Assessment Report

Sault Ste. Marie Region

Source Protection Area

APPENDIX 2 - CHAPTER 4
GROS CAP INTAKE PROTECTION ZONE

STUDY NUMERICAL MODELING

February 5, 2015

The Assessment Report was initially approved on November 25, 2011.
Amendments were made in 2014 to include Chapter 2c.

Baird

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Gros Cap Intake Protection Zone Study

Addendum: Numerical Modeling in Support of IPZ-2 Delineation

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Gros Cap Intake Protection Zone Study

Addendum: Numerical Modeling in Support of IPZ-2 Delineation

Prepared for

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1.0 INTRODUCTION

1.1 Background

The Clean Water Act received Royal Assent on October 19, 2006. It ensures communities are able to protect their municipal drinking water supplies through developing collaborative, locally driven, science-based protection plans. The Act establishes a framework for the development and implementation of source protection plans across Ontario.

Source protection is a watershed based, locally driven program that uses scientifically sound methods for assessing risks to drinking water and is an approach to decision-making that emphasizes information sharing, consultation and involvement by interested members in the watershed communities. Under the Act, source protection plans are to be developed on a watershed basis. To facilitate efficient use of resources and coordination of source water protection planning, regulations under the Act group individual conservation authorities into source protection regions. The Act mandates that source protection plans be developed to address threats to all municipal residential drinking-water systems within these source protection regions.

The framework for source protection, as set out in the Act, requires the development of a watershed based assessment report. The assessment report includes a watershed characterization, a water budget, municipal long term water supply strategies (aligned with the municipal residential systems), a groundwater and/or surface water vulnerability analysis, a threats assessment and issues evaluation, and a risk assessment for water quality and quantity. Once the assessment reports are complete and risks to drinking water have been identified, source protection will focus on the development of the source protection plan. The plan is to set out locally based risk management measures to reduce or eliminate significant risks to drinking-water supplies, and set out a strategy to implement these measures.

In June 2006, the Sault Ste. Marie Conservation Authority (SSMRCA) in partnership with The Corporation of the City of Sault Ste. Marie (CSSM) and Public Utilities Commission (PUC) retained Baird & Associates (Baird) to undertake source water protection studies for the municipal intake at Gros Cap. Refer to Figure 1.1 for a map of the region noting the intake location.

The SSMRCA applied for and received additional funding in June 2007, to complete the surface water vulnerability analysis. This Addendum describes the additional work undertaken to delineate the IPZ-2 using numerical modeling.

As further background, key findings from the Phase 1 report (January 2008), related to this Addendum are outlined in Section 1.2 and the scope of work for this Addendum is discussed in Section 1.3. It is strongly recommended that the Addendum be read with the original report.

1.2 Review of Phase 1 Studies

The *Gros Cap Intake Protection Zone Study*, completed in January 2008 included data collection, intake characterization, ADCP current data collection and analysis, water and sediment sampling and analysis, and preliminary IPZ delineation.

An Acoustic Doppler Current Profiler (ADCP) was deployed offshore of Gros Cap, near the intake. The current data was collected to better define the hydrodynamic regime, for the delineation of the IPZ-2. The ADCP was deployed on July 13, 2006 and currents were recorded at 1 m intervals through the water column, from the surface to the lakebed. The ADCP was retrieved on October 15, 2006, having collected 3 months of data.

The ADCP data showed that the predominant flow direction at the instrument location was from west to the east. This was not surprising, given the proximity to the St. Marys River, the outlet of Lake Superior. However, the ADCP current data identified complex flow patterns that could not be easily generalized. The bathymetry around the intake is irregular, with a shallow shelf located southeast of the intake, and the Gros Cap Reefs located offshore. This meant that the measured currents are specific to the location of deployment, and currents would vary considerably, throughout the IPZ-2. Furthermore, the data collected was representative of the period of data collection, and currents vary with different seasonal wind patterns and storm events.

The IPZ-1 was delineated as a 1 km radius around the Gros Cap intake as shown in Figure 1.1. Given the close proximity of this region to the actual water intake, it is considered the most vulnerable region for contaminants to negatively impact the source water. The IPZ-2 acts as a secondary protective zone around the intake and the geographic limits of this zone are related to the plant operator's ability to respond to an adverse spill, and travel time for contaminants in the lake and local tributaries. A 3-hour response time was selected based on the operator survey. A preliminary IPZ-2 with a 5 km radius was delineated around the intake.

It was recommended that a three dimensional (3D) hydrodynamic model be developed to better define local currents as required for the IPZ-2 delineation, and that the modeled data be calibrated with the measured ADCP data, to provide an assessment of the level of uncertainty of the IPZ-2 delineation.

1.3 Scope of Work

The focus of the Addendum work was to develop a 3D hydrodynamic model to improve our understanding of current patterns in the vicinity of the intake and to use the model to delineate the IPZ-2. Specifically, this included:

- Data collection in support of modeling;
- Model setup
- Comparison of modeled currents with measured current data collected during Phase 1 (detailed model calibration was beyond the scope of this work due to budget limitations);
- Statistical analysis of measured wind data to define return period events;

- Numerical model runs using reverse particle tracking in support of IPZ-2 delineation;
- Delineation of in-water extent of IPZ-2 based on model results;
- Delineation of inland and up-tributary extent of IPZ-2; and
- Refinement of Vulnerability Scores and Uncertainty Analysis

After this work was awarded, MOE issued the Draft Technical Rules: Assessment Report (MOE, 2008). Several revisions of the Draft Technical Rules were issued as this work proceeded. The work presented in this report is based on the final revision to date (MOE, 2009a).

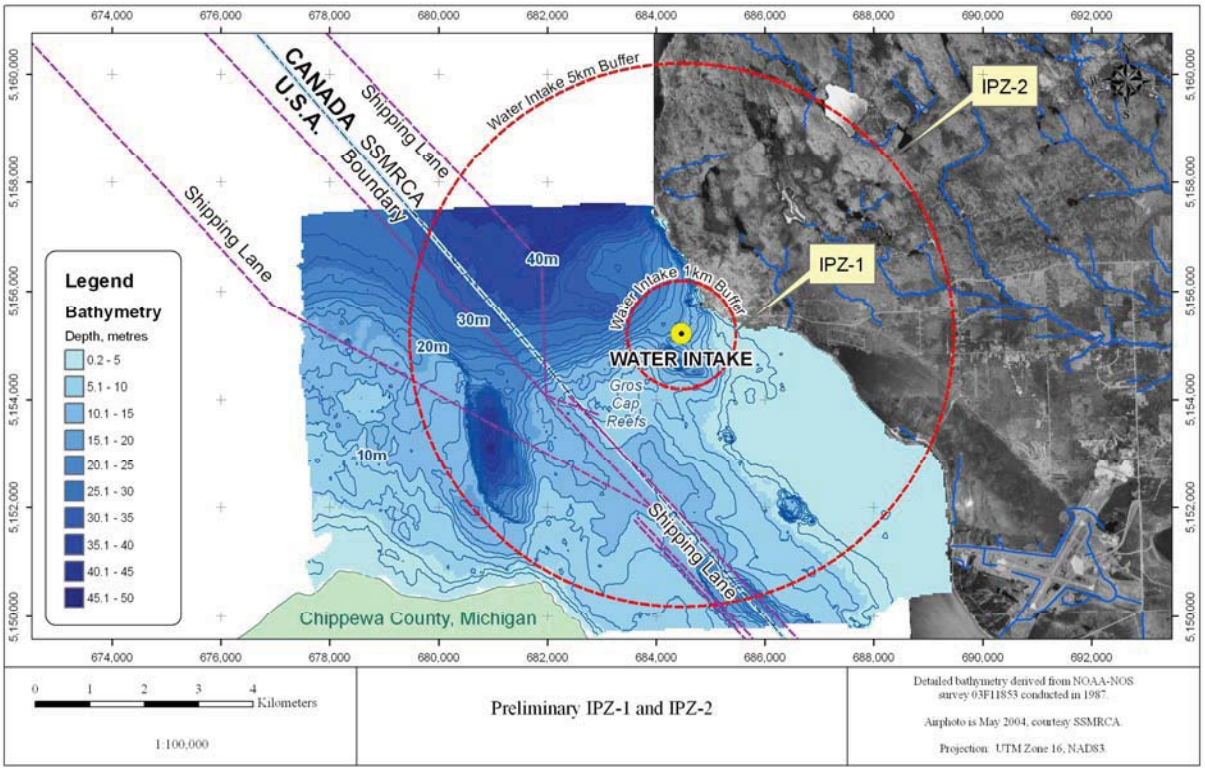


Figure 1.1 Preliminary IPZ-1 and IPZ-2 Delineations from Phase 1 Studies

2.0 NUMERICAL MODELING IN SUPPORT OF IPZ DELINEATION

Numerical modeling was undertaken in support of IPZ delineation for the municipal intake at Gros Cap. Delineation of the in-lake IPZ-2 on Lake Superior is based on two factors: the time required to shut down the water treatment facility in the event of a spill; and the distance that the contaminant could be transported during that time. The time required to shut down the WTPs was defined as 3 hours (Baird, 2008). An understanding of the local current velocities around the water intake is required to define the distances and directions that the contaminant may be transported.

