis for this project.

Table 5.8: Probable Maximum Precipitation Estimates - Summary

Storm Duration	Total Rainfall by Source (mm)			
	OMNR 2004 statistical	**NWS 1978 statistical NWS 1982**	**OMNR 2006 statistical**	**Environment Canada Hershfield Method 2010**
72 hrs	N/A	818	630	313
48 hrs	460	773	637	332
36 hrs	445	N/A	n/a	n/a
24 hrs	440	711	596	328
12 hrs	420	660	570	n/a
6 hrs	405	572	550	n/a
3 hrs	365 [6]	515 [5]	495 [6]	n/a
2 hrs	337 [6]	476 [5]	458 [6]	n/a
1 hrs	280 [6]	395 [1]	380 [6]	n/a
30 min	216 [6]	305 [2]	293 [6]	n/a
15 min	152 [6]	215 [3]	207 [6]	n/a
5 min	96 [6]	135 [4]	130 [6]	n/a

Notes:

1. NWS 1 hour from NWS, 1982 Figure 24 page 79
2. NWS 30 minutes from NWS, 1982 Figure 38 page 96
3. NWS 15 minutes from NWS, 1982 Figure 37 page 95
4. NWS 5 minutes from NWS, 1982 Figure 36 page 94
5. NWS PMP estimates for the other durations were used as the basis for graphical interpolation to estimate PMP for 2 and 3 hour duration events.
6. Statistical PMP estimates for (OMNR 2004) and (OMNR 2006) data were based on a percentage reduction similar to that computed for the 'NWS' estimates.

The following comments are relevant with regard to the remaining PMP estimates.

- OMNR has commented that the PMP estimates provided in the LRIA are out of date. However, these are still the current "approved" values for the Province of Ontario.
- The US NWS PMP estimates are the most conservative. However, these estimates are based on data analyses from continental US weather stations only. The underlying analyses did not include weather stations located in Canada and may not be reflective of rainfall patterns on the lee side of Lake Huron. The US NWS PMP isohyets (NWS 1978) were used as a means of interpolating the PMP estimates for the DGR site.

- The revised PMP for Ontario report (OMNR 2006) values represent the most up-to-date assessment of Province wide PMP estimates taking into consideration recent severe rainfall events. Although, OMNR has been in possession of the report for about 2 years and no decision seems imminent on adopting the report and revising relevant regulatory rainfall events, the underlying data and analyses are the most up to date in the Province.

Table 5.9: Examples of Extreme Rainfall in Ontario

Storm	Year of Occurrence	Duration (hr)	Total Precipitation (mm)
Hurricane Hazel	1954	48	285 mm
Harrow	1989	30	450 mm
49th Parallel	2002	48	362 mm
Peterborough	2004	9	250 mm

It is recommended that the revised PMP estimates for Ontario (OMNR 2006) outlined in Table 5.8 be adopted as the most appropriate design rainfall estimates for subsequent flood risk analyses for the DGR site.

5.1.5 Rainfall Distributions

Rainfall distributions to be used in the hydrological modelling effort will be based on those outlined in Table 5.2 for the 6 hr and 12 hr durations. The 24 hr and 48 hr rainfall distributions will be based on a U.S. National Resources Conservation Service (NRCS)[21] Type II synthetic rainfall distribution because of its applicability to flood assessments (NRCS 1986). These rainfall distributions are summarized in Table 5.10. Rainfall distributions for PMP durations less than 6 hours used the 6 hour mass curve with a time base reduced to the other durations. For example, from Table 5.10, the total rainfall in the first timestep for the 6 hour PMP will be 8% of the total rainfall. This first timestep represents 1 hour. For the 1 hour PMP duration 8% of the total rainfall will fall in the first timestep. However, this first timestep is taken to be 10 minutes for the 1 hr PMP.

5.1.6 Sensitivity Analyses

Procedures for determining PMP, whatever method/approach is used, are inexact and the results should be considered as estimates only. Alternate methods will yield different estimates. As such, selection of a single PMP estimate for further analyses could lead to complicated argument as why “the other estimate” was not used. This is particularly the case if the most extreme estimate is not recommended.

With this in mind, subsequent hydrologic and hydraulic analyses will review the potential impacts of all methods outlined in Table 5.8 but the Environment Canada (2010c) Hershfield Method PMP estimates. This sensitivity analysis will provide the basis for discussion of the range of potential impacts resulting from the alternate PMP estimates.

[21] The ‘National Resources Conservation Service’ was formerly known as the ‘USDA Soil Conservation Service’ or ‘SCS’. Details regarding the SCS Type II synthetic rainfall distribution may be found in (NRCS 1986).

Table 5.10: PMP Rainfall Distributions

Time(hours)	Incremental Rainfall Totals (%)		
	LRIA – (OMNR 2004)		SCS Type II – (NRCS 1986)
	PMP – 6 hr	PMP – 12 hr	PMP – 24 hr
1	8	2	1.1
2	9	3	1.2
3	11	3	1.2
4	49	4	1.4
5	15	6	1.5
6	8	51	1.7
7		15	1.9
8		4	2.2
9		4	2.6
10		3	3.4
11		3	5.4
12		2	42.8
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

5.2 Riverine Flood Hazard Assessment

5.2.1 Hydrologic Model Development

5.2.1.1 Modeling Approach

A single event hydrologic modeling approach was used to compute estimates of stormwater runoff rates (i.e., peak flows) and volumes for the subject drainage areas. This approach is considered appropriate for this analysis given that the PMP is a single event design rainfall.

5.2.1.2 Visual Otthymo v2.0

The computer model Visual OTTHYMO v2.0 (VO2) (VO2 2002, VO2 2009) was selected to generate runoff hydrographs for the site due to its applicability to urban and rural design settings. VO2 is a successful hydrologic management model that has been used for: Watershed Studies, Sub-watershed Studies, Master Drainage Plans, Functional Stormwater Management Plans, Site Plans, and Stormwater Management Pond Design. VO2 is the second version of the INTERHYMO – OTTHYMO hydrologic model simulation software package designed for Microsoft Windows OS. VO2 has been accepted by the MOE, the Ministry of Natural Resources, the Ministry of Transportation, the Ministry of Municipal Affairs, the Association of Conservation Authorities of Ontario, and most municipal governments, as a valid hydrologic simulation model.

5.2.1.3 Drainage Area Delineation and Parameterization

Overall watershed delineation for local drainage areas is detailed previously. Subcatchment delineation for the purposes of hydrologic model development and runoff computation is illustrated in Figure 5.2 for local watersheds. From the site reconnaissance visit conducted in April 2010, the following drainage areas were not considered to be relevant to the present assessment:

- Unnamed Creeks (UN1, UN2, UN3, and UN4); and
- Underwood Creek (U1).

This is due primarily to their small drainage areas, the local topography precluding trans-boundary spills, distance from the DGR site and presence of direct outlets to Lake Huron.

The soil conditions of the study area were obtained from Preliminary Safety Report (OPG 2011a) and the Ontario Soil Map of Bruce County (Hoffman et al. 1954). The overburden within the Bruce nuclear site is comprised of surface sand and gravel from former beach deposits overlying clayey silt to sandy silt till with lenses and layers of sand of variable thickness and lateral extent. Near the present Lake Huron shoreline, sand gravel and boulders left from beach deposits thinly overlie the bedrock. At the inland of the watershed, the main deposits are gravelly loam over loam and silty clay loam over stone free horizons.

No information was available to indicate any planned future development in these watersheds of a substantive nature that would influence hydrologic response.

5.2.2 Critical Probable Maximum Precipitation Duration

The duration of PMP that causes the most critical flood at a site is termed the “critical duration” for that drainage basin (ASCE 1996). In general, the critical duration is short for a small basin and increases with the size of the drainage area. To determine the critical duration, peak flows resulting from PMP of several durations should be derived. The duration of the PMP that causes maximum peak flows at the subject location is the critical duration. The general guideline for determining the critical duration is that it should be at least equal to the time of concentration of the drainage area (ASCE 1996).

The hydrologic model (see Section 5.2.1) was used to compute peak flows for the various drainage areas for the range of PMP depth values and for several durations as described in Section 5.1 of this report. Table 5.11 summarizes computed peak flows for both the Little Sauble River and Stream ‘C’.

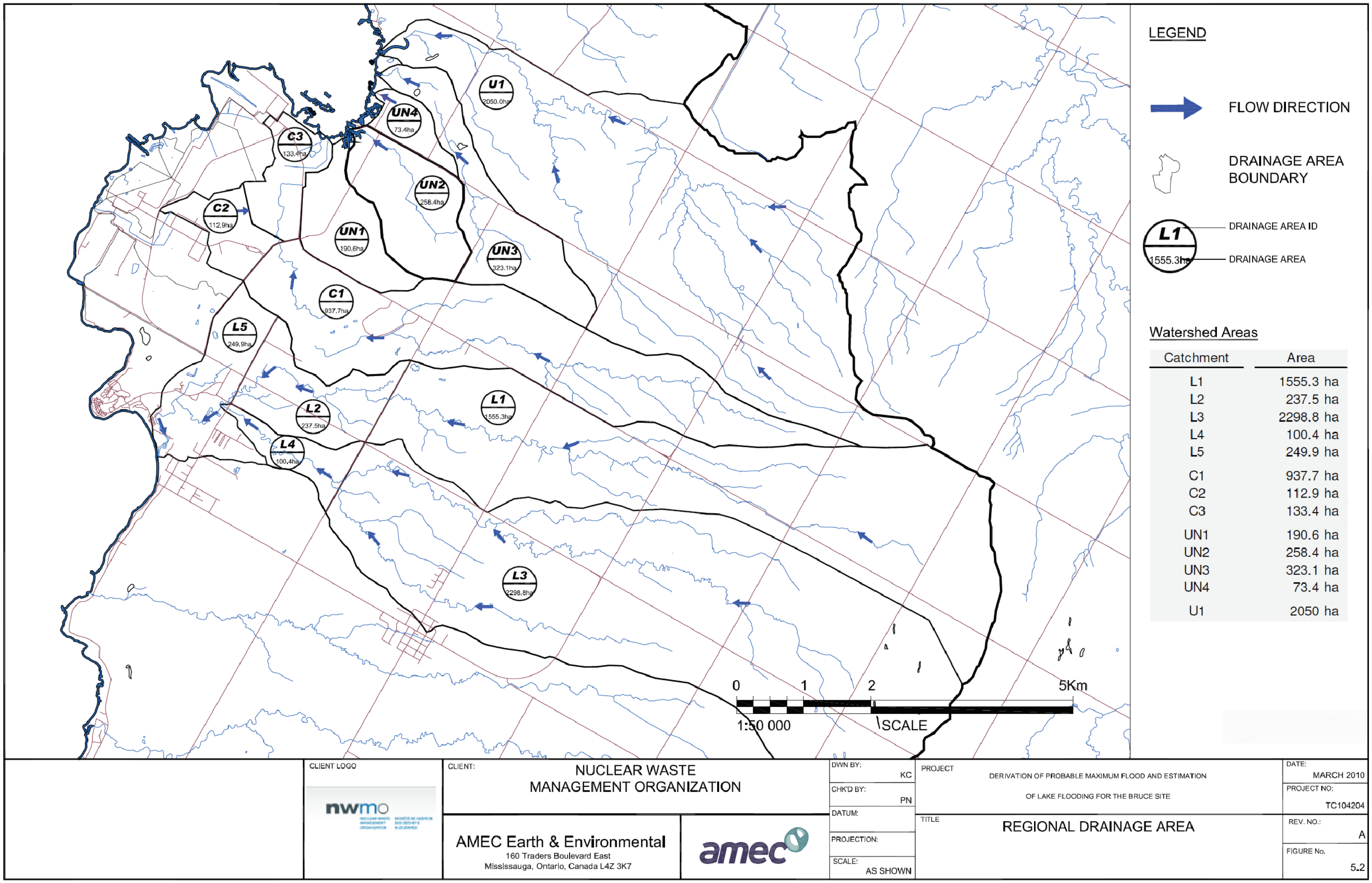

Figure 5.2: Riverine Subcatchment Delineation

Table 5.11: Riverine Flood Risk - Critical PMP Duration Evaluation Peak Flow Summary at Computational Nodes

Little Sauble River – Computed Peak Flows (m^3/s)					
PMP Duration	**L1**	**L2**	**L3**	**L4**	**L5**
1 hr	192.5	229.2	237.4	245.4	506.1
2 hr	238.3	283.9	294.8	305.0	628.4
3 hr	257.8	307.1	320.3	331.5	681.5
6 hr[22]	**274.9**	**325.7**	**347.1**	**360.0**	**731.1**
12 hr	258.0	304.0	329.4	341.2	684.1
24 hr	238.7	281.6	306.4	317.4	635.8

Stream 'C' – Computed Peak Flows (m^3/s)			
PMP Duration	**C1**	**C2**	**C3**
1 hr	122.6	42.9	160.9
2 hr	151.7	50.2	189.6
3 hr	164.3	50.6	215.6
6 hr[22]	**174.1**	**44.0**	**225.2**
12 hr	162.9	43.5	208.5
24 hr	150.7	42.0	193.8

From the comparison of PMP results it is clear that, for the Little Sauble River and Stream 'C', a PMP duration of 6 hours produces maximum peak flows. The 6 hour PMP will therefore be used for the assessment of potential surface flooding from riverine sources for the Bruce DGR site. By way of comparison, the computed time of concentration for these watersheds is 7.4 hours and 5.9 hours, respectively for the Little Sauble River and Stream 'C'.

The base PMP case for analysis of riverine PMF conditions is the 6 hr PMP based on (OMNR 2006).

Table 5.12 provides a summary of computed results for the 6 hour duration PMP for the three source definitions provided previously, namely: OMNR 2004, OMNR 2006 and NWS 1978.

[22] The 6 hour PMP is used for the assessment of potential surface flooding from riverine sources for the Bruce DGR site.