Hydrodynamic processes on the Great Lakes are in most cases three-dimensional due to phenomena such as lake stratification, upwelling/downwelling, wind and waves. Field data, where it exists, defines the current patterns for the duration of the data set only, at the specific instrument location. It is useful in providing current information for a specific time and location, but it does not define the current patterns throughout the IPZ for the full range of conditions. Therefore, numerical modeling calibrated against field measurements is the only scientifically defensible and practical approach to delineate the IPZ-2. It allows us to evaluate and understand the current patterns around the intake under a range of conditions.

This section describes the models used, model setup, model validation, the runs and results of the numerical modeling undertaken in support of the delineation of the IPZ-2.

2.1 Model Description

Two numerical models were used in this study: The Danish Hydraulic Institute (DHI) MIKE3 model was used to define the hydrodynamic conditions for the south end of Whitefish Bay on Lake Superior in the vicinity of the raw water intake, and the National Oceanic and Atmospheric Administration (NOAA) lakewide Princeton Ocean Model (POM) was used to provide boundary conditions, initial conditions and external forcing mechanisms, such as wind, for the MIKE3 model. A brief description of each model follows.

2.1.1 DHI - MIKE3

Developed by DHI, MIKE3 is used to simulate un-steady three-dimensional flows in lakes, rivers and oceans taking into consideration density variations, bathymetry and external forcing functions including meteorology, tides, current velocity and surface elevation. Several levels of nesting can be defined in order to provide the necessary resolution for different locations within the computational domain. For this study, the MIKE3 model was used to evaluate hydrodynamic conditions in the lake and around the intake, for selected wind events.

2.1.2 NOAA's Princeton Ocean Model

NOAA's Great Lakes Operational Forecast System (GLOFS), which is an application of the Princeton Ocean Model (POM) was used to define the boundary conditions, initial conditions and forcing mechanisms for the MIKE3 model. The GLOFS is used to forecast water levels, currents and temperatures for the entire Lake Superior. The Lake Superior Operational Forecast System

(LSOFS) is run with a 10 km grid and 20 sigma layers in the vertical. This grid setup is too coarse for delineating the IPZ-2 and does not extend into the nearshore. The model output does however describe the large-scale hydrodynamic processes in the lake; this data was used to define the boundary conditions, initial conditions and forcing mechanisms for the MIKE3 model including spatial wind fields, air temperature and water temperatures.

2.2 Model Setup

The computational domain of the MIKE3 model extends from Whitefish Point into the St. Marys River shown in Figure 2.1. The resolution of the outer grid was 2430m and four levels of nesting were used (i.e. 810 m, 270 m, 90 m, and 30 m) in order to achieve a reasonable resolution to predict the hydrodynamic conditions around the intake.

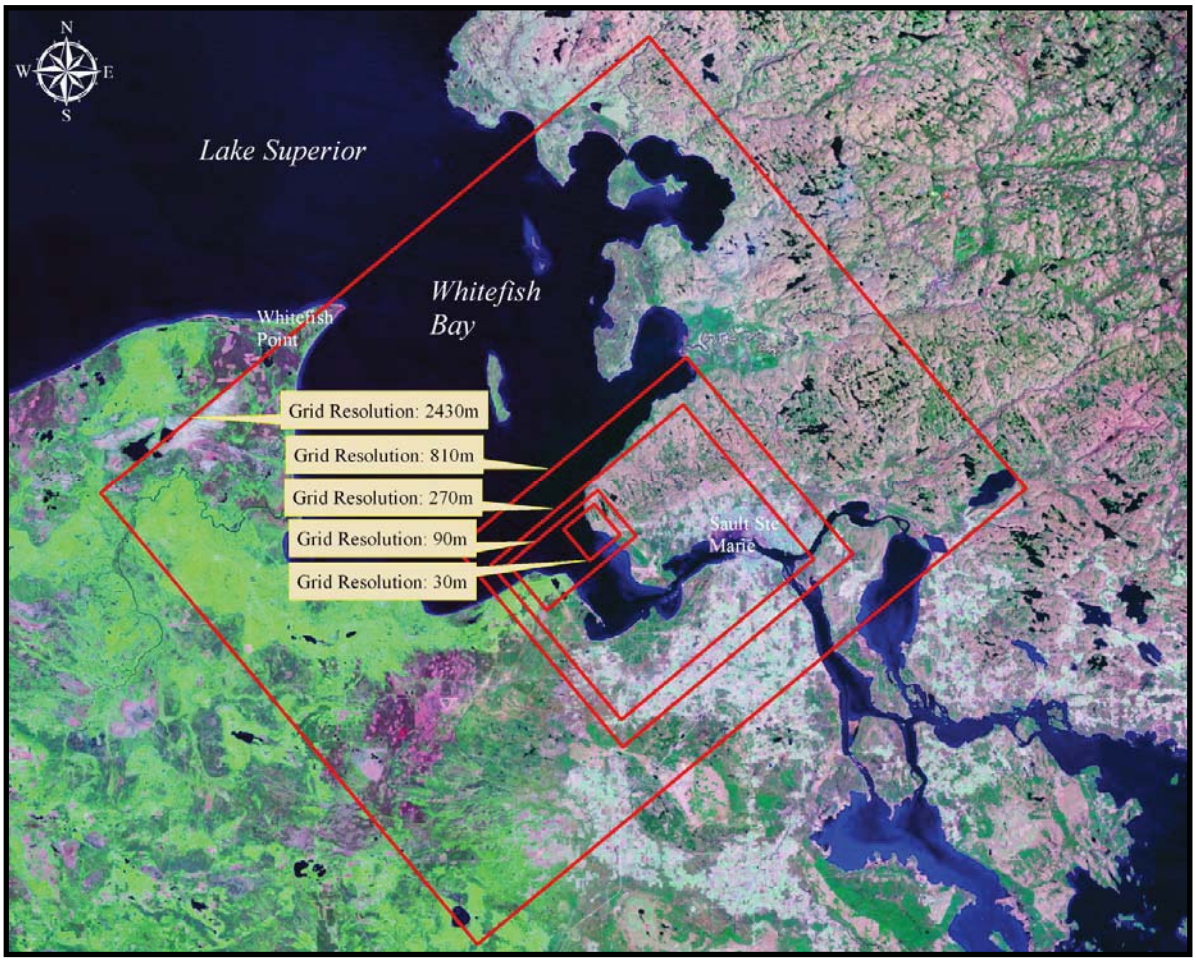


Figure 2.1 MIKE3 Model Setup of Computational Grids

The outer grid of the MIKE3 model contains one open boundary at the north end of Whitefish Bay. Flow in the St. Mary's River was defined using sinks on the 270m grid, which draws water from the system. In order to utilize and apply the meteorological and hydrodynamic datasets from the

LSOFS to the MIKE3 grid, the data were interpolated from the 10 km POM grid onto the 2430m MIKE3 grid using Baird's Spatial Data Analyzer (SDA). SDA is a visualization and data analysis tool for temporal and spatial data. It converts the model results from one grid to another grid using linear interpolation in space (horizontal vertical) and in time. The initial conditions were defined based on 3D water temperatures from the LSOFS, a constant water level was used along the open boundary, and the 2D wind fields from the LSOFS were used as the external forcing mechanism.

Other meteorological information including 2D maps of air temperature and the clearness coefficient (which was derived from 100- Percent Cloud Cover) were extracted from the LSOFS results and used to define components of the MIKE3 atmospheric heat exchange module. Relative humidity is another parameter required in the heat exchange module; the LSOFS dataset did not contain this information therefore data recorded at the Sault Ste Marie Airport (AES Station 6057592) was used in its place. Environment Canada and the U.S. Army Corps of Engineers, Detroit District Office supplied flow conditions in the St. Mary's River. Table 2.1 summarizes key parameters used in the model setup. The values used were selected based on Baird's experience using the MIKE3 model on a large number of applications in the past.

Table 2.1
Definition of Key Model Parameters

Model Parameters	Values/Description
Hydrodynamic Engine	Hydrostatic
Timestep (s)	10
No. Vertical Layers	80
Vertical Layer Resolution (m)	1
Turbulence Model	mixed k-e/smagorinsky
Smag Coefficient	0.35
Bed Roughness (m)	0.01
Horiz Dispersion Factor	0.1
Vert Dispersion Factor	0.1
Evapouration	Atmoshperic Heat Exchange

2.3 Comparison of Measured Data and Model Results

As discussed previously, although recommended, funding was not provided for a detailed calibration of the model. In lieu of this, the modelled currents were compared with the measured Aquadopp ADCP data collected by Baird from July to October 2006 (see Baird, 2008). The objective was to evaluate the model's ability to capture general trends in lake hydrodynamics, with particular attention to extreme wind events, as extreme events were used to delineate the IPZ-2. Due to the computational demands of the three-dimensional model, it was not realistically possible to simulate the entire period of the measured dataset. In addition, much the data record included

low wind speeds. After reviewing the ADCP data, the model was set up to simulate hydrodynamic conditions from August 8, 2006 to August 20, 2006. This period included a significant wind event.

From August 8, 2006 to August 20, 2006 the average current speeds at the surface as measured by the ADCP and predicted by the MIKE3 model were determined to be 0.08m/s and 0.08 m/s, respectively. Average currents 10m below the water surface were determined to be 0.06 m/s (measured) and 0.05 m/s (modelled). A review of the measured data and model results suggests that the raw water intake is situated in a region characterized by complex hydrodynamic patterns such as eddy currents driven by changes in wind conditions. Figure 2.2 compares the measured and modelled current directions at the surface and at 10m below the surface.

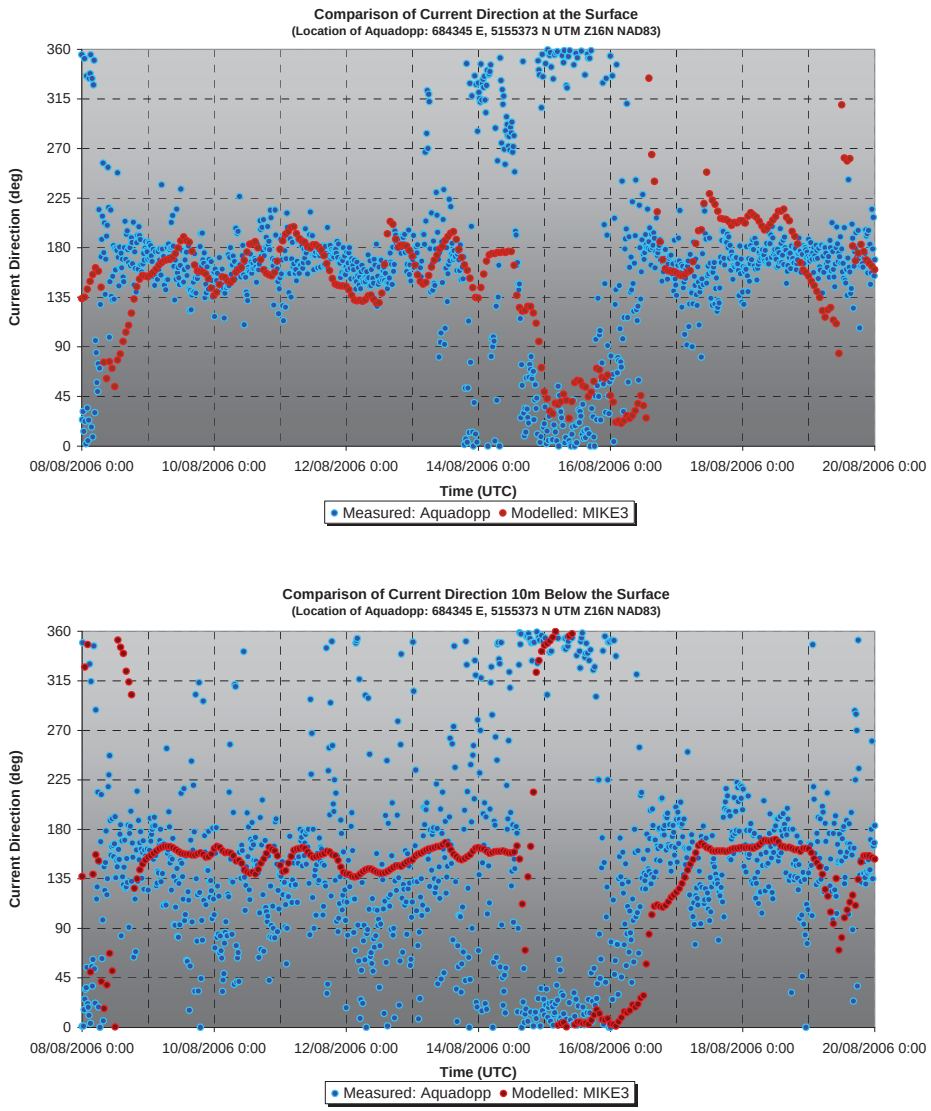


Figure 2.2 Comparison of Measured and Modelled Current Direction at the Surface and 10m Below the Surface (directions to)

The MIKE3 model captured the transition in current direction from south to north that occurred between August 14 and August 16, 2006 at the surface and at a depth of 10m. More variability in direction was observed in the measured data at a depth of 10m, however a north-south trend is still evident. Interestingly, the northerly current patterns that were measured by the Aquadopp and predicted by the numerical model occurred during a strong and relatively consistent wind from the WNW/NW as shown in Figure 2.3. The wind conditions shown in Figure 2.3 were extracted from the spatial wind fields used by NOAA in the LSOFS at a location near the raw water intake and Nortek Aquadopp instrument. A comparison with measured wind conditions at the Sault Ste Marie Airport showed very similar results.

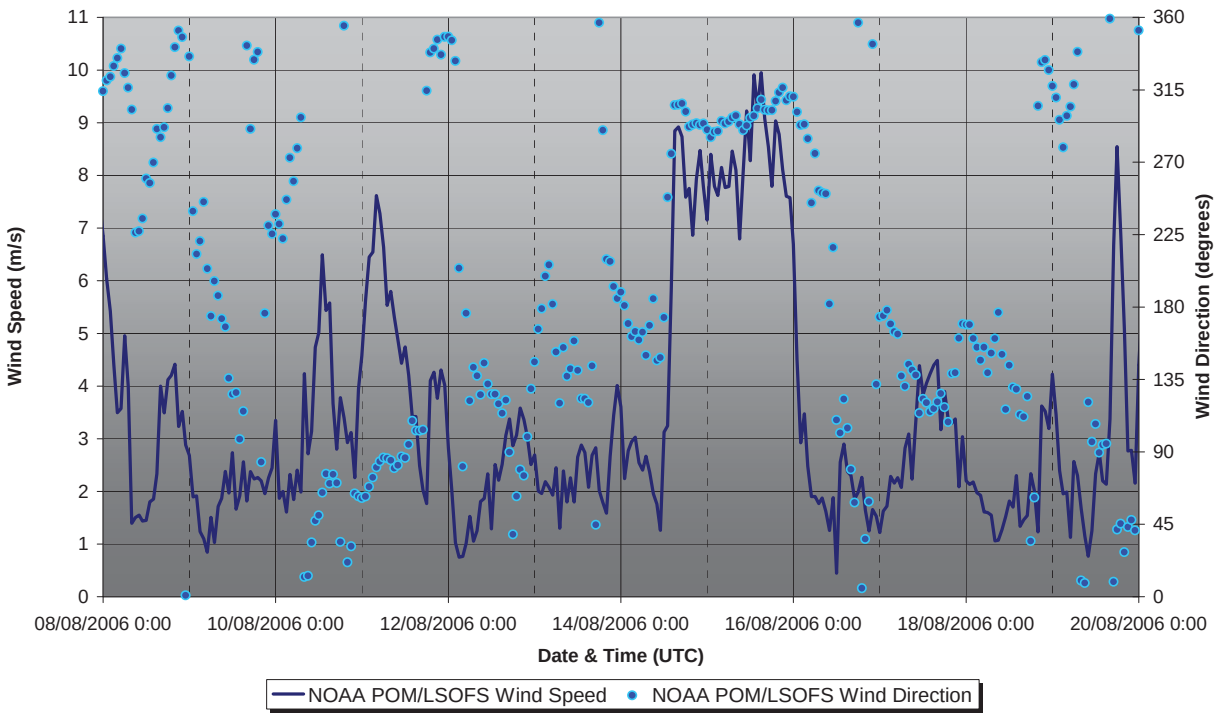


Figure 2.3 NOAA LSOFS Wind Conditions offshore of Gros Cap near the Water Intake (directions from)