Table 5.12: Riverine Flood Risk - Comparison of Computed Peak Flows with Different Critical Duration PMP definitions

Little Sauble River – Computed Peak Flows (m^3/s)					
PMP Definition	**L1**	**L2**	**L3**	**L4**	**L5**
OMNR, 2006	274.9	325.7	347.1	360.0	731.1
OMNR, 2004	193.5	229.0	243.6	252.5	513.0
NWS, 1978	287.3	340.4	362.9	376.4	764.3
Little Sauble River – Relation to OMNR, 2006					
PMP Definition	**L1**	**L2**	**L3**	**L4**	**L5**
OMNR, 2004	70.4%	70.3%	70.2%	70.1%	70.2%
NWS, 1978	104.5%	104.5%	104.5%	104.5%	104.5%

Stream 'C' – Computed Peak Flows (m^3/s)			
PMP Definition	**C1**	**C2**	**C3**
OMNR, 2006	174.1	44.0	225.2
OMNR, 2004	122.3	31.0	158.2
NWS, 1978	182.0	46.0	235.5
Stream 'C' – Relation to OMNR, 2006			
PMP Definition	**C1**	**C2**	**C3**
OMNR, 2004	70.3%	70.5%	70.3%
NWS, 1978	104.5%	104.5%	104.5%

5.2.3 Hydraulic Model Development

5.2.3.1 Modeling Approach

A one-dimensional steady flow modeling approach was adopted for this assessment given the linear nature of the subject watercourses.

5.2.3.2 Hydraulic Model HEC-RAS

HEC-RAS (USACE 2008a, USACE 2008b, USACE 2008c), the successor to HEC-2, is a hydraulic modelling application developed by the U.S. Army Corps of Engineers to simulate water surface profiles for steady and gradually varied flow in open channel watercourses. The computational procedures used by HEC-2 and HEC-RAS to model steady flow are generally similar and are based on the solution of the one-dimensional energy equation. The application will estimate water surface elevation and related output along a channel reach under sub-critical, supercritical or mixed flow regimes. The program is capable of modelling complicated networks with multiple reaches and tributaries. Flow through culverts, bridges, weirs and gated spillways is accommodated. Levees, blocked obstructions, lids and ineffective flow areas can also be modelled as can ice jam and debris flow condition. Version 4 of the HEC-RAS software was used for this assessment.

5.2.3.3 Model Setup

The HEC-RAS models developed for this assessment were based on the following.

- The cross section data were abstracted from available 0.5 m LIDAR contour data.
- Culvert data (diameter, length, slope, etc.) were field measured during the April 2010 site reconnaissance visit.
- Roughness coefficients were estimated based on observations during the April 2010 site reconnaissance visit. The Manning's n roughness co-efficient has been conservatively estimated for the main channel and bank as 0.035 and 0.06, respectively. This is very typical for a slightly meandering earthen channel, with some stones and weeds, having overbanks scattered with light to dense brush and trees.
- Peak flows from Table 5.11 for the 6 hour duration PMP were used.
- Lake Huron represents the starting point for the hydraulic models of Little Sauble River and Stream 'C'. In order to quantify the impact of varying Lake Huron water levels on flood risk at the DGR site a number of starting water surface elevations were be used as outlined in Table 5.13.

Table 5.13: Lake Huron Starting Water Surface Elevations

Description	Water Elevation (m)
Mean Annual	176.43
Mean Monthly	176.59
100 year	177.60
Mean Annual + Storm Surge[1,2]	178.21
500 year	178.40

Notes:

1. Storm Surge water level = Mean Annual Lake Huron Water Level (176.43 m) + Storm Surge (1.3 m, see Section 4.2.7) + Wave Setup (0.48 m, see Section 4.3.5)
2. This water level scenario not computationally assessed.

The Provincial Floodplain Technical Guidelines (OMNR 1988) identify high riverine water levels resulting from an extreme rainfall event as an independent event from high lake levels. Notwithstanding, higher starting water surface elevations have also been used as a means of quantifying their impact to flood elevations at the DGR site.

The hydraulic model cross section locations for Little Sauble River and Stream 'C' are illustrated on Figure 5.3 and Figure 5.4, respectively.

5.2.4 Derivation of the Probable Maximum Flood

The computed water surface elevations for Little Sauble River and Stream 'C' are summarized in Table 5.14 and Table 5.15. The computed water surface elevations outlined in these tables is based on the 6 hr PMP as defined from (OMNR 2006) with a starting Lake Huron water surface elevation of 176.43 m (mean annual).

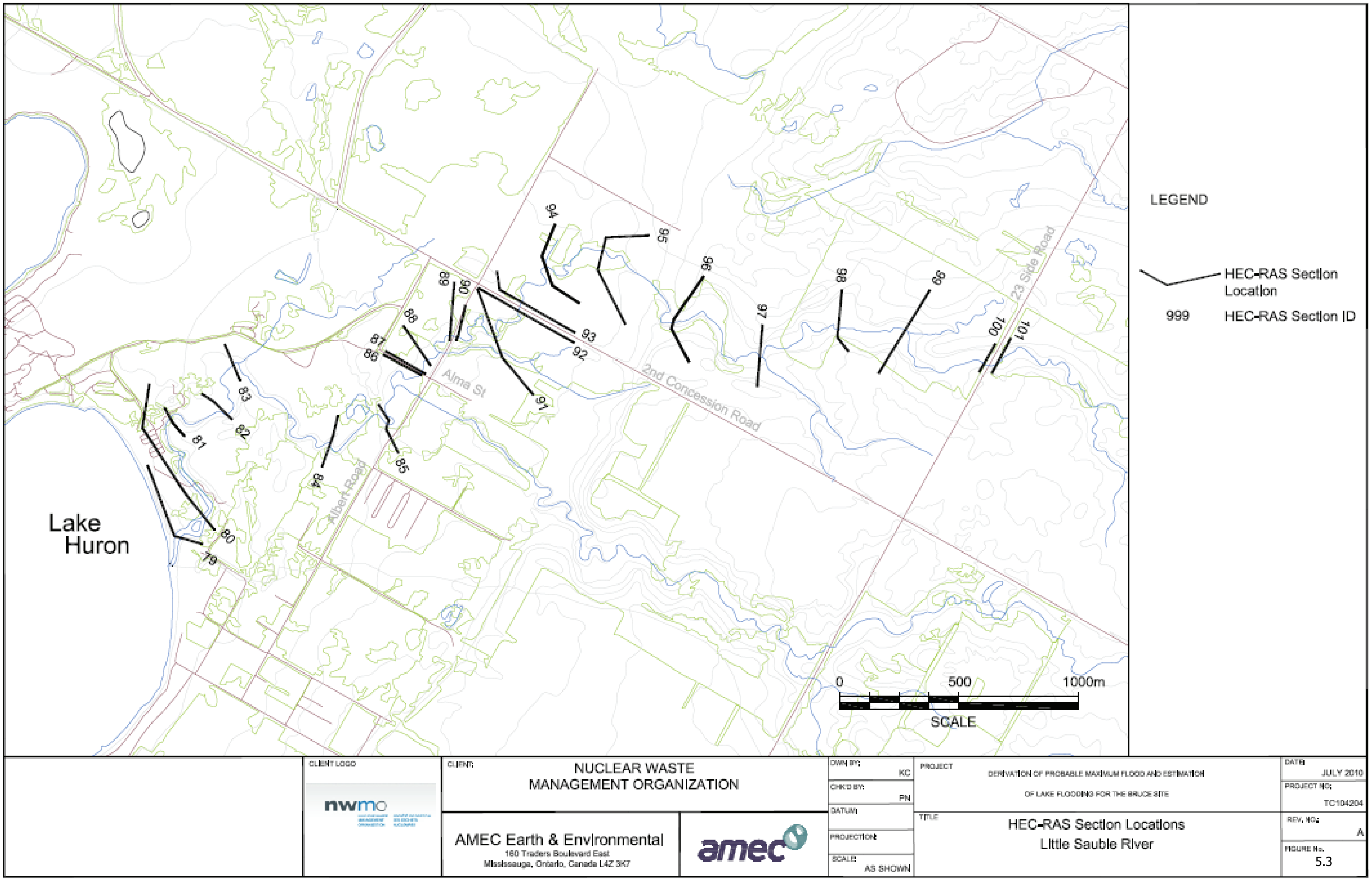

Figure 5.3: HEC-RAS Section Locations – Little Sauble River

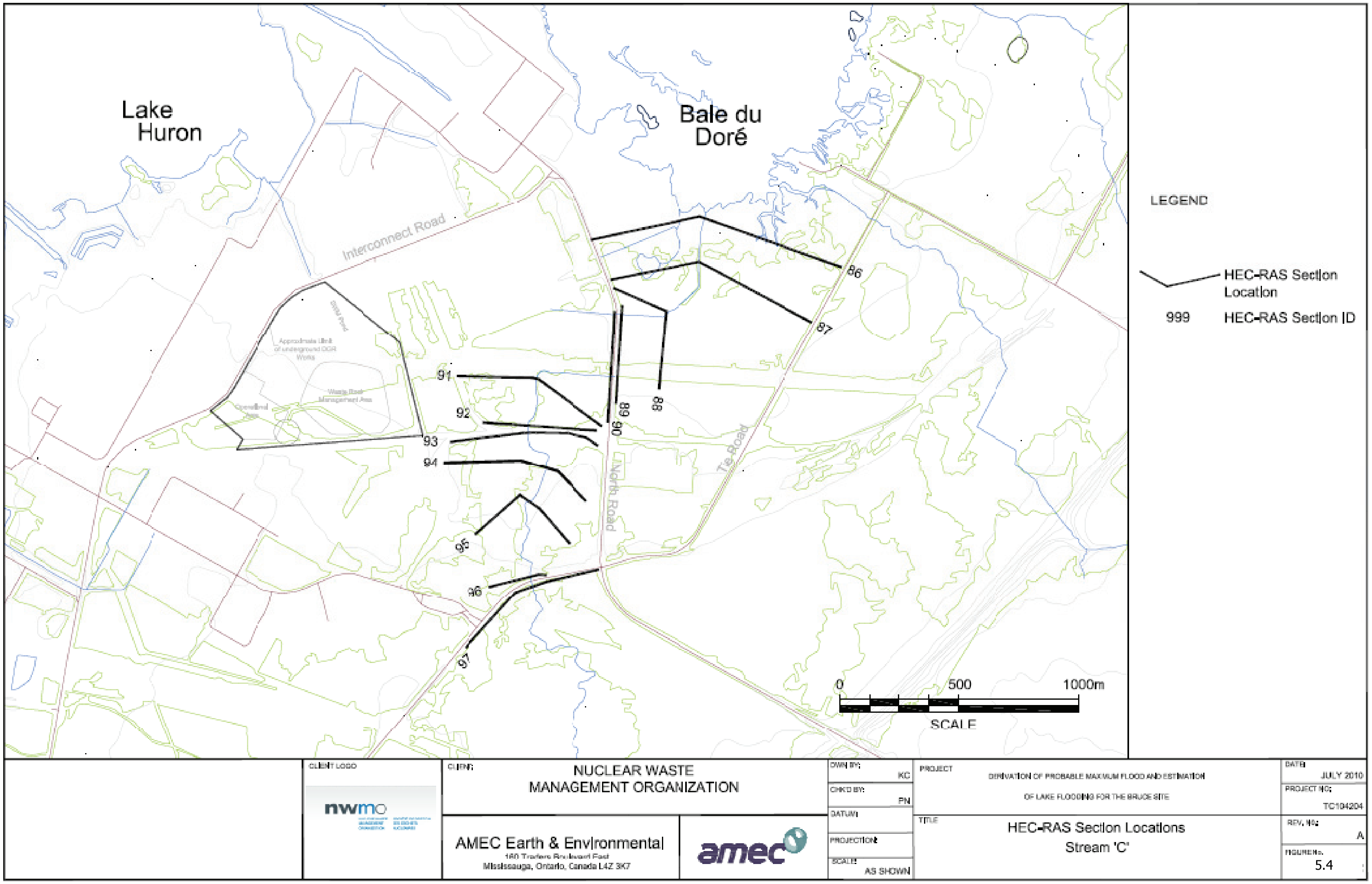

Figure 5.4: HEC-RAS Section Locations – Stream ‘C’

Table 5.14: Little Sauble River PMF Summary

HEC-RAS Section ID	PMP[1,3] Flow Rate (m^3/s)	Computed Water Surface Elevation[2] (m)	Comments
101	274.9	220.93	
100.5	Culvert at 23 Side Road		
100	274.9	219.50	
99	281.4	214.84	
98	284.1	211.87	
97	293.7	207.98	Although computed water surface elevations are higher than the currently planned design elevation of the DGR operational area (186 m) through this critical zone, existing topography between the Little Sauble River and the DGR site precludes any impacts.
96	296.5	200.26	
95	299.5	193.30	
94	302.5	192.14	
93	309.2	191.94	
92.5	Culvert at Concession Road 2		
92	309.2	191.00	
91	310.8	190.74	
90	310.8	190.43	
89.5	Culvert at Albert Road		
89	310.8	189.93	
88	325.7	189.79	
87	325.7	189.36	
86.5	Bridge at Alma Street		
86	325.7	188.87	
85	679.2	187.67	
84	692.8	185.87	
83	724.2	184.52	
82	726.5	184.12	
81	728.3	182.37	
80	730.7	180.53	
79 Lake Huron	731.1	179.26	

Notes:

1. 6 hr PMP as defined by (OMNR 2006).
2. Starting water surface elevation in Lake Huron Mean Annual 176.43 m.
3. Flow rates defined from hydrological modeling. Flows at specific sections defined at catchment discharge points (where locations are coincident) or pro-rated (by drainage area) between computational nodes from the hydrological model. Flows at sections located in first order catchments are based on the total outflow from that catchment.