A 2D map of the currents around the intake on August 15, 2006 at 08:00 is presented in Figure 2.4. The current patterns shown in Figure 2.4 are driven by a WNW/NW wind condition. The currents divide north and south on the shore side of the intake. A weak eddy current is visible to the southeast of the intake; other gyres were observed at various locations and times throughout the model simulation at locations near the intake suggesting very dynamic and complex hydrodynamic conditions.

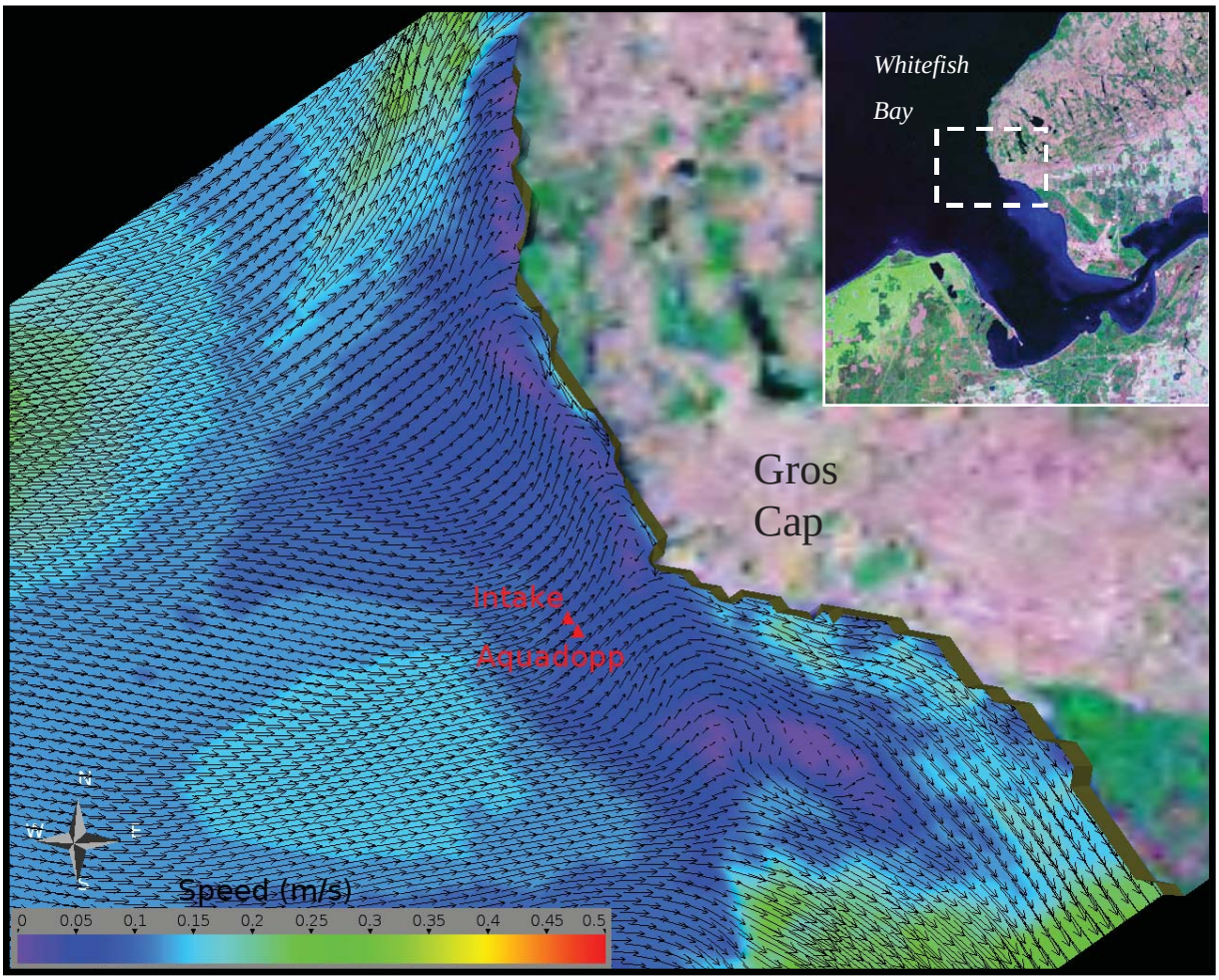
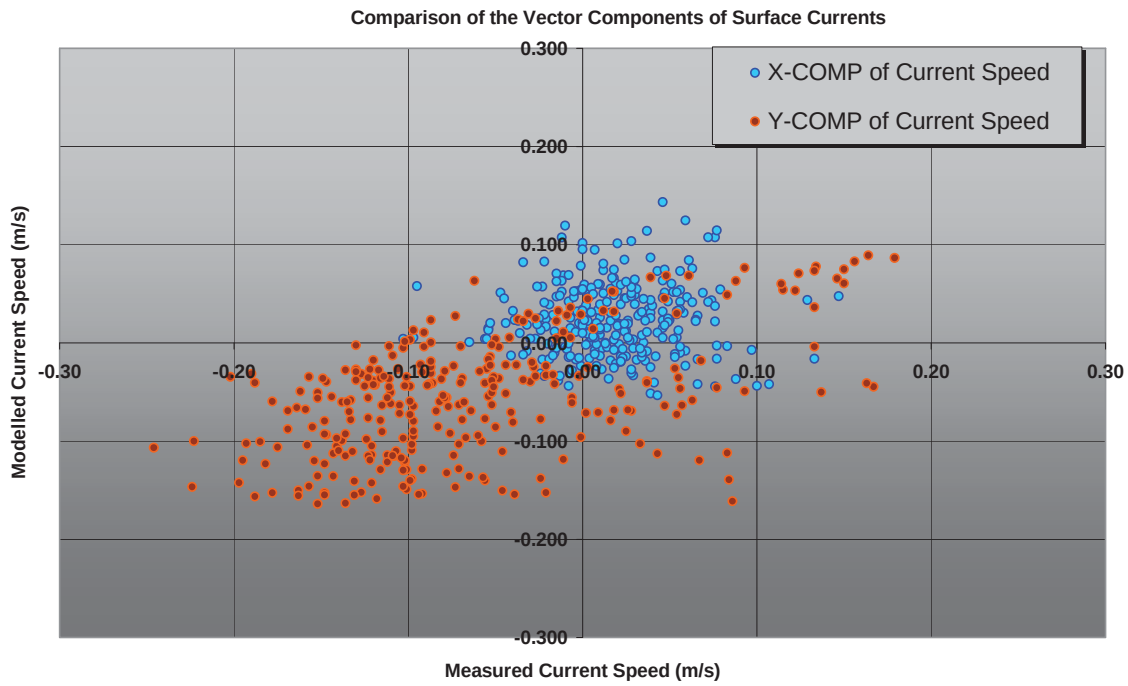


Figure 2.4 2D Map of Predicted Currents from MIKE3 Model for August 15, 2006 08:00 (directions to)

A comparison of the vector components of current speeds at the surface and at 10m below the water surface from August 8, 2006 to August 20, 2006 is presented in Figure 2.5. A review of the Y-component (north-south) of the surface currents showed currents to be predominately to the south. A stronger relationship was evident between the measured data and modelled results in the north-south direction compared to the east-west direction (X-component) as the correlation coefficients were determined to be 0.54 and 0.04, respectively. Similar trends were observed 10 m below the water surface as the dominant flow directions are to the south and east. The correlation coefficients were determined to be 0.49 for the Y-component and 0.14 for the X-component. It is noted that it is generally difficult to get good correlation between measured and modeled currents in a lake environment, due to phase lags and scatter in the measured data. The numerical model does not account for wave induced currents, which would have a more significant effect in shallow water (less than 10 m depth).



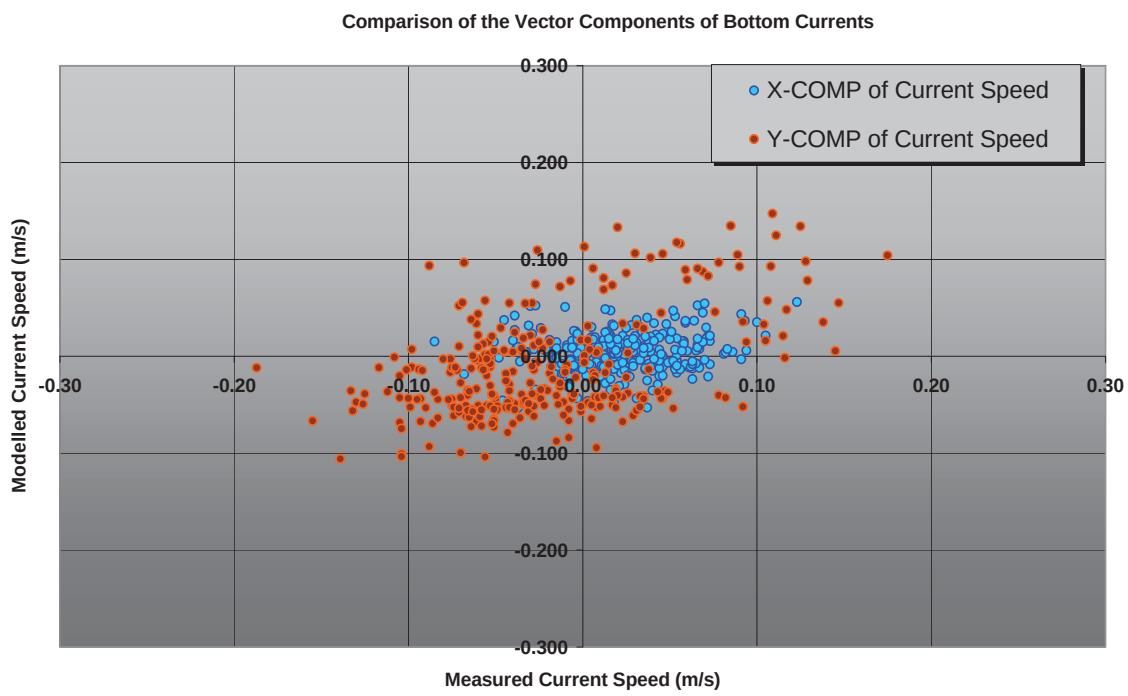


Figure 2.5 Comparison of the Vector Components of Current Speed

2.4 Model Runs in Support of IPZ-2 Delineation

An extreme value analysis was undertaken to define directional wind speeds for varying return periods. The model was then run for a range of conditions as described below, and the results were used to delineate the IPZ-2.

2.4.1 Extreme Value Analysis to Define Matrix Runs

An extreme value analysis was undertaken to define extreme wind events for varying return periods, for use in the numerical model runs, to delineate the IPZ-2. Hourly wind data were obtained from the Atmospheric Environment Services (AES), which is a division of Environment Canada, for the Sault Ste Marie Airport (ID: 6057592) for the period 1971 to 2007. This data set is described in the original report for this study (Baird, 2008).

A directional Peaks-Over-Threshold (POT) analysis was undertaken to define extreme wind events for varying return periods, for the full range of directions on an 8-point compass. The results of the POT analysis are summarized in Table 2.2 and Figure 2.6. The analysis indicates that the most severe events are from the west, northwest and southwest. The 10-year return period winds were used as input to the MIKE3 model, as described in Section 2.4.2.

Table 2.2 Wind Analysis by Direction (m/s)
(AES Station 6057592, 10m Elevation, 1971 to 2007)

	N	NE	E	SE	S	SW	W	NW
1.5 yr Return Period	12.0	9.6	11.8	10.5	9.4	13.6	16.4	17.4
2 yr Return Period	12.5	10.0	12.1	10.9	9.7	14.1	16.8	17.8
5 yr Return Period	13.9	11.4	13.1	11.9	11.0	15.5	18.1	19.1
10 yr Return Period	15.0	12.6	13.8	12.6	12.1	16.5	19.2	19.9
20 yr Return Period	16.1	14.0	14.5	13.3	13.4	17.4	20.3	20.8
25 yr Return Period	16.4	14.5	14.7	13.5	13.9	17.7	20.7	21.0
50 yr Return Period	17.5	16.1	15.4	14.1	15.6	18.6	21.9	21.8
100 yr Return Period	18.6	18.0	16.1	14.7	17.7	19.4	23.2	22.6