Table 5.15: Stream 'C' PMF Summary

HEC-RAS Section ID	PMP[1,3] Flow Rate (m^3/s)	Computed Water Surface Elevation[2] (m)	Comments
97	174.1	191.90	
96.5	Culvert at Tie Road		
96	174.1	191.50	
95	177.9	183.21	
94	183.6	183.24	Computed water surface elevations are lower than the currently planned design elevation of the DGR operational area (186 m) through this critical zone.
93	191.0	183.23	
92.5	Culvert at railway crossing		
92	191.0	182.50	
91	196.5	181.12	
90	212.4	181.09	
89.5	Culvert at North Road		
89	212.4	180.50	
88	214.0	179.22	
87	216.3	178.24	
86 Lake Huron	225.2	177.27	

Notes:

1. 6 hr PMP as defined by (OMNR 2006)
2. Starting water surface elevation in Lake Huron Mean Annual 176.43 m
3. Flow rates defined from hydrological modeling. Flows at specific sections defined at catchment discharge points (where locations are coincident) or pro-rated (by drainage area) between computational nodes from the hydrological model. Flows at sections located in first order catchments are based on the total outflow from that catchment.

As noted previously, numerous roadway culverts have been identified along the Little Sauble River and Stream 'C' watercourses. Flooding resulting from transient obstructions (such as debris and/or ice) is a relevant consideration. This possibility has been investigated by constricting critical culvert dimensions in the hydraulic model.

For Little Sauble River the critical culvert was identified as the 2nd Concession Road location. The four 1.8 m diameter culverts at this location were re-modelled as having diameter 0.1 m as a representation of blockage due to debris. This resulted in computed PMF water levels, resulting in overtopping of the 2nd Concession Road, increasing by an additional 6 cm immediately upstream of the culvert. The propagation of changed computed PMF water levels extends for the next two upstream sections as +4 cm (section 94) and -1 cm (section 95). As such, culvert blockage at this location will not increase computed PMF water levels sufficiently to cause a flooding impact at the DGR site.

For Stream ‘C’ blockage of the culverts at the North Road and railway crossing were investigated. The about 2 m high arch Corrugated Steel Pipe (CSP) presently at the North Road was reduced to a 0.1 m high arch CSP as a representation of blockage due to debris. This resulted in computed PMF water levels, resulting in overtopping of the North Road, increasing by an additional 12 cm immediately upstream of the culvert. All computed PMF water levels through the critical reach are still well below 186 m (presently the DGR operational area design elevation). As a separate analysis the 1.2 m CSP culvert at the railway crossing was reduced to a diameter of 0.1 m. Again, localized minor increases in computed PMF water levels are evident but still below 186 m through the critical reach. As such, culvert blockage at these locations will not increase computed PMF water levels sufficiently to cause a flooding impact at the DGR site.

5.2.5 Assessment of Potential Surface Flooding at the Bruce DGR Site

Figure 5.5 and Figure 5.6 illustrate partial floodplain representations for Little Sauble River and Stream ‘C’, respectively. Two conclusions are apparent from these figures, namely the following.

- The computed Little Sauble River PMF floodplain does not extend into the DGR site. Further, transfer of flood water from the Little Sauble River to Stream ‘C’ during a PMP/PMF event is not anticipated given the topography that separates the watercourses along the critical reach between HEC-RAS sections 93 to 100 and the computed Little Sauble River PMF water surface elevations.
- The computed Stream ‘C’ PMF floodplain does not extend into the DGR site. The spill area identified on the upstream side of North Road flowing in the direction of Interconnect Road is not anticipated to represent a flood risk to the DGR site as the spill elevation (approximately 181.3 m) at the spill discharge location is well below currently planned elevations of the operational areas of the DGR site (i.e., 186 m).

The conclusion from this assessment is that riverine flood potential resulting from a PMP/PMF event will not impact the DGR site given currently planned elevations of the DGR operational areas and existing topography.

5.2.6 Sensitivity Analysis

A sensitivity analysis has been conducted to facilitate better understanding of the impacts to flood risk at the DGR site resulting from changes in modeling input parameters. Changes to computed water surface elevations at the DGR site have been quantified for peak flows resulting from alternate 6 hour duration PMP definitions (as defined in Table 5.12) and alternate starting water surface elevations (as defined in Table 5.13). Computed water surface elevations for the Little Sauble River and Stream ‘C’ resulting from these scenarios are summarized in the tables in Appendix C.

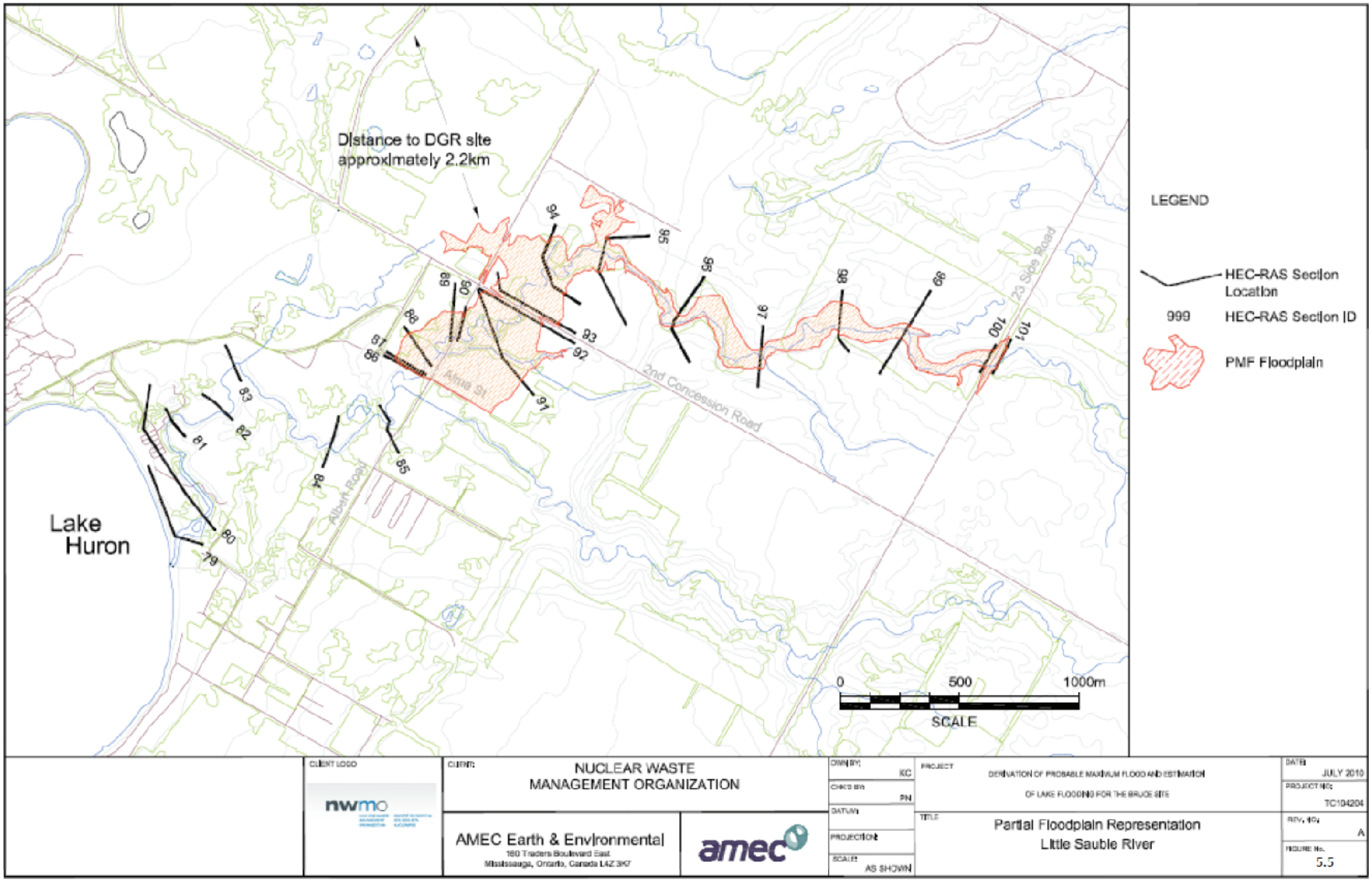

Figure 5.5: Partial Floodplain Representation – Little Sauble River

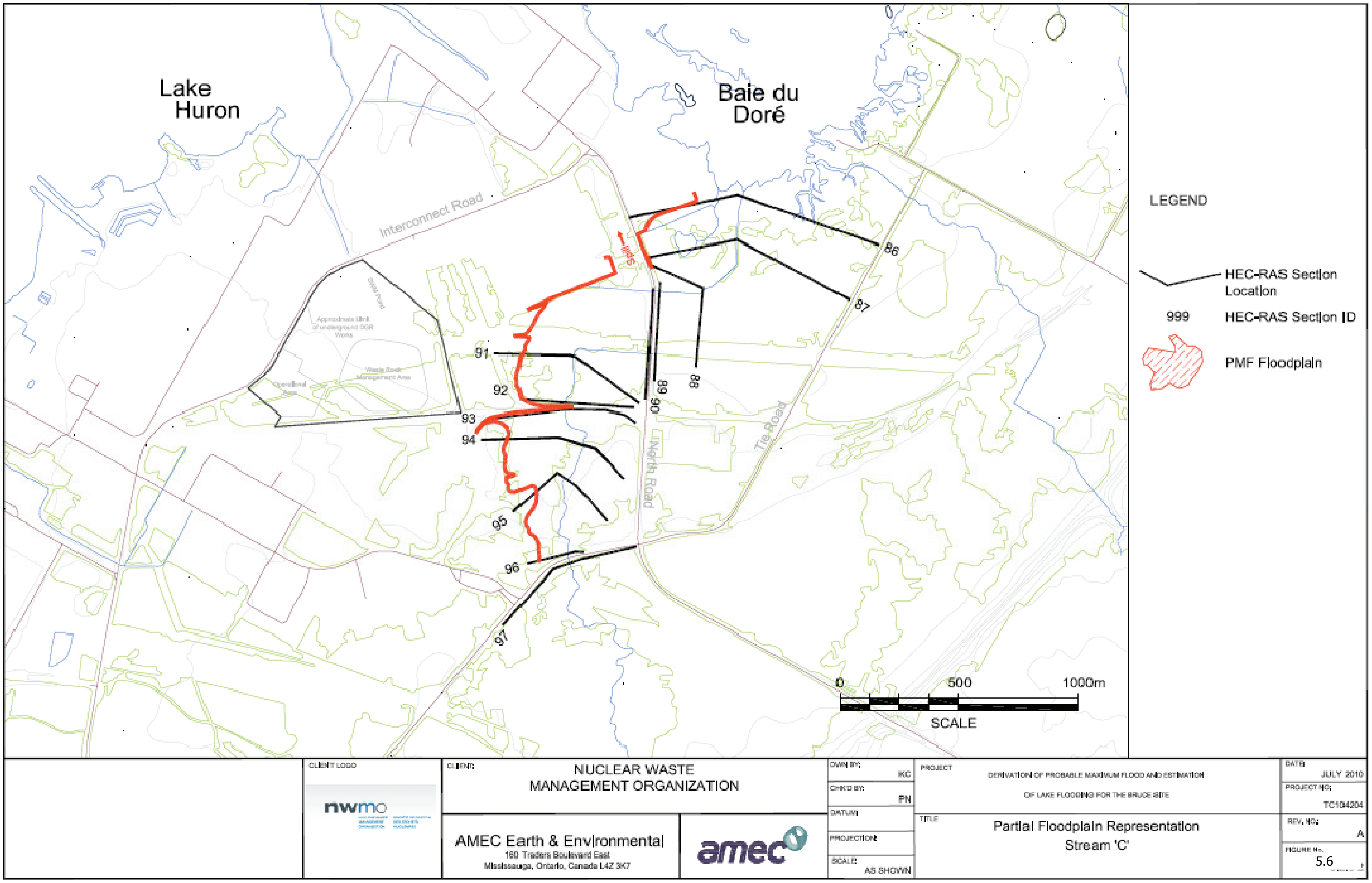

Figure 5.6: Partial Floodplain Representation – Stream 'C'

The following conclusions are apparent from this sensitivity analysis.

- Computed water surface elevations, for both the Little Sauble River and Stream 'C', across the three definitions of PMP (i.e., OMNR 2004, OMNR 2006 and NWS 1978) discussed in this report, are within a few centimetres (max 13cm) for the base scenario (i.e., OMNR 2006 with the mean annual lake level being used as the starting water surface elevation at Lake Huron). The differences in computed water surface elevations between the base scenario and the PMP definition of NWS 1978 is negligible.
- Computed water surface elevations at Lake Huron in the Little Sauble River are governed by flows in the river and not by lake levels. As such, the Lake Huron starting water surface elevations do not influence upstream computed water surface elevations.
- Computed water surface elevations at Lake Huron in Stream 'C' are governed by flows in the river at lower lake levels only. For starting water surface elevations using Lake Huron mean annual and mean monthly annual levels no changes in computed upstream water surface elevations were noted. When the starting water surface elevation was increased to the Lake Huron 100 year and 500 year level some increases in computed water surface elevations were noted. However, these increases did not extend beyond the North Road culvert.
- As noted in Table 5.13, the water level scenario 'Mean Annual + Storm Surge' (i.e., mean annual Lake Huron water level + maximum storm surge + maximum wave setup) was not computationally assessed. However, the '500 year' Lake Huron water level exceeds the 'Mean Annual + Storm Surge' water level scenario. As such, the conclusions associated with the sensitivity analysis using the '500 year' Lake Huron water level will also hold true for the 'Mean Annual + Storm Surge' scenario.

This sensitivity analysis reinforces the conclusion that riverine flood potential resulting from a PMP/PMF event, for all of the combination of events reviewed, will not impact the DGR site given currently planned elevations of the operational areas.

5.3 Assessment of Flood Hazard Due to Direct Rainfall

5.3.1 Hydrologic Model Development

The overall watershed delineation for drainage areas internal to the Bruce nuclear site is detailed previously. Subcatchment delineation for the purposes of hydrologic model development and runoff computation is outlined in Figure 5.7 for drainage areas internal to the Bruce nuclear site. From the site reconnaissance visit conducted in April 2010, the following drainage areas were not considered to be relevant to the present assessment:

- Bruce B South and North (B1 and B2);
- Douglas Pt South and North (D1 and D2); and
- MacPherson Bay North (M2).

This is due primarily to their small drainage areas, local topography precluding trans-boundary spills and direct outlets to Lake Huron.

Detailed subcatchment delineation for drainage areas specific to the DGR site is illustrated in Figure 5.8.

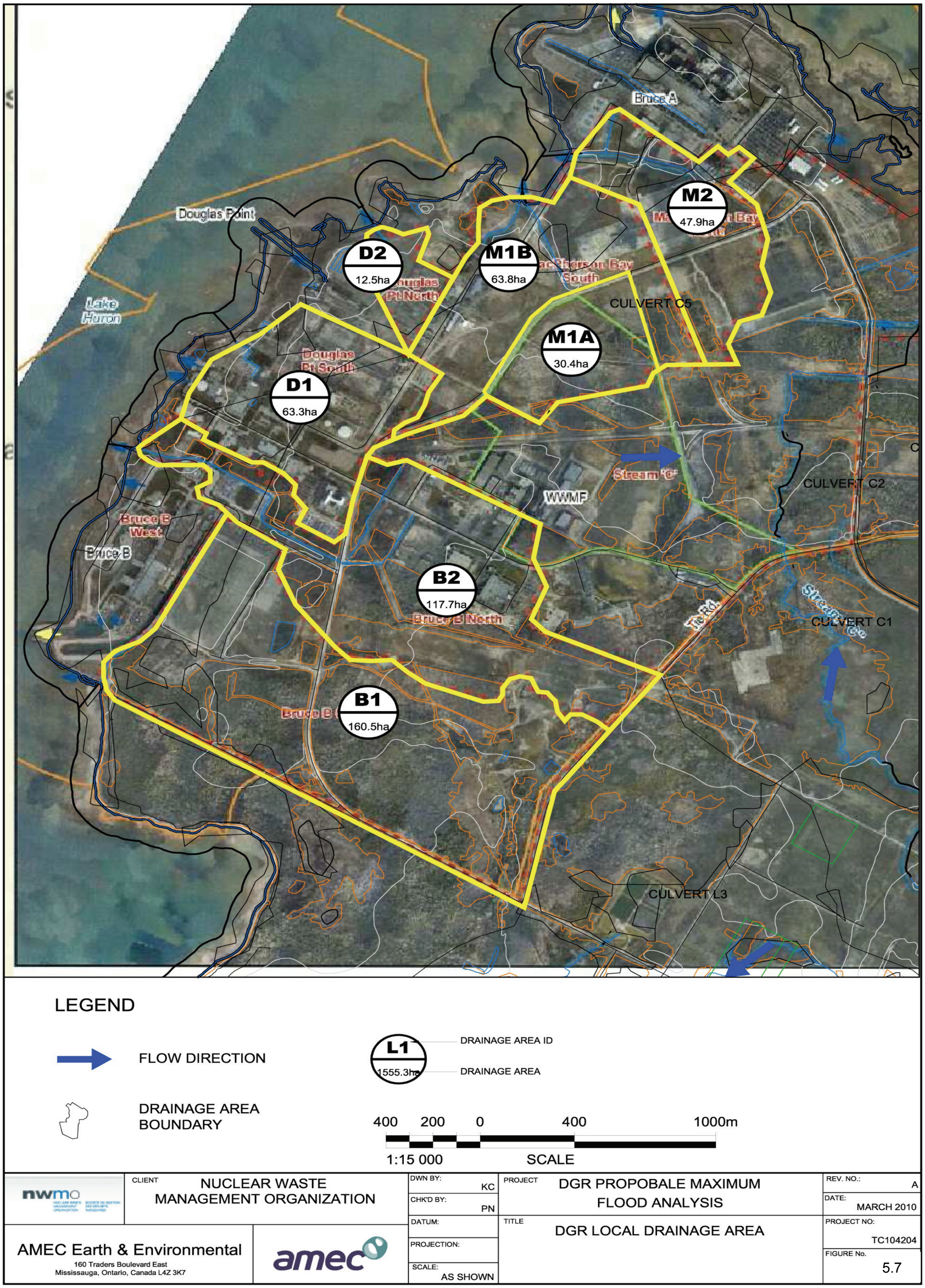

Figure 5.7: Drainage Area Delineation – Bruce Nuclear Site

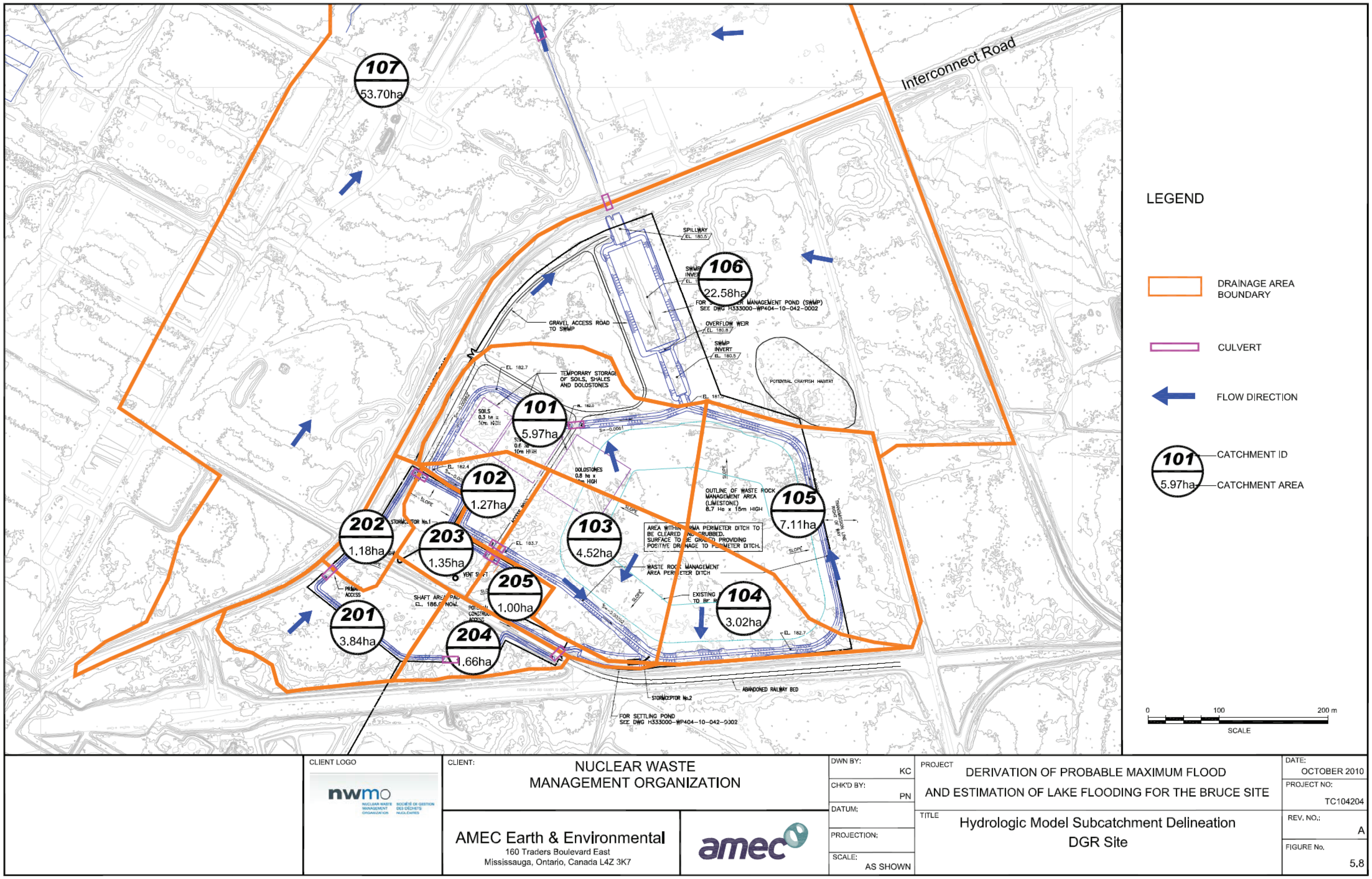

Figure 5.8: Hydrologic Model Subcatchment Delineation – DGR Site

The DGR site will consist of a series of surface infrastructure elements supporting the excavation and transfer of the waste rock from the underground works to the WRMA. The permanent waste rock pile is anticipated to be about 15 m high with a volume of approximately 832,000 m^3. Capping is not currently being recommended (OPG 2011a). The hydrologic model represents the waste rock piles conservatively using a curve number of 85 as a representation of the imperviousness of the rock material, potential pile settlement and void filling and higher runoff potential. Capped waste rock piles have not been explicitly assessed given that capping would provide a rougher vegetated surface offering the potential for increased infiltration and lower runoff rates.

Additional details regarding local DGR site drainage is provided in Section 3.2 of this report.

5.3.2 Critical Probable Maximum Precipitation Duration

Similar to Section 5.2.2, a critical PMP duration analysis was completed for the site specific flood risk assessment. The results are summarized in Table 5.16 and Table 5.17. From this analysis it is concluded that the 1 hr duration is critical for this drainage area. Therefore, the base PMP case for analysis of site specific PMF conditions is the 1 hr PMP based on (OMNR 2006).

Table 5.16: Local Flood Risk - Critical PMP Duration Evaluation Peak Flow Summary at Computational Nodes

DGR Site – Computed Peak Flows (m^3/s)			
PMP Duration	**Into SWM Pond**	**Out of SWM Pond**	**Discharge to Lake Huron**
5 min	15.6	9.1	31.7
15 min	27.6	21.0	67.5
30 min	37.9	32.8	87.6
1 hr	**42.2**	**37.1**	**108.8**
2 hr	33.0	32.6	97.4
3 hr	29.4	28.0	92.0
6 hr	18.3	18.1	65.6
12 hr	19.3	19.0	68.7
24 hr	33.5	29.9	88.1
48 hr	21.1	20.1	64.4

5.3.3 Hydraulic Model Development

The hydraulic modeling approach for DGR drainage features is similar to that described in Section 5.2.3. Also, the computer simulation program, HEC-RAS, has been used for this analysis.

Table 5.17: Local Flood Risk - Comparison of Computed Peak Flows with Different Critical Duration PMP definitions

DGR Site – Computed Peak Flows (m^3/s)			
PMP Definition	**Into SWM Pond**	**Out of SWM Pond**	**Discharge to Lake Huron**
OMNR, 2006	42.2	37.1	108.8
OMNR, 2004	29.4	25.0	69.3
NWS, 1978	43.4	38.3	113.7
DGR Site – Relation to OMNR, 2006			
PMP Definition	**Into SWM Pond**	**Out of SWM Pond**	**Discharge to Lake Huron**
OMNR, 2004	69.7%	67.4%	63.7%
NWS, 1978	102.8%	103.2%	104.5%

The HEC-RAS models developed for this assessment was based on the following.

- The cross section data was abstracted from available 0.5 m LIDAR contour data supplemented with Site Grading and Drainage data, provided by OPG.
- The main shaft area elevation of DGR site is currently planned as 186.0 m and the bottom elevation of the settling pond at the discharge point of the Shaft Surface Facilities Area (SSFA) perimeter ditch where it meets the perimeter ditch for the WRMA is planned as 185.0 m (OPG 2011a). As a result, to keep a slope from the perimeter ditch to the settling pond, it is impossible to keep a minimum 1 m depth of the ditch as indicated in the drawing H333000-WP404-10-042-0001. Therefore, considering the maximum length of the ditch will be approximately 750 m, to keep a minimum 0.1% slope of the ditch, the starting cross section can only be about 0.25 m depth.
- It was assumed that the main channel will be earthen, straight and uniform with some short grass and the bank will have some grasses and scattered brush. Manning’s n values for main channel and bank have been conservatively estimated as 0.03 and 0.04, respectively.

Figure 5.9 (also in rear pocket) illustrates the HEC-RAS section locations for the hydraulic model specific to the DGR site.

5.3.4 Derivation of Probable Maximum Flood

The computed water surface elevations for drainage features relevant to the DGR site are summarized in Table 5.18. The computed water surface elevations outlined in this table are based on the 1 hr PMP as defined from (OMNR 2006) with a starting Lake Huron water surface elevation of 176.43 m (mean annual).

The following three scenarios were assessed.

- Only confined channel flow (scenario #1):
  - For this scenario the PMF was confined to the defined sections of the hydraulic model. No flow was allowed to leave the system (i.e., spill out of the channel thereby reducing downstream flows). This represents the maximum potential PMF scenario. Existing culverts at Interconnect Road and elsewhere are included in this scenario.

- With potential spill zones (scenario #2):
  - This scenario builds on scenario #1 by adding four potential spill zones. For this scenario the PMF was allowed to spill out of the defined channel/ditch where computed water levels exceeded the maximum section overbank elevation. Spills out of the channel have the effect of reducing downstream channel flows and possibly reducing computed water levels both downstream and upstream of the spill location. A number of potential spill zones were identified, based on computed water surface elevations from scenario #1, as illustrated in Figure 5.10 and described below:
    - Spill #1 – This zone starts a short distance upstream of Interconnect Road to approximately 200 m downstream of Interconnect Road. Based on the available information, spill flow would continue to the east and leave the modelled system;
    - Spill #2 – This zone lies along the eastern edge of the WRMA perimeter ditch. Based on the available information, spill flow would continue to the east into the Stream 'C' watershed, leaving the modelled system;
    - Spill #3 – This zone lies along the eastern edge of the DGR perimeter ditch. Based on the available information, spill flow would enter the western WRMA ditch; and
    - Spill #4 – This zone lies along the northern edge of the DGR perimeter ditch along Interconnect Road. Based on the available information, spill flow would cross Interconnect Road and be conveyed back to the modelled system on the downstream side of the Interconnect Road culvert just downstream from the SWM pond.