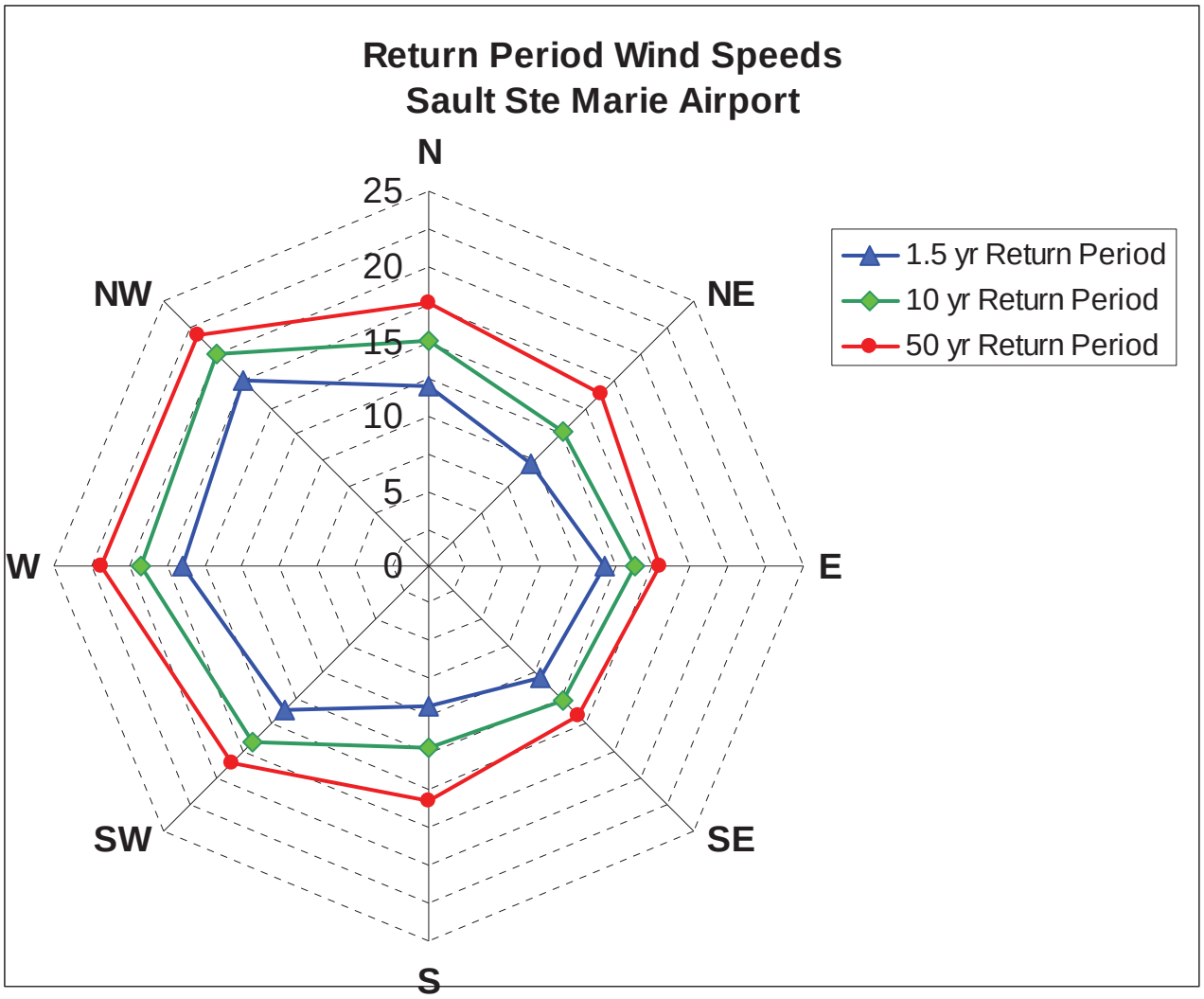


Figure 2.6 Wind Rose of Speed as a Function of Return Period and by Direction

2.4.2 Matrix of Runs

A matrix of runs was undertaken using the statistical wind conditions described in Section 2.4.1. The model was run for the 10-year return period winds for directions N clockwise through NW, at 45 degree intervals. Although a specific return period event is not specified in MOE (2009a), for delineating the in-water IPZ-2, several source protection regions that we are aware of have adopted the 10 year return period event, and this seems reasonable. The directional wind speeds and return periods are listed in Table 2.2. Flow in the St. Marys River was defined as 3465 m^3/s (NOAA-GLERL), with a constant water level of 0.96 m above Chart Datum representing the 10-year water level at Gros Cap (OMNR, 1989). The model was run until it reached steady state, for each direction (in each case this occurred within 24 hours). Output from the model runs is provided in Appendix A. The figures show the currents in the vicinity of the intake, for each of the eight wind directions modeled.

The strongest currents observed at the intake were from the south-west, north and west as speed ranged from 30 to 40 cm/s. The lowest current speeds predicted by the numerical model occurred under a northwest wind conditions as the intake was subjected to an eddy current. A review of the measured data in August 2006 showed that variations in current directions (moving from a predominately south direction to north) occurred under strong northwesterly winds. The measured data collected in September showed much more variability suggesting that eddy patterns do occur around the intake, as predicted by the model.

2.4.3 Reverse Particle Tracking

Reverse particle tracking was used to delineate the in-lake IPZ-2. The output from the MIKE3 model runs were used as input to SDA for the reverse particle tracking. Using a Lagrangian approach with a Gaussian Random Walk Theory to define dispersion, neutrally buoyant particles were introduced. Particles were introduced at the surface and near the lakebed. The model was run in reverse mode with the particles tracking the paths by which the currents would have transported neutrally buoyant particles to the intake over a 3 hour travel time. One particle was released each second. The pathways are indicated by the for the surface and bottom release particles, and for both 2 hour and 3 hour durations in Figure 2.7. Although the intake is located near the lakebed, the particles released at both depths were considered in delineating the IPZ-2. The most conservative results were used to delineate the IPZ-2. This is a more conservative approach since the currents at the surface are larger than the near lakebed currents.

Figure 2.8 shows the travel distance contours for 1 hour intervals from 1 hour to 3 hours. The lines delineate the time that it would take a particle to reach the intake from the specified contour lines. The travel distance contours are based on the particles released at the surface.

2.5 Model Limitations

It is important to understand the limitations of the modeling, as this provides a measure of the level of uncertainty, which is assigned to the IPZ delineation in Section 5. The key limitations of the modeling are as follows:

1. Current velocities predicted by the model were compared with measured ADCP data collected by Baird in 2006. Calibration of the model was not undertaken due to funding limitations. The objective of the comparison was to provide a measure of the level of uncertainty in the model. A comparison of the vector components of current speeds at the surface and at 10m below the water surface from August 8, 2006 to August 20, 2006 was undertaken. The correlation coefficients for the Y-component (north-south) and X-component (east-west) at the surface were 0.54 and 0.04, respectively. Similar trends were observed 10 m below the water surface where the correlation coefficients were determined to be 0.49 for the Y-component and 0.14 for the X-component. It is noted that it is generally difficult to get good correlation between measured and modeled currents in a lake environment, due to phase lags and scatter in the measured data. However, confidence in the model would improve if the model were calibrated.

2. For the model runs used to delineate the IPZ-2, neutrally buoyant particles were released at the surface and at the lakebed. Particles were free to move through the water column. The intake is located near the lakebed. The particles released at the surface (where current velocities are higher) resulted in a larger IPZ-2, and those results were used to delineate the IPZ-2. However, considering the level of agreement between measured data and modeled output as noted above, this is the recommended approach.

3. In this phase, the model was run for a matrix of wind conditions using the 10-year return period wind from eight directions. In each case, the model was run to steady state. In reality, running the model to steady state is not a realistic condition and the flow velocities produced using a constant wind in a "steady state" model application might be expected to over-predict the currents, when compared to those predicted using event based winds (i.e. actual measured winds).

4. The model is not a full lake model. It includes Whitefish Bay and a section of the St. Mary's River. This means that the model has an open boundary at the north end of Whitefish Bay. The model domain was selected considering the location of the intake and computation time required for model runs. Some processes are affected by the fact that the model does not include the entire lake, including its ability to model lakewide circulation currents and surge.

5. Wave-induced currents were not considered in the modeling used to delineate the IPZ-2. The effect of the wave induced currents would be more significant for intakes located in shallow water. The Gros Cap intake is located in 15 m depth (see Baird, 2008). However, currents near shore, within the IPZ-2 would be affected by waves.