- With potential spill zones and internal DGR culvert network (scenario #3):
  - This scenario builds on scenario #2 by adding an internal DGR culvert network at roadway channel/ditch crossings as identified in Preliminary Safety Report (OPG 2011a). The PSR does not provide specific information with regard to design of the culvert crossings, only locations. As culverts are not typically designed to accommodate the PMF, it was initially assumed for the purposes of this assessment that the culverts were sized to accommodate the 100 year flood while maintaining freeboard requirements at the crossings. Culvert inverts were defined as equal to the channel bottom. At some locations this culvert configuration was not possible due to insufficient channel depth. In these locations a smaller culvert was modelled maintaining freeboard and channel invert assumptions.

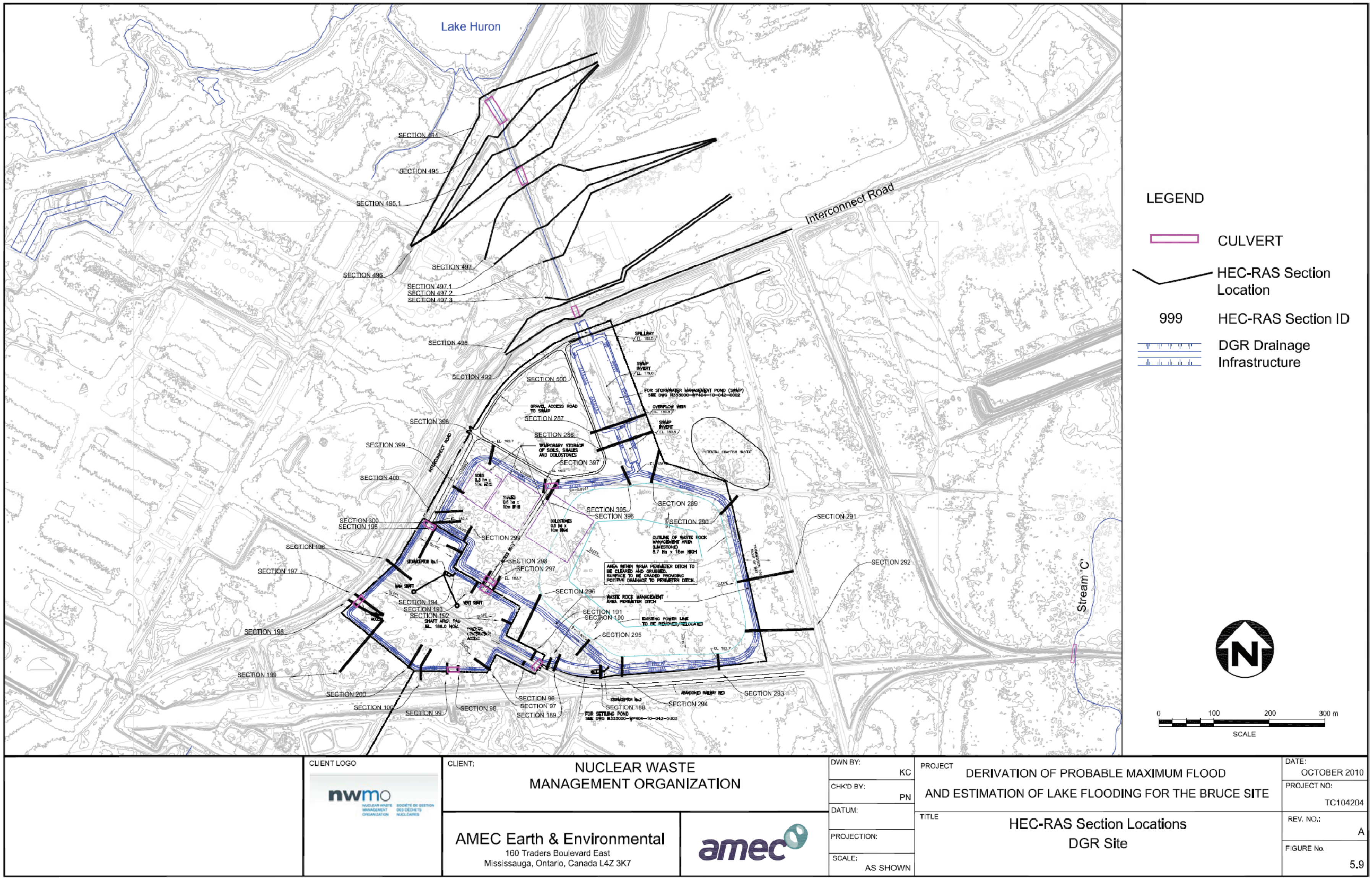

Figure 5.9: HEC-RAS Section Locations –DGR Site

Figure 5.10: Hydraulic Modelling Scenarios 2 and 3 - Potential Spill Zones

5.3.5 Assessment of Potential Flooding Due to Direct Rainfall at the Bruce DGR Site

As noted before, detailed design of the facility is as yet to be completed. However, a preliminary design elevation of 186 m has been established for critical features at the DGR site relevant to this flood risk assessment including the main shaft, intake and exhaust plenums and ventilation shaft.

As indicated in Table 5.18, computed PMF elevations exceed 186 m, to a maximum computed water surface elevation of 186.86 m (for scenario #1), at a number of locations around the operational area of the DGR site. Similarly, results were computed for scenario #3 with a maximum computed water surface elevation of 186.58 m.

The conclusion from this assessment is that a PMP event occurring across the DGR site has the potential to generate flood levels in excess of the DGR site preliminary design elevation of 186 m.

Table 5.18: DGR Site PMF Summary

	Scenario #1		Scenario #2		Scenario #3	
HEC-RAS Section ID	**PMP[1,5] Flow Rate (m^3/s)**	**Computed Water Surface Elevation[2,3] (m)**	**PMP[1,6] Flow Rate (m^3/s)**	**Computed Water Surface Elevation[2,3] (m)**	**PMP[1,6] Flow Rate (m^3/s)**	**Computed Water Surface Elevation[2,3] (m)**
Highlighted area below delineates hydraulic sections around the perimeter of the DGR site operational area. The preliminary design elevation associated with this area for the purposes of this assessment is 186 m.						
100 Upstream end of south side Operational Area drainage ditch	4.53	**186.67**	4.53	**186.47**	4.53	**186.58**
99	4.53	**186.64**	4.53	**186.39**	4.53	**186.54**
98	4.53	**186.63**	4.53	**186.28**	4.53	**186.53**
97	4.53	**186.63**	4.53	**186.23**	4.53	**186.53**
96 confluence of Operational Area drainage ditch with WRMA perimeter ditch, upstream along south side Operational Area drainage ditch	4.53	**186.6**	4.53	185.96	4.53	**186.49**
200 Upstream end of north side of Operational Area drainage ditch	8.07	**186.86**	8.07	**186.49**	8.07	**186.48**
199	8.07	**186.86**	8.07	**186.44**	8.07	**186.42**
198	8.07	**186.85**	8.07	**186.44**	8.07	**186.39**
197	9.98	**186.85**	9.98	**186.40**	9.98	**186.38**
196	9.98	**186.85**	9.98	**186.33**	9.98	**186.30**
195	12.42	**186.84**	8.55	**186.10**	9.11	**186.11**
194	12.42	**186.82**	0.04	185.80	0.61	185.90
193	13.92	**186.77**	0.01	185.88	0.01	185.88
192	13.92	**186.67**	0.01	185.88	0.01	185.88
191	13.92	**186.50**	0.01	185.88	0.01	185.88

HEC-RAS Section ID	Scenario #1 PMP[1,5] Flow Rate (m^3/s)	Scenario #1 Computed Water Surface Elevation[2,3] (m)	Scenario #2 PMP[1,6] Flow Rate (m^3/s)	Scenario #2 Computed Water Surface Elevation[2,3] (m)	Scenario #3 PMP[1,6] Flow Rate (m^3/s)	Scenario #3 Computed Water Surface Elevation[2,3] (m)
190	17.28	**186.30**	3.30	185.64	3.30	185.64
189	17.28	185.94	3.30	185.42	3.30	185.42
188 confluence of Operational Area drainage ditch with WRMA perimeter ditch, upstream along north side Operational Area drainage ditch	17.28	185.5	3.30	185.17	3.30	185.17
300 Upstream end of WRMA Perimeter Ditch (Northeast/South section)	3.06	185.18	3.06	185.58	3.06	185.63
299	3.06	185.17	7.32	185.56	6.55	185.60
298	3.06	185.15	13.09	185.46	13.62	185.50
297	13.47	184.99	23.65	185.24	24.21	185.25
296	13.47	184.85	23.65	185.22	24.23	185.23
295	13.47	184.59	23.65	184.61	24.23	184.63
294	19.57	184.42	15.75	184.31	16.33	184.33
293	19.57	183.96	15.75	183.80	16.33	183.80
292	31.93	183.87	16.47	183.62	16.81	183.62
291	31.93	183.67	15.73	183.36	15.73	183.36
290	31.93	183.44	15.73	183.09	15.73	183.09
289 WRMA Perimeter Ditch (Northeast/South section)	31.93	182.85	15.73	182.34	15.73	182.34
400 Upstream end of WRMA Perimeter Ditch (Northwest/West section)	14.39	185.2	14.40	185.20	14.40	185.2
399	14.39	184.54	14.40	184.54	14.40	184.54
398	14.39	183.69	14.40	183.74	14.40	183.69
397	14.39	183.02	14.40	183.10	14.40	183.52
396	14.39	183.00	14.40	183.02	14.40	183.00
395 WRMA Perimeter	14.39	182.09	14.40	182.09	14.40	182.09

HEC-RAS Section ID	Scenario #1		Scenario #2		Scenario #3	
	PMP[1,5] Flow Rate (m^3/s)	Computed Water Surface Elevation[2,3] (m)	PMP[1,6] Flow Rate (m^3/s)	Computed Water Surface Elevation[2,3] (m)	PMP[1,6] Flow Rate (m^3/s)	Computed Water Surface Elevation[2,3] (m)
Ditch (Northwest/West section)						
288 Upstream side of SWM Pond	42.15	181.74	26.03	181.47	26.03	181.47
287	42.15	181.37	26.03	181.14	26.03	181.14
500 Downstream side of SWM Pond	53.53	181.46	53.52	181.46	53.52	181.46
499	53.53	180.53	53.52	180.38	53.52	180.36
498.5	Interconnect Road Culvert					
498	53.53	180.53	53.52	180.37	53.52	180.36
497.3	67.3	180.45	35.52	180.26	33.22	180.25
497.2	73.5	180.39	33.97	180.22	32.12	180.21
497.1	75.1	180.35	32.03	180.19	30.37	180.19
497	77.0	180.25	30.10	180.16	28.65	180.16
496.5	Culvert					
496	94.2	180.27	47.30	180.17	45.85	180.16
495.1	95.4	180.25	48.50	180.16	47.05	180.15
495	96.6	180.23	49.70	180.15	48.25	180.15
494.5	Road Culvert					
494 Lake Huron	102.0	180.00	55.10	180.00	53.70	180.00

Notes:

1. 1 hr PMP as defined by (OMNR 2006)
2. Starting water surface elevation in Lake Huron - Mean Annual 176.43 m
3. Computed flood elevations **exceeding 186 m** (i.e., the DGR site preliminary design elevation).
4. Highlighted area delineates hydraulic sections around the perimeter of the operational area of the DGR site. The preliminary design elevation associated with this area for the purposes of this assessment is 186 m.
5. Flow rates defined from hydrological modeling. Flows at specific sections defined at catchment discharge points (where locations are coincident) or pro-rated (by drainage area where significant changes exist) between computational nodes from the hydrological model. Flows at sections located in first order catchments are based on the total outflow from that catchment.
6. Flows calculated by HEC-RAS based on input flows less spill flow

The following comments regarding this assessment are relevant.

- The present DGR stormwater drainage design has not reached the detailed design phase. As such, some aspects of the drainage infrastructure, such as culverts, have as yet to be quantified/sized. Therefore, assumptions, in this regard, were required to facilitate this assessment.
- A conservative approach to the hydraulic analysis was adopted for this project. As such, the resultant computed PMF water levels in proximity to the DGR operational area are considered to be conservative.
- The potential for floodwater entering the underground works can be mitigated by setting collar elevations at the maximum computed PMF elevation plus an appropriate freeboard.
- Increasing the general DGR operational site elevation (presently set at 186 m) is not anticipated to result in higher computed PMF water levels.
- Increasing the elevation/grade of Interconnecting Road in the vicinity of the DGR site is anticipated to increase PMF water levels across the DGR site.
- If the final design for drainage works (e.g. ditches and culverts) is of a similar nature to that depicted in the Preliminary Safety Report, then computed PMF water levels will be similar to that documented in this report. "Upsized" drainage infrastructure could, however, potentially have a positive influence on computed PMF water levels (i.e., lower water level) and conversely downsizing could have a negative impact.

5.3.6 Sensitivity Analysis

Following a similar procedure to that outlined in Section 5.2.6, a sensitivity analysis of peak flows resulting from a 1 hr PMP (as defined in Table 5.11) and Lake Huron starting water surface elevations (as defined in Table 5.13) was conducted for the DGR site specific analysis for scenario #1. Computed water surface elevations for the DGR site resulting from these scenarios are summarized in the tables in Appendix C.

The following conclusions are apparent from this sensitivity analysis.

- Computed water surface elevations, for both the drainage features around the DGR site across the three definitions of PMP (i.e., OMNR 2004, OMNR 2006 and NWS 1978) discussed in this report, are within a few centimetres (maximum 32 cm representing the maximum difference between computed water surface elevations for the three PMP definitions) of the base scenario (i.e., OMNR 2006) with the mean annual lake level being used as the starting water surface elevation at Lake Huron. The difference in computed water surface elevations between the base scenario and a (NWS 1978) PMP definition is negligible.
- Computed water surface elevations at Lake Huron in the discharge ditch are governed by flows in the river and not by lake levels. As such, Lake Huron starting water surface elevations do not influence upstream computed water surface elevations for the drainage features associated with the DGR site.

This sensitivity analysis reinforces the conclusion that a PMP event occurring across the DGR site has the potential to generate flood levels in excess of 186 m (i.e., the DGR site preliminary design elevation).