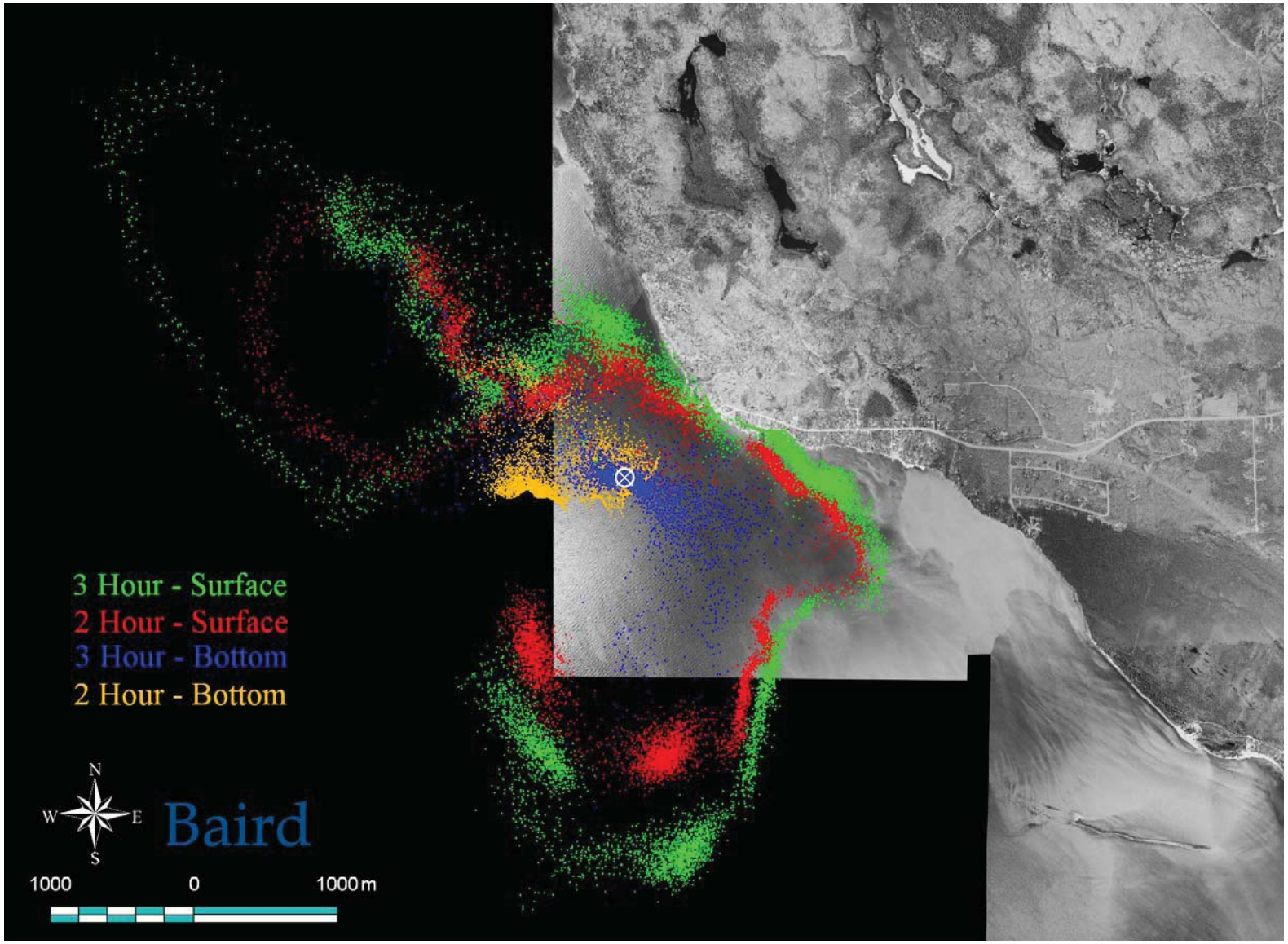


Figure 2.7 Reverse Particle Tracking for IPZ-2 Delineation

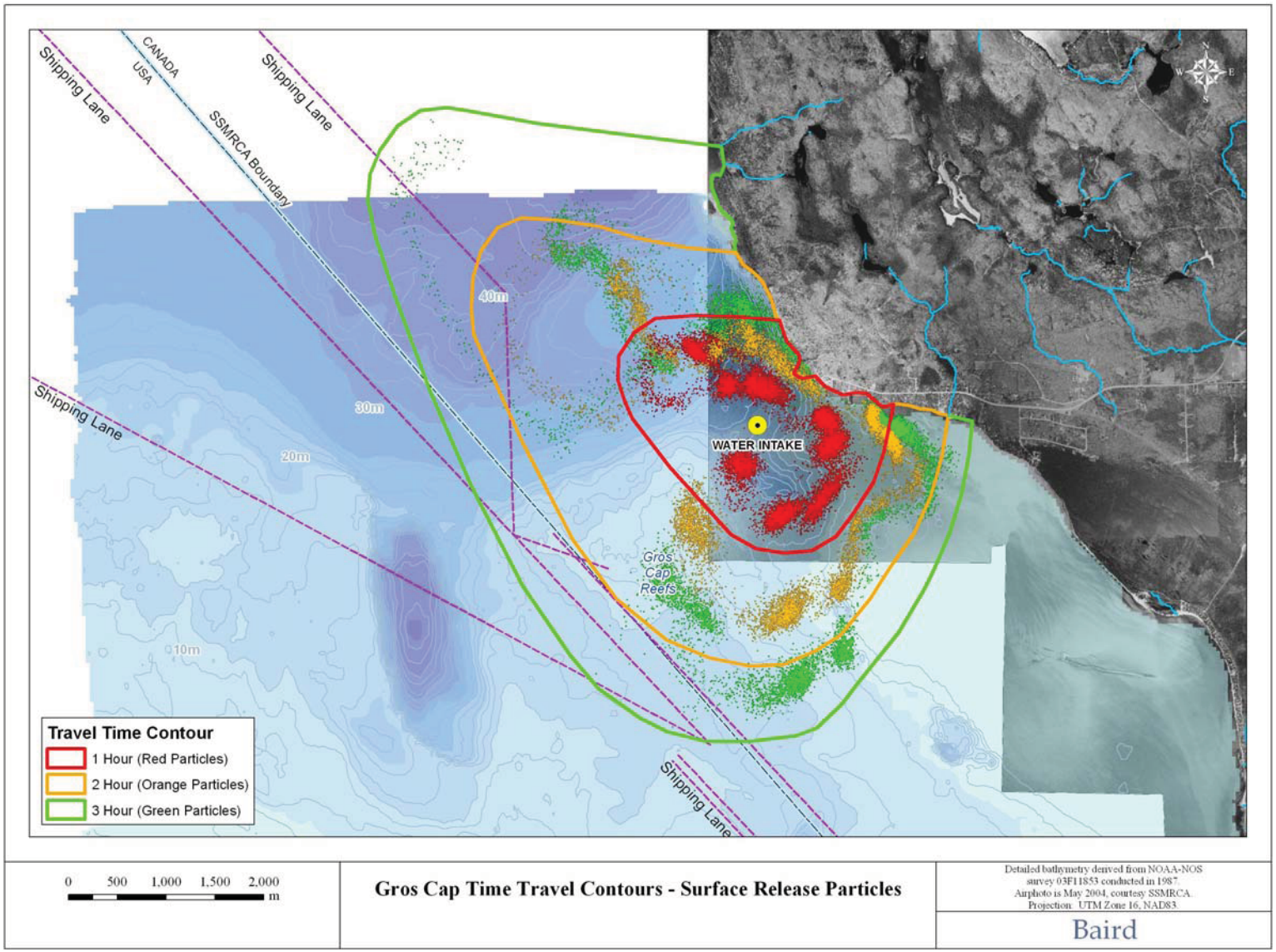


Figure 2.8 Travel Time Contours based on Particles Released at the Surface

3.0 IPZ DELINIATION

The Gros Cap intake is located in Lake Superior and it is classified as a Type A intake [Rule 55(1); MOE, 2009a].

The Technical Rules require that intake protection zones reflecting the intake vulnerability be delineated around the intake. In each case, three intake protection zones are delineated: IPZ-1 (the area closest to the intake); IPZ-2 (a zone delineated based on the time required to shut down the WTP in the event of a spill); and IPZ-3 (the furthest zone from which a spill could potentially reach the intake and compromise the water supply). Delineation of the IPZ-3 will be described in an addendum to this report.

The Technical Rules (MOE, 2009a) that relate to the IPZ-1 and IPZ-2 delineations described in this report include:

- Rule 55 — Classification of intake type
- Rules 56 and 57 — Identification of surface water bodies
- Rule 58 — Direction for intake protection zones
- Rule 61 — IPZ-1 delineation
- Rules 65 and 66 — IPZ-2 delineation
- Rules 72 to 75 — Delineation of transport pathways

Delineation of the IPZ-1 and IPZ-2 are described in the following sections. The geospatial datasets (IPZ-1 and IPZ-2) were developed according to the rules identified in the MOE (2009b). These datasets are depicted in figures and graphics using the symbology defined in MNR (2009).

3.1 Delineation of IPZ-1

The IPZ-1 is the area immediately around the intake crib, defined for Type A intakes as a 1 km radius centered on the crib of the intake [Rule 61-1; MOE, 2009a]. Due to its close proximity to the intake, this area is considered the most vulnerable to any contaminant of concern that may be released in this zone. Any contaminants released in this zone will have limited dilution prior to reaching the intake and will have the highest potential to impact water quality.

If the IPZ-1 includes any land, the IPZ-1 shall include a setback on the land that is the greater of the area that drains into the surface water body measured from the high water mark, not exceeding 120 m; and if a Conservation Authority Regulation Limit is in effect, the area of land that is within the Conservation Authority Regulation Limit [Rule 61-2a and 61-2b; MOE, 2009a].

No Regulation Limit meeting MOE's requirements has been developed for the study area and the default value of 120 m from the HWM was therefore applied [Rule 61(2)(a); MOE, 2009a]. Although MOE (2009a) does not provide guidance on the specific definition of high water mark (which is open to interpretation), the more recent MOE Liaison Officer Program Update (MOE, 2009c) defines the high water mark for water bodies where a long term water level record exists, as

the 80th percentile for the month within which the highest water level occurs. A value of 183.69 m IGLD 1985 is defined for Lake Superior (DFO, 2004). The vertical datum for the DEM provided by SSMRCA is not specified and is unknown. To complete the delineation, it was assumed that the vertical datum for the DEM is IGLD 1985. This must be confirmed. The on land limit of the IPZ-1 is shown in Figure 3.1.

3.2 Delineation of IPZ-2

The IPZ-2 acts as a secondary protective zone around the IPZ-1. In the event of a spill or acute situation, the treatment facility will have minimal time to respond. Contaminants released in this zone have a high chance of reaching the intake quickly and will have limited time to be diluted prior to reaching the intake (MOE, 2006a).