6. MODIFICATION OF THE FLOOD HAZARD WITH TIME

6.1 Physical/Geographical Changes

Potential alteration of the flood hazard resulting from changes in the physical geography of a drainage basin, including the estuaries, and changes to the offshore/lake bathymetry, coastal profile and catchment areas are discussed in this section.

6.1.1 Physical Geography of the Drainage Basin

Floodplain management guidelines assess a future built out condition based on documented future planning in the watershed. These plans are usually projected out 25 years. No information available for this assessment indicated any substantial projected changes to land uses in the riverine watersheds. Therefore, the potential for physical geographic changes have been accounted for in the riverine flood hazard analysis.

6.1.2 Changes to Lake Huron Bathymetry

Changes to Lake Huron bathymetry near the Bruce nuclear site, which might affect coastal flooding potential, are likely only due to sediment accumulation which may be due to natural sediment transport regimes. The region is otherwise geologically and seismically stable so that no change in bathymetry is likely in that regard.

In general, water depths in the nearshore zone of the lake range from 6 to 20 m, except in Baie du Doré, where depths do not exceed 5 m. Bedrock substrate predominates in the shallow areas of the open shoreline, grading to a mixture of pebble, cobble and boulder at the 7 and 12 m depths. Extensive marsh areas are located along the shore of Baie du Doré. Further, the shoreline region near the Bruce nuclear site is classified as being susceptible to only light erosion (OMNR 2001) suggesting limited opportunity for sediment accumulation at a scale that could influence potential flooding.

It is, therefore, presently assessed that the flooding hazard potential is unlikely to change as a result of any bathymetry changes with time.

6.1.3 Lake Huron Shoreline

The Lake Huron shoreline fronting the Bruce nuclear site consists of either beaches armoured with cobbles/boulders or exposed bedrock. As such, the shoreline is not expected to change over time.

6.2 Climate Change and the PMP

PMP estimation currently does not take into account the potential influences of a changing climate. Since the DGR has a long life span it is relevant to consider potential effects of climate change on estimates of Probable Maximum Precipitation.

Climate change could possibly impact PMP estimates in a number of ways. Firstly, as temperature increases, the capacity of the air to hold water vapour changes, and, secondly, the frequency of occurrence of extreme events changes (Collier 2009). Other influences may include storm types, depth-duration-area curves and relative storm efficiency (Jakob et al 2009).

The conclusions from the research and documentation reviewed for the DGR study concluded that there is no substantive basis for increasing current PMP estimates in order to account for climate change (Collier 2009, Jakob et al 2009, Alberta Transportation 2004).

7. CONCLUSION AND RECOMMENDATION

This flood assessment concluded that there is no potential for lake or riverine based flooding and the DGR area is not affected by tsunamis or riverine flooding.

A PMP event occurring across the DGR site has the potential to generate flood level in excess of 186 m (the DGR site preliminary design elevation), and the maximum water surface elevation was estimated as 186.86 m (i.e., maximum 86 cm PMF level) and 186.58 m (i.e., maximum 58 cm PMF level) at a number of locations around the operational area of the DGR site based on scenario #1 and #3, respectively. Scenario #1 was based on confined channel flow with no allowance for out of channel spills. Scenario #3 was based on general stormwater/channel ditch configurations, culverts internal to the DGR site and the allowance for out of channel spills. As such, it is recommended that future design efforts recognize and accommodate this potential flood hazard.

The overall conclusion from this assessment is that the identified potential maximum flood hazards can be mitigated through conventional engineering means and methods. In this regard, assumptions were made in the assessment that included such measures, as well as a number of site design parameters that have yet to be finalized. During the detailed site design phase, potential on-site flooding hazards should be re-assessed taking into account final design parameters, in particular the final site grading, stormwater infrastructure and internal stormwater ditch crossings.

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9. ABBREVIATIONS AND ACRONYMS

ADCP	Acoustic Doppler Current Profiler
AES	Atmospheric Environment Service, Environment Canada
BNGS	Bruce Nuclear Generating Stations
CD	Chart Datum
CHS	Canadian Hydrographic Service
CIS	Canadian Ice Service
CNSC	Canadian Nuclear Safety Commission
CSP	Corrugated Steel Pipe
DEM	Digital Elevation Model
DFO	Department of Fisheries and Oceans Canada
DGR	Deep Geologic Repository
GLERL	Great Lakes Environmental Research Laboratory
GSC	Geological Survey of Canada
GSD	Geodetic Survey of Canada Datum
IAEA	International Atomic Energy Agency
IGLD	International Great Lakes Datum
L&ILW	Low and Intermediate Level Waste
LIDAR	Light Detection And Ranging
mASL	Metres Above Sea Level
NGDC	National Geophysical Data Center
NOAA	National Oceanic and Atmospheric Administration
NRCS	National Resources Conservation Service
NWMO	Nuclear Waste Management Organization
NWS	National Weather Service
OMNR	Ontario Ministry of Natural Resources
OMOE	Ontario Ministry of Environment

OPG	Ontario Power Generation
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PMSA	Probable Maximum Snow Accumulation
PQP	Project Quality Plan
SCS	Soil Conservation Service
SSFA	Shaft Surface Facilities Area
SVCA	Saugeen Valley Conservation Authority
SWAN	Simulating WAves Nearshore
SWM	Stormwater Management
TSD	Technical Support Document
USACE	U.S. Army Corps of Engineers
VO2	Visual OTTHYMO v2.0
WDC	World Data Center for Geophysics and Marine Geology
WIS	Wave Information Studies
WMO	World Meteorological Organization
WRMA	Waste Rock Management Area
WWMF	Western Waste Management Facility

10. GLOSSARY

100-Year Flood - A flood event that statistically has a 1 out of 100 (or one percent) probability of being equalled or exceeded on a specific watercourse or water body in any given year.

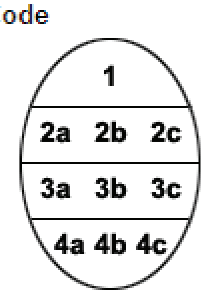
Chart Datum - All surveyed features on a navigational chart are positioned on some horizontal datum system such as NAD27 (North American Datum of 1927) or NAD83 (North American Datum of 1983). In addition to a horizontal datum reference, all charts also require a vertical datum reference. For navigational safety, depths on a chart are shown from a low-water surface or a low-water datum called chart datum. Chart datum is selected so that the water level will seldom fall below it and only rarely will there be less depth available than what is portrayed on the chart.

Discharge - The amount of water that passes a specific point on a watercourse over a given period of time. Rates of discharge are usually measured in cubic feet per second.

Drainage Basin - A geographical area which contributes surface water runoff to a particular point. The terms “drainage basin,” “tributary area,” and “watershed” can be used interchangeably.

Egg Code – In the early 1980s, the Canadian Ice Services upgraded the way it reports on ice conditions. In co-operation with other countries, Canada developed a reporting standard for the World Meteorological Organization (WMO). This standard is known as "the Egg Code," named for its oval shape. This oval device, as seen below, is an efficient means of delivering vital information on ice conditions to mariners and other users. Ice conditions are monitored by satellites and by observers onboard aircraft and ships, and at coastal stations. This information is expressed in codes and symbols contained in the oval, which is placed on maps to represent the type of ice contained within each area. Mariners and others use this information to make navigational decisions. Ice conditions are monitored in five regions: the Great Lakes, the St. Lawrence River, the Gulf of St. Lawrence, the East Coast and the Arctic.” (CIS 2002). Note that details on how the ice code works, e.g., how much ice is there? and how thick is it? are provided from links provided on the Egg Code pages at (CIS 2002).

International Egg Code



Flood Proofing - Any combination of changes to a structure or property using berms, flood walls, closures or sealants, which reduces or eliminates flood damage to buildings or property.

Flood/Flooding - A temporary condition caused by the accumulation of runoff from any source, which exceeds the capacity of a natural or man-made drainage system and results in inundation of normally dry land areas.

Floodplain - The area, usually low lands adjoining a watercourse, which has been, or may be, covered by flood water

Floodplain Management - A program that uses corrective and preventative measures to reduce flood and erosion damage and preserve natural habitat and wildlife resources in flood prone areas. Some of these measures include: adopting and administering Floodplain Regulations, riparian habitat communities, and assuring effective maintenance and operation of flood control works.

Floodplain Regulations - Adopted policies, codes, ordinances, and regulations pertaining to the use and development of lands that lie within a regulatory floodplain.

Flow Velocity - The speed of water flowing in any drainage works, measured in units of distance over time.

Freeboard - A safety factor used in the design of drainage works. It defines the distance between the design water surface and a designated elevation of a structural element (e.g., edge of pavement).

HEC-2 - Hydrologic Engineering Center - 2

HEC-RAS - Hydrologic Engineering Center's River Analysis System

Hurricane Hazel - A storm that occurred in October, 1954 over southern Ontario. It is the largest recorded 12-hour rainfall event in Ontario. It was selected to be used for regulatory purposes in South Central and South Western Ontario.

Hydraulics - A field of study dealing with the flow pattern and rate of water movement based on the principles of fluid mechanics.

Hydrology - Science dealing with the occurrence, distribution and circulation of water on the earth, including precipitation, stormwater runoff and groundwater.

IGLD 1985 - The International Great Lakes Datum (1985). IGLD 1985 was implemented in January 1992 and replaced the previous system, IGLD 1955. Since the plane of chart datum was not changed, the depths and heights portrayed on the charts are the same for both reference systems. However, the elevation assigned to chart datum is slightly different.

Major Drainage System - The route followed by runoff when the capacity of the minor drainage system is exceeded. The major drainage system consists of the roadway surface, median drains, boulevards, and storage areas; drainage swales, trunk sewers, channels or roadside ditches conveying the major storm.

Minor Drainage System - Collects runoff that results from the more frequent storm events (typically the 2 year to 10 year event), and conveys the runoff to the outlet at the drainage system. In urban settings, the minor system typically consists of curbs, gutters, catchbasin inlets, storm sewers, minor drainage swales and roadside ditches. In rural settings, the minor drainage system generally consists of roadside ditches and minor drainage swales. It can also include curbs, gutters, and catchbasin inlets; however these components are less frequently used in rural settings.

Peak Flow - The maximum rate of flow through a watercourse for a given storm

Probable Maximum Flood - The PMF is defined as the “hypothetical flood that is considered to be the most severe reasonably possible at a particular location and time of year, based on comprehensive hydro-meteorological analysis of critical runoff-producing precipitation and hydrologic factors favourable for maximum flood runoff”

Probable Maximum Precipitation – The PMP is defined as the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year, with no allowance made for long-term climatic trends.

Reach - A term used to describe a specific length of a stream or watercourse. For example, the term can be used to describe a section of a stream or watercourse between two bridges.

Regulatory Flood - The approved standard(s) used in a particular watershed to define the limit of the flood plain for regulatory purposes. The Ganaraska River Watershed lies within Zone 1, as defined by the OMNR guidelines and as such the Regulatory Flood is defined by the greater of:

- The flood level corresponding to the peak flow generated by the Regional Storm (Hurricane Hazel);
- An observed and well documented flood level; and,
- The 100-year flood level.

Regulatory Floodplain - A portion of the geologic floodplain that may be inundated by the base flood where the peak discharge is 100 cubic feet per second (cfs) or greater. Regulatory floodplains also include areas which are subject to sheet flooding, or areas on existing recorded subdivision plats mapped as being flood prone.

Regulatory Flow - A flow generated by a storm designated by OMNR for flood plain management purposes in a given zone.

Regulatory Storm - Storm events that have been selected as the approved standard(s) to be used in particular watershed(s) to define the limits of the flood plain for regulatory purposes (OMNR).

Regulatory Storm Flow Rate - The flow rate for the runoff resulting from applying a regulatory storm to a catchment area.

Rip-rap - Rock or other material placed to protect shorelines, river/.stream beds etc. from erosion or waves.

Roughness Coefficient - A numerical measure of the frictional resistance of a surface to the flow of water.

Runoff - The portion of precipitation on land that ultimately reaches streams, especially water from rain or melted snow that flows over ground surface.

Seiche - is a standing wave in an enclosed or partially enclosed body of water. Seiches and seiche-related phenomena have been observed on lakes, reservoirs, bays and seas. The effect is caused by resonances in a body of water that has been disturbed by one or more of a number of factors, most often meteorological effects (wind and atmospheric pressure variations), seismic activity or by tsunamis.

Slope – the ratio of change in vertical height to change in horizontal distance over a particular bathymetry or shoreline section. A slope of 1:x refers to 1 unit vertically to x units horizontally, e.g., a 200 m horizontal shoreline section that is 100 m higher at one end has a slope of 1V:2H.

Starting Water Surface Elevation - The water surface elevation at a point from which other water surface elevations are deduced using hydraulic calculations

Steady Flow - Flow in which the discharge at a given point remains constant with time.

Storm Drainage System - A drainage system for collecting runoff of stormwater on highways and removing it to appropriate outlets. The system includes inlets, catch basins, storm sewers, drains, reservoirs, pump stations, and detention basins.

Storm Surge – high water levels that result from very low pressure, strong winds blowing toward land, and high tides (if present). Depending on the conditions and geographical setting, water levels may be “set up” by as much as several metres and have potential to cause severe flooding for low-lying coastal regions.

Stormwater - Precipitation from rain or snow that accumulates in a natural or man-made watercourse or conveyance system.

Surface Water - Water that flows in streams and rivers and in natural lakes, in wetlands, and in reservoirs constructed by humans.

Tides – the alternate rise and fall of sea level, with an average period of 12.4 or in some places 24.8 hours, as a consequence of the simultaneous action of the moon’s, sun’s, and earth’s gravitational forces, and the revolution of the moon about the earth, and the earth and the sun. In the Great Lakes, and Lake Huron, largest spring tides are less than 5 cm. These minor variations are masked or hidden by greater water level fluctuations produced by wind and barometric pressure changes, and so these lakes are considered essentially to be non-tidal.

Tsunami – is a series of waves created when a body of water, such as an ocean, is suddenly displaced. Earthquakes, mass movements above or below water, some volcanic eruptions and other underwater explosions, landslides, underwater earthquakes, large asteroid impacts and testing with nuclear weapons at sea all have the potential to generate a tsunami.

Water Surface Elevations - The various depths of flowing water, measured to a common datum (e.g., stream channel invert, sea level, etc.) at prescribed locations (e.g., cross-section, catchbasins, etc.) along a water crossing, minor system, major system, or stream channel system.

Watercourse - A stream, river or channel in which a flow of water occurs, either continuously or intermittently, with some degree of regularity.

Watershed - An area from which water drains into a lake, stream or other body of water. A watershed is also often referred to as a basin, with the basin boundary defined by a high ridge or divide, and with a lake or river located at a lower point.

Wave Height – The vertical distance from trough to crest of a wave. Significant wave height, commonly abbreviated as Hs or Hsig, is a descriptive wave height measure defined as the average height of the highest one-third of the waves. Significant wave height can also be estimated from a measured or idealized/synthesized wave spectrum as $4\sqrt{mo}$, where mo is the variance of the wave spectrum.

Wave Overtopping – Passing of water over the top of a structure as a result of wave uprush or wave action. Generally overtopping does not mean some spray or splash due to a combination of splitting of water by impact or wave action but describes overrun by clear water (green water) (Atria 1997)

Wave Setup – Wave setup is the superelevation of mean water level caused by wave action (additional changes in water level may include wind setup or tide). Total water depth is a sum of still-water depth and setup (USACE 2008d).

Wave Uprush – The vertical height above the still-water level to which water, from an incident wave, will rush up to on a shoreline or shoreline structure" (Atria 1997) or "Runup is the maximum elevation of wave uprush above still-water level. Wave uprush consists of two components: superelevation of the mean water level due to wave action (setup) and fluctuations about that mean (swash) (USACE 2008d).

APPENDICES

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APPENDIX A: QUALITY ASSURANCE PROGRAMS

A1. Project Quality Plan

A project specific Quality Plan (PQP) has been developed in line with the requirement of the DGR Project Quality Plan (NWMO 2009a). All activities associated with the Project have been carried out by the Project team as defined in the project specific PQP (AMEC NSS 2010).

A2. Software Qualification

The following computing programs were used in this Project:

- HEC-RAS;
- Visual OttHymo;
- SWAN;
- SPLASH; and
- HYDRO2D

In accordance with NWMO Technical Computing Software Procedure (NWMO 2009b), these computing programs are identified as “Standard Grade” Software. The first four programs are third-party software and the last one, HYDRO2D, is proprietary software. The third-party software represents software supplied by a third party vendor and is either commercially or publicly available. All third-party software packages used in the assessment are industry standard and widely used and accepted by Canadian regulatory authorities and are the best available products for this application. For the in-house software package (HYDRO2D) which has been in extensive use in the industry in Canada for several years, AMEC has confirmed that it meets the required QA criteria defined by NWMO and that the following documentation is available: a User Manual, a verification report, and version tracking information. In both cases the software has been validated against actual site data at a multitude of locations for a range of different scenarios through extensive usage and the predictions were found to be satisfactory. As such, it can be confirmed that the software used in this Project satisfies the requirement specified in NWMO Technical Computing Software Procedure (NWMO 2009b).

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APPENDIX B: ENVIRONMENT CANADA PMP ESTIMATES FOR KINCARDINE (GAUGE NO. 6124127)

ATMOSPHERIC ENVIRONMENT SERVICE

RAINFALL INTENSITY, DURATION, FREQUENCY VALUES

PREPARED BY THE HYDROMETEOROLOGY DIVISION, CANADIAN CLIMATE CENTRE

****

STATION : Kincardine, ON   STATION NUMBER 6124127

CRITICAL PERIOD : 1ST OF MONTH 01 TO THE END OF MONTH 12   NOTE : MODIFIED GUMBEL 12/82

YEARS	TOTAL DAYS	% VALID	FLAG		1 DAY	2 DAY	3 DAY	4 DAY	5 DAY	6 DAY	7 DAY	8 DAY	9 DAY	10 DAY	15 DAY	20 DAY	25 DAY	30 DAY
1900	328	89	**	START DATE	21/11	20/11	20/11	20/11	20/11	20/11	20/11	20/11	13/11	13/11	7/11	2/11	30/10	24/10
				MAX VALUE	406	673	719	719	719	719	719	719	884	930	973	1031	1395	1563
1901	358	98		START DATE	14/12	14/12	14/12	14/12	26/ 7	26/ 7	26/ 7	26/ 7	26/ 7	26/ 7	21/ 7	11/ 7	11/ 7	5/ 7
				MAX VALUE	483	483	483	483	625	625	625	625	661	661	686	777	813	945
1902	365	100		START DATE	10/ 9	20/ 7	20/ 7	10/ 9	10/ 9	10/ 9	10/ 9	20/ 7	20/ 7	4/ 9	6/ 9	20/ 7	20/ 7	20/ 7
				MAX VALUE	406	620	620	780	780	780	780	915	915	950	978	1329	1418	1418
1903	10	2	0 **															
1994	153	41	**	START DATE	5/11	19/ 8	3/11	3/11	3/11	31/10	31/10	31/10	31/10	31/10	23/10	18/10	17/10	8/10
				MAX VALUE	248	394	440	492	492	592	644	644	700	700	872	1065	1132	1276
1995	334	91		START DATE	10/11	10/11	10/11	10/11	7/11	6/11	6/11	27/ 7	27/ 7	27/ 7	27/ 7	27/ 7	22/ 7	15/ 7
				MAX VALUE	470	622	622	622	626	712	712	840	840	840	1224	1360	1484	1602
1996	366	100		START DATE	7/11	6/11	13/ 9	13/ 9	13/ 9	11/ 9	9/ 9	7/ 9	7/ 9	6/ 9	13/ 9	7/ 9	6/ 9	6/ 9
				MAX VALUE	358	480	614	616	616	618	672	730	890	898	1050	1176	1364	1404
1997	365	100		START DATE	21/ 2	18/ 9	17/ 9	16/ 9	16/ 9	31/12	31/12	31/12	31/12	31/12	10/ 8	10/ 8	16/ 9	25/ 7

			MAX VALUE	264	360	466	476	476	600	642	714	776	784	884	928	994	1160
1998	365	100	START DATE	5/ 1	4/ 1	3/ 1	4/ 1	4/ 1	3/ 1	3/ 1	3/ 1	3/ 1	3/ 1	1/ 9	22/ 8	22/ 8	7/ 9
			MAX VALUE	410	546	600	660	722	776	784	784	784	804	828	926	1118	1198
1999	365	100	START DATE	13/ 6	3/ 8	3/ 8	3/ 8	3/ 8	3/ 8	3/ 8	3/ 8	3/ 8	3/ 8	31/ 7	13/ 6	29/ 9	27/ 9
			MAX VALUE	400	450	464	468	676	676	736	756	764	770	820	910	1099	1169
2000	366	100	START DATE	12/ 5	11/ 5	10/ 5	9/ 5	8/ 5	8/ 5	11/ 5	10/ 5	9/ 5	8/ 5	9/ 5	6/ 5	8/ 5	19/ 4
			MAX VALUE	550	672	746	916	1080	1100	1154	1228	1398	1562	1666	1866	1994	2106
2001	365	100	START DATE	9/ 9	8/ 9	7/ 9	7/ 9	7/ 9	7/ 9	3/ 9	3/ 9	3/ 9	3/ 9	12/10	7/ 9	3/ 9	30/ 8
			MAX VALUE	540	602	798	798	798	864	928	928	928	994	1222	1716	1856	1946
2002	363	99	START DATE	8/ 4	7/ 4	7/ 4	7/ 4	8/ 4	7/ 4	7/ 4	7/ 4	7/ 4	7/ 4	29/ 3	29/ 3	7/ 4	7/ 4
			MAX VALUE	320	420	460	460	570	670	680	680	680	680	820	836	1008	1048
2003	361	98	START DATE	22/ 9	22/ 9	22/ 9	22/ 9	22/ 9	19/ 9	22/ 9	19/ 9	18/ 9	22/ 9	14/ 9	14/ 9	13/ 9	13/ 9
			MAX VALUE	298	358	598	598	684	720	766	806	852	902	1264	1584	1702	1736
2004	366	100	START DATE	23/ 5	22/ 5	22/ 5	22/ 5	22/ 5	22/ 5	17/ 5	17/ 5	17/ 5	14/ 5	9/ 5	4/ 5	30/ 4	24/ 4
			MAX VALUE	476	748	776	776	776	792	860	888	888	896	1074	1254	1520	1654
2005	363	99	START DATE	25/ 9	25/ 9	24/ 9	25/ 9	25/ 9	24/ 9	22/ 9	22/ 9	22/ 9	22/ 9	14/ 9	14/ 9	14/ 9	7/ 9
			MAX VALUE	828	854	856	1166	1174	1176	1198	1206	1206	1206	1360	1388	1392	1412
2006	365	100	START DATE	12/ 9	12/ 9	29/11	28/11	28/11	26/11	11/10	10/10	10/10	11/ 7	10/10	9/10	9/ 7	29/ 9
			MAX VALUE	422	442	516	532	532	534	600	664	702	748	1044	1274	1452	1546

****

	1 DAY	2 DAY	3 DAY	4 DAY	5 DAY	6 DAY	7 DAY	8 DAY	9 DAY	10 DAY	15 DAY	20 DAY	25 DAY	30 DAY
MEAN EXTREME(MM)	50.2	56.9	63.4	68.8	73.8	77.5	81.1	85.7	88.6	91.6	107.6	123.7	137.2	145.3
STD. DEV.(MM)	15.8	15.3	13.7	20.9	20.0	18.7	18.8	18.8	20.5	23.7	26.6	33.6	34.0	33.7
YEARS ANALYSED	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0

** NOTE ** MEAN AND STANDARD DEVIATION HAVE BEEN ADJUSTED FOR ONE OBSERVATION PER DAY.

NOTE ** VALUE IN FLAG INDICATES YEAR NOT INCLUDED IN ANALYSIS BASED ON % DAYS OPERATIONAL (<90.0%)

** WARNING : RETURN PERIOD RAINFALL VALUE IS BASED ON LESS THAN 15.00 YEARS DATA

ATMOSPHERIC ENVIRONMENT SERVICE

RAINFALL INTENSITY, DURATION, FREQUENCY VALUES

PREPARED BY THE HYDROMETEOROLOGY DIVISION, CANADIAN CLIMATE CENTRE

****

STATION : Kincardine, ON STATION NUMBER 6124127

CRITICAL PERIOD : 1ST OF MONTH 01 TO THE END OF MONTH 12 NOTE : MODIFIED GUMBEL 12/82

RETURN PERIOD VALUES (MM) WITH 50% CONFIDENCE LIMITS

****

RETURN PERIOD YEARS	1 DAY	2 DAY	3 DAY	4 DAY	5 DAY
2	47.66+/- 2.60	54.38+/- 2.52	61.16+/- 2.27	65.38+/- 3.45	70.57+/- 3.30
5	61.57+/- 4.39	67.86+/- 4.25	73.29+/- 3.83	83.80+/- 5.81	88.19+/- 5.56
10	70.80+/- 5.93	76.80+/- 5.74	81.35+/- 5.17	96.02+/- 7.85	99.88+/- 7.51
25	82.44+/- 7.99	88.08+/- 7.74	91.51+/- 6.97	111.44+/-10.58	114.63+/-10.12
50	91.08+/- 9.56	96.45+/- 9.26	99.04+/- 8.34	122.87+/-12.66	125.57+/-12.11
100	99.66+/-11.14	104.77+/-10.79	106.53+/- 9.72	134.24+/-14.75	136.44+/-14.11
PROBABLE MAXIMUM RAINFALL	328.0	331.9	313.2	450.5	439.4

RETURN PERIOD YEARS	6 DAY	7 DAY	8 DAY	9 DAY	10 DAY

2	74.48+/- 3.09	78.05+/- 3.12	82.62+/- 3.11	85.26+/- 3.38	87.70+/- 3.91
5	90.96+/- 5.20	94.69+/- 5.24	99.24+/- 5.24	103.33+/- 5.70	108.61+/- 6.59
10	101.90+/- 7.02	105.73+/- 7.09	110.26+/- 7.08	115.33+/- 7.70	122.48+/- 8.91
25	115.69+/- 9.47	119.65+/- 9.55	124.17+/- 9.54	130.45+/-10.38	139.98+/-12.01
50	125.92+/-11.32	129.97+/-11.43	134.48+/-11.42	141.66+/-12.42	152.95+/-14.37
100	136.09+/-13.19	140.24+/-13.32	144.73+/-13.30	152.82+/-14.47	165.86+/-16.74
PROBABLE MAXIMUM RAINFALL	420.8	428.0	432.7	466.4	529.5

RETURN PERIOD YEARS	15 DAY	20 DAY	25 DAY	30 DAY
2	103.28+/- 4.39	118.23+/- 5.56	131.67+/- 5.62	139.78+/- 5.58
5	126.73+/- 7.39	147.91+/- 9.36	161.67+/- 9.46	169.57+/- 9.39
10	142.29+/- 9.99	167.61+/-12.64	181.58+/-12.78	189.34+/-12.69
25	161.92+/-13.47	192.45+/-17.05	206.68+/-17.23	214.27+/-17.11
50	176.47+/-16.11	210.87+/-20.39	225.30+/-20.61	232.76+/-20.47
100	190.94+/-18.77	229.19+/-23.76	243.81+/-24.02	251.15+/-23.85
PROBABLE MAXIMUM RAINFALL	599.1	746.1	766.7	772.2

APPENDIX C: SENSITIVITY ANALYSIS

Table C.1: Little Sauble River PMF Sensitivity Analysis - Computed Water Surface Elevations (m)

HEC-RAS Section ID	Starting Water Surface Elevation 176.43 m (Mean Annual)			Starting Water Surface Elevation 176.59 m (Mean Monthly)			Starting Water Surface Elevation 177.60 m (100 year)			Starting Water Surface Elevation 178.40 m (500 year)		
	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978
101	220.79	220.92	220.98	220.79	220.92	220.98	220.79	220.92	220.98	220.79	220.92	220.98
100.5	Culvert at 23 Side Road											
100	218.76	219.5	219.5	218.76	219.5	219.5	218.76	219.5	219.5	218.76	219.5	219.5
99	214.56	214.84	214.88	214.56	214.84	214.88	214.56	214.84	214.88	214.56	214.84	214.88
98	211.66	211.87	211.92	211.66	211.87	211.92	211.66	211.87	211.92	211.66	211.87	211.92
97	207.71	207.98	208	207.71	207.98	208	207.71	207.98	208	207.71	207.98	208
96	199.96	200.26	200.29	199.96	200.26	200.29	199.96	200.26	200.29	199.96	200.26	200.29
95	193.03	193.3	193.33	193.03	193.3	193.33	193.03	193.3	193.33	193.03	193.3	193.33
94	191.89	192.14	192.15	191.89	192.14	192.15	191.89	192.14	192.15	191.89	192.14	192.15
92.5	Culvert at Concession Road 2											
92	191	191	191	191	191	191	191	191	191	191	191	191
91	190.4	190.74	190.85	190.4	190.74	190.85	190.4	190.74	190.85	190.4	190.74	190.85
90	190.16	190.43	190.53	190.16	190.43	190.53	190.16	190.43	190.53	190.16	190.43	190.53
89.5	Culvert at Albert Road											
89	189.33	189.93	190	189.33	189.93	190	189.33	189.93	190	189.33	189.93	190
88	189.19	189.79	189.86	189.19	189.79	189.86	189.19	189.79	189.86	189.19	189.79	189.86
87	188.68	189.36	189.42	188.68	189.36	189.42	188.68	189.36	189.42	188.68	189.36	189.42
86.5	Bridge at Alma Street											
86	188.24	188.87	188.96	188.24	188.87	188.96	188.24	188.87	188.96	188.24	188.87	188.96
85	187.11	187.67	187.76	187.11	187.67	187.76	187.11	187.67	187.76	187.11	187.67	187.76

HEC-RAS Section ID	Starting Water Surface Elevation 176.43 m (Mean Annual)			Starting Water Surface Elevation 176.59 m (Mean Monthly)			Starting Water Surface Elevation 177.60 m (100 year)			Starting Water Surface Elevation 178.40 m (500 year)		
	OMNR 2004	**OMNR 2006**	**NWS 1978**	**OMNR 2004**	**OMNR 2006**	**NWS 1978**	**OMNR 2004**	**OMNR 2006**	**NWS 1978**	**OMNR 2004**	**OMNR 2006**	**NWS 1978**
84	185.17	185.87	185.95	185.17	185.87	185.95	185.17	185.87	185.95	185.17	185.87	185.95
83	183.84	184.52	184.61	183.84	184.52	184.61	183.84	184.52	184.61	183.84	184.52	184.61
82	183.44	184.12	184.21	183.44	184.12	184.21	183.44	184.12	184.21	183.44	184.12	184.21
81	181.88	182.37	182.45	181.88	182.37	182.45	181.88	182.37	182.45	181.88	182.37	182.45
80	179.91	180.53	180.63	179.91	180.53	180.63	179.91	180.53	180.63	179.91	180.53	180.63
79 Lake Huron	178.54	179.26	179.34	178.54	179.26	179.34	178.54	179.26	179.34	178.54	179.26	179.34

Notes:
1. Starting Water Surface Elevation refers to the boundary condition at the most downstream end of the hydraulic model … in this case Lake Huron.
2. Table cell highlighting in [green] above is provided to facilitate better readability only.
3. Table cell highlighting in [yellow] above indicates the base hydraulic model.

Table C.2: Stream 'C' PMF Sensitivity Analysis - Computed Water Surface Elevations (m)

HEC-RAS Section ID	Starting Water Surface Elevation 176.43 m (Mean Annual)			Starting Water Surface Elevation 176.59 m (Mean Monthly)			Starting Water Surface Elevation 177.60 m (100 year)			Starting Water Surface Elevation 178.40 m (500 year)		
	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978
97	191.82	191.9	191.9	191.82	191.9	191.9	191.82	191.9	191.9	191.82	191.9	191.9
96.5	Culvert at Tie Road											
96	191.5	191.5	191.5	191.5	191.5	191.5	191.5	191.5	191.5	191.5	191.5	191.5
95	183.1	183.21	183.23	183.1	183.21	183.23	183.1	183.21	183.23	183.1	183.21	183.23
94	183.12	183.24	183.25	183.12	183.24	183.25	183.12	183.24	183.25	183.12	183.24	183.25
93	183.11	183.23	183.24	183.11	183.23	183.24	183.11	183.23	183.24	183.11	183.23	183.24
92.5	Culvert at railway crossing											
92	182.5	182.5	182.5	182.5	182.5	182.5	182.5	182.5	182.5	182.5	182.5	182.5
91	181	181.12	181.14	181	181.12	181.14	181	181.12	181.14	181	181.12	181.14
90	180.98	181.09	181.1	180.98	181.09	181.1	180.98	181.09	181.1	180.98	181.09	181.1
89.5	Culvert at North Road											
89	180.5	180.5	180.5	180.5	180.5	180.5	180.5	180.5	180.5	180.5	180.5	180.5
88	179.11	179.22	179.25	179.11	179.22	179.25	179.31	179.39	179.42	179	179.16	179.18
87	178.13	178.24	178.26	178.13	178.24	178.26	177.82	177.99	178.02	178.41	178.42	178.42
86 Lake Huron	177.22	177.27	177.28	177.22	177.27	177.28	177.6	177.6	177.6	178.4	178.4	178.4

Notes:
1. Starting Water Surface Elevation refers to the boundary condition at the most downstream end of the hydraulic model … in this case Lake Huron.
2. Table cell highlighting in [green] above is provided to facilitate better readability only.
3. Table cell highlighting in [yellow] above indicates the base hydraulic model.

Table C.3: DGR Site PMF Sensitivity Analysis - Computed Water Surface Elevations (m)

HEC-RAS Section ID	Starting Water Surface Elevation 176.43 m (Mean Annual)			Starting Water Surface Elevation 176.59 m (Mean Monthly)			Starting Water Surface Elevation 177.60 m (100 year)			Starting Water Surface Elevation 178.40 m (500 year)		
	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978
The table subset (Sections 100-96 and 200-192) below delineates hydraulic sections around the perimeter of the DGR site operational area. The preliminary design elevation associated with this area for the purposes of this assessment is 186 m.												
100	186.5	186.67	186.69	186.5	186.67	186.69	186.5	186.67	186.69	186.5	186.67	186.69
99	186.48	186.64	186.66	186.48	186.64	186.66	186.48	186.64	186.66	186.48	186.64	186.66
98	186.47	186.63	186.65	186.47	186.63	186.65	186.47	186.63	186.65	186.47	186.63	186.65
97	186.47	186.63	186.66	186.47	186.63	186.66	186.47	186.63	186.66	186.47	186.63	186.66
96	186.45	186.6	186.62	186.45	186.6	186.62	186.45	186.6	186.62	186.45	186.6	186.62
95	186.44	186.6	186.62	186.44	186.6	186.62	186.44	186.6	186.62	186.44	186.6	186.62
200	186.68	186.86	186.88	186.68	186.86	186.88	186.68	186.86	186.88	186.68	186.86	186.88
199	186.67	186.86	186.88	186.67	186.86	186.88	186.67	186.86	186.88	186.67	186.86	186.88
198	186.67	186.85	186.87	186.67	186.85	186.87	186.67	186.85	186.87	186.67	186.85	186.87
197	186.67	186.85	186.87	186.67	186.85	186.87	186.67	186.85	186.87	186.67	186.85	186.87
196	186.66	186.85	186.87	186.66	186.85	186.87	186.66	186.85	186.87	186.66	186.85	186.87
195	186.66	186.84	186.86	186.66	186.84	186.86	186.66	186.84	186.86	186.66	186.84	186.86
194	186.64	186.82	186.84	186.64	186.82	186.84	186.64	186.82	186.84	186.64	186.82	186.84
193	186.59	186.77	186.79	186.59	186.77	186.79	186.59	186.77	186.79	186.59	186.77	186.79
192	186.51	186.67	186.69	186.51	186.67	186.69	186.51	186.67	186.69	186.51	186.67	186.69
191	186.36	186.5	186.51	186.36	186.5	186.51	186.36	186.5	186.51	186.36	186.5	186.51
190	186.2	186.3	186.31	186.2	186.3	186.31	186.2	186.3	186.31	186.2	186.3	186.31
189	185.77	185.94	185.96	185.77	185.94	185.96	185.77	185.94	185.96	185.77	185.94	185.96
188	185.39	185.5	185.51	185.39	185.5	185.51	185.39	185.5	185.51	185.39	185.5	185.51

HEC-RAS Section ID	Starting Water Surface Elevation 176.43 m (Mean Annual)			Starting Water Surface Elevation 176.59 m (Mean Monthly)			Starting Water Surface Elevation 177.60 m (100 year)			Starting Water Surface Elevation 178.40 m (500 year)		
	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978
300	185.02	185.18	185.19	185.02	185.18	185.19	185.02	185.18	185.19	185.02	185.18	185.19
299	185	185.17	185.18	185	185.17	185.18	185	185.17	185.18	185	185.17	185.18
298	184.99	185.15	185.16	184.99	185.15	185.16	184.99	185.15	185.16	184.99	185.15	185.16
297	184.87	184.99	184.99	184.87	184.99	184.99	184.87	184.99	184.99	184.87	184.99	184.99
296	184.66	184.85	184.86	184.66	184.85	184.86	184.66	184.85	184.86	184.66	184.85	184.86
295	184.39	184.59	184.6	184.39	184.59	184.6	184.39	184.59	184.6	184.39	184.59	184.6
294	184.23	184.42	184.43	184.23	184.42	184.43	184.23	184.42	184.43	184.23	184.42	184.43
293	183.87	183.96	183.96	183.87	183.96	183.96	183.87	183.96	183.96	183.87	183.96	183.96
292	183.75	183.87	183.87	183.75	183.87	183.87	183.75	183.87	183.87	183.75	183.87	183.87
291	183.51	183.67	183.68	183.51	183.67	183.68	183.51	183.67	183.68	183.51	183.67	183.68
290	183.28	183.44	183.45	183.28	183.44	183.45	183.28	183.44	183.45	183.28	183.44	183.45
289	182.54	182.85	182.86	182.54	182.85	182.86	182.54	182.85	182.86	182.54	182.85	182.86
400	185.03	185.2	185.22	185.03	185.2	185.22	185.03	185.2	185.22	185.03	185.2	185.22
399	184.37	184.54	184.56	184.37	184.54	184.56	184.37	184.54	184.56	184.37	184.54	184.56
398	183.54	183.69	183.72	183.54	183.69	183.72	183.54	183.69	183.72	183.54	183.69	183.72
397	183.01	183.02	183.02	183.01	183.02	183.02	183.01	183.02	183.02	183.01	183.02	183.02
396	183	183	183	183	183	183	183	183	183	183	183	183
395	181.92	182.09	182.11	181.92	182.09	182.11	181.92	182.09	182.11	181.92	182.09	182.11

HEC-RAS Section ID	Starting Water Surface Elevation 176.43 m (Mean Annual)			Starting Water Surface Elevation 176.59 m (Mean Monthly)			Starting Water Surface Elevation 177.60 m (100 year)			Starting Water Surface Elevation 178.40 m (500 year)		
	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978
288	181.53	181.74	181.76	181.53	181.74	181.76	181.53	181.74	181.76	181.53	181.74	181.76
287	181.19	181.37	181.39	181.19	181.37	181.39	181.19	181.37	181.39	181.19	181.37	181.39
500.1	181.34	181.53	181.56	181.34	181.53	181.56	181.34	181.53	181.56	181.34	181.53	181.56
500	181.27	181.46	181.48	181.27	181.46	181.48	181.27	181.46	181.48	181.27	181.46	181.48
499	180.45	180.53	180.55	180.45	180.53	180.55	180.45	180.53	180.55	180.45	180.53	180.55
498.5	Interconnect Road Culvert											
498	180.44	180.53	180.54	180.44	180.53	180.54	180.44	180.53	180.54	180.44	180.53	180.54
497.3	180.38	180.45	180.45	180.38	180.45	180.45	180.38	180.45	180.45	180.38	180.45	180.45
497.2	180.34	180.39	180.4	180.34	180.39	180.4	180.34	180.39	180.4	180.34	180.39	180.4
497.1	180.3	180.35	180.35	180.3	180.35	180.35	180.3	180.35	180.35	180.3	180.35	180.35
497	180.22	180.25	180.24	180.22	180.25	180.24	180.22	180.25	180.24	180.22	180.25	180.24
496.5	Culvert											
496	180.23	180.27	180.26	180.23	180.27	180.26	180.23	180.27	180.26	180.23	180.27	180.26
495.1	180.22	180.25	180.24	180.22	180.25	180.24	180.22	180.25	180.24	180.22	180.25	180.24
495	180.2	180.23	180.22	180.2	180.23	180.22	180.2	180.23	180.22	180.2	180.23	180.22
494.5	Roadway Culvert											
494	180	180	180	180	180	180	180	180	180	180	180	180

Notes:
1. Data in bolded red indicates an area of potential flood risk.
2. Starting Water Surface Elevation refers to the boundary condition at the most downstream end of the hydraulic model (in this case Lake Huron).

HEC-RAS Section ID	Starting Water Surface Elevation 176.43 m (Mean Annual)			Starting Water Surface Elevation 176.59 m (Mean Monthly)			Starting Water Surface Elevation 177.60 m (100 year)			Starting Water Surface Elevation 178.40 m (500 year)		
	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978	OMNR 2004	OMNR 2006	NWS 1978

3. Table cell highlighting in [green] above is provided to facilitate better readability only.
4. Table cell highlighting in [yellow] above indicates the base hydraulic model.