The IPZ-2 is defined based on the area that may contribute water to the intake where the time of travel to the intake is equal to or less than the time that is sufficient to allow the operator of the system to respond to an adverse condition in the quality of the surface water [Rule 65; MOE, 2009a]. Where the time that is sufficient to allow the operator to respond to an adverse condition in the quality of the surface water is less than two hours, the time of travel to the intake shall be deemed to be two hours [Rule 66; MOE, 2009a]. A 3-hour response time has been used on this project based on the operator survey described in Baird (2008). The operator indicated a 1 hour maximum time for the MOE Spills Action Centre (SAC) to inform the PUC operator if a spill is called into their centre, plus an allowance of 2 hours to shut the WTP down upon notification of a spill.

The IPZ-2 is comprised of four areas: the area within each surface water body (in this case, the lake which the intake is located in and an extension up tributaries flowing into the IPZ-2); the area within the storm sewershed of each storm sewer that discharges into the surface water body; a setback inland along the abutted land; and an extension to include areas that contribute water to the IPZ-2 through transport pathways [Rules 65 and 72-74; MOE, 2009a].

Delineation of each of the areas that comprise the IPZ-2 is described in this section. Storm sewershed mapping was not available and storm sewersheds were therefore not included in the IPZ-2 delineation.

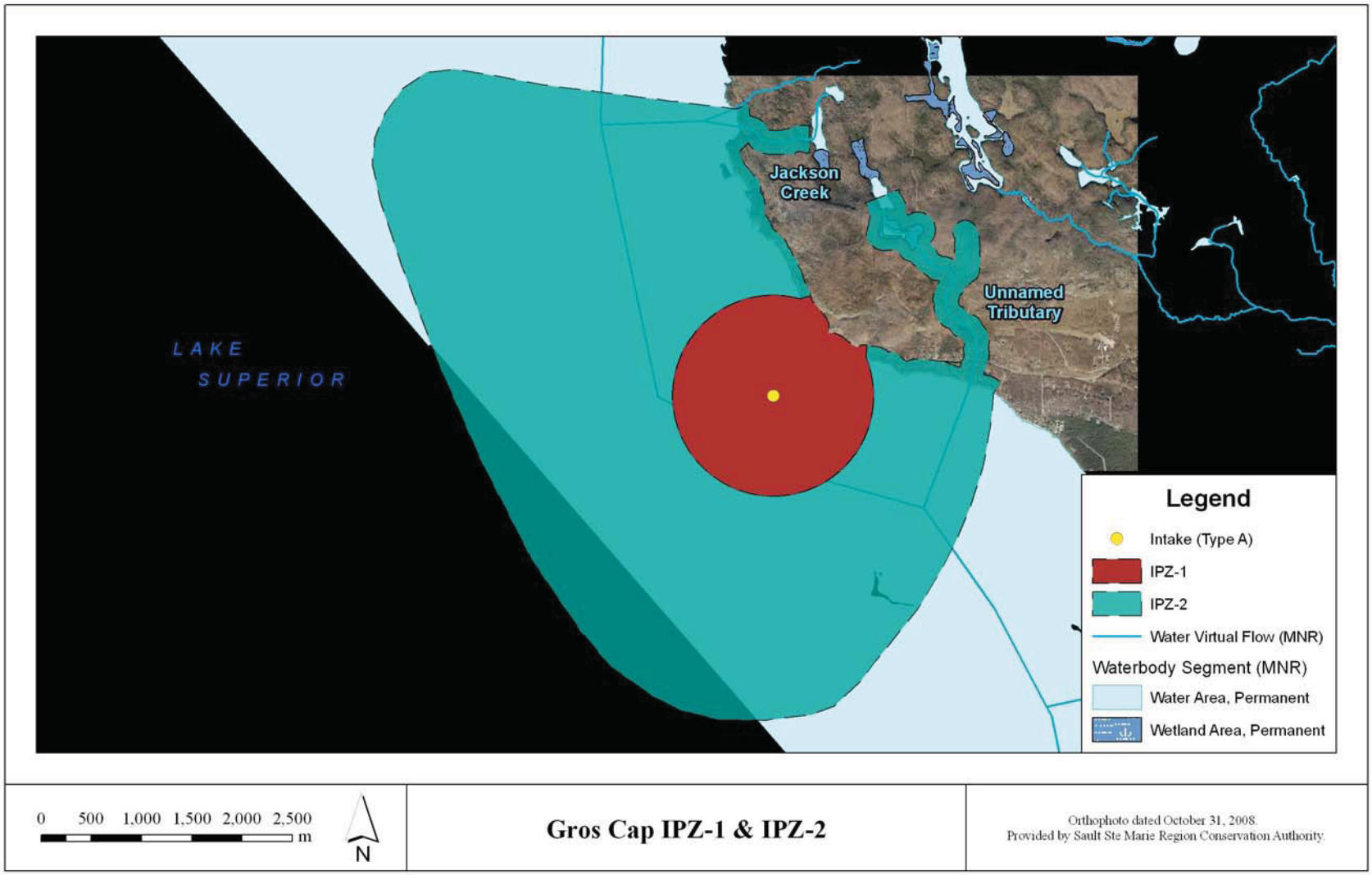


Figure 3.1 IPZ-1 and IPZ-2 for Gros Cap Intake

3.2.1 In-lake IPZ-2

The in-lake IPZ-2 is defined as the area within a surface water body that may contribute water to the intake where the time of travel to the intake is equal to or less than the time that is sufficient to allow the operator of the system to respond to an adverse condition in the quality of the surface water [Rule 65; MOE, 2009a]. There is no specific guidance in MOE (2009a) regarding the return periods to be used to determine the current velocities used to define the in-lake IPZ-2. For Great Lakes intakes, Previous guidance from MOE recommended using the average longshore current velocity during high wind and current period. This is not a specific event with a defined return period. The approach used in this study is based on the numerical modelling described in Section 2. The reverse particle tracking model was run with the 10-year return period winds for directions N clockwise through NW (at 45 degree intervals) as described in Section 2. The model was run until steady state was reached, for each direction (in each case this occurred within 24 hours). This provides a scientifically defensible definition of the hydrodynamic conditions used to delineate the IPZ-2. The limits of the 3-hour travel time used to delineate the IPZ-2 are shown in Figure 3.1. The IPZ-2 crosses into the International Shipping Lane.

3.2.2 Upstream Limit of IPZ-2

Where tributaries flowing into the lake lie within the IPZ-2, the IPZ-2 will extend up the tributaries a distance calculated as:

$$D = (t_s - t_{is})*v$$

where D = travel distance; ts = shutdown time; tis = travel time from the intake to shore, and v = stream flow velocity [Rule 65; MOE, 2009b]. The velocity was estimated based on the flow and tributary cross-section data collected in Phase 1 and described in Baird (2008).

There are two tributaries visible in the mapping, that flow into Lake Superior within the in-lake limits of the IPZ-2: Jackson Creek, and an un-named tributary east of the Gros Cap intake. The tributaries are identified in Figure 3.1. The calculation of the upstream limit of the IPZ-2 is provided in Table 3.1. There is a third tributary immediately north of Jackson Creek that lies on the 3 hour travel contour, and the IPZ-2 does not therefore extend up this tributary.

Table 3.1
Values used to Calculate Upstream Limit of IPZ-2 in Tributaries

Watercourse	Measurement Point	Bankfull Hydraulic Radius (m)	Slope	Manning Roughness	Estimated Velocity at Bankfull (m/s)	Travel Time (min)	Estimated Travel Distance (km)
Jackson Creek	N/A	0.67	0.05	0.04	4.27	15	3.8
Un-named Tributary	SW0012	0.30	0.03	0.037	2.21	60	8.0

The estimated travel time from the Gros Cap intake to shore is 2 hours 45 minutes. The remaining travel time is therefore 15 minutes. The IPZ-2 extends 710 m upstream in Jackson Creek, to where it connects with a small waterbody. With an estimated bankfull velocity of 4.27 m/s, the travel time upstream is 2.8 minutes to the lake (therefore, 12.2 minutes of travel time remain). We are not aware of any current measurements from the small waterbody upstream of Jackson Creek. Analysis of the 2008-Oct-31 orthophoto (provided by SSMRCA) reveals that the water body is an emergent wetland. A flow velocity of 0.128 m/s was used based on Stern et al. (2001). This was the maximum flow velocity for emergent wetlands measured by the author. A travel distance of 94 m (12.2 min*60 s*0.128 m/s) was calculated within the wetland. Therefore, the total travel distance from the mouth of Jackson Creek is 804 m as shown in detail in Figure 3.2.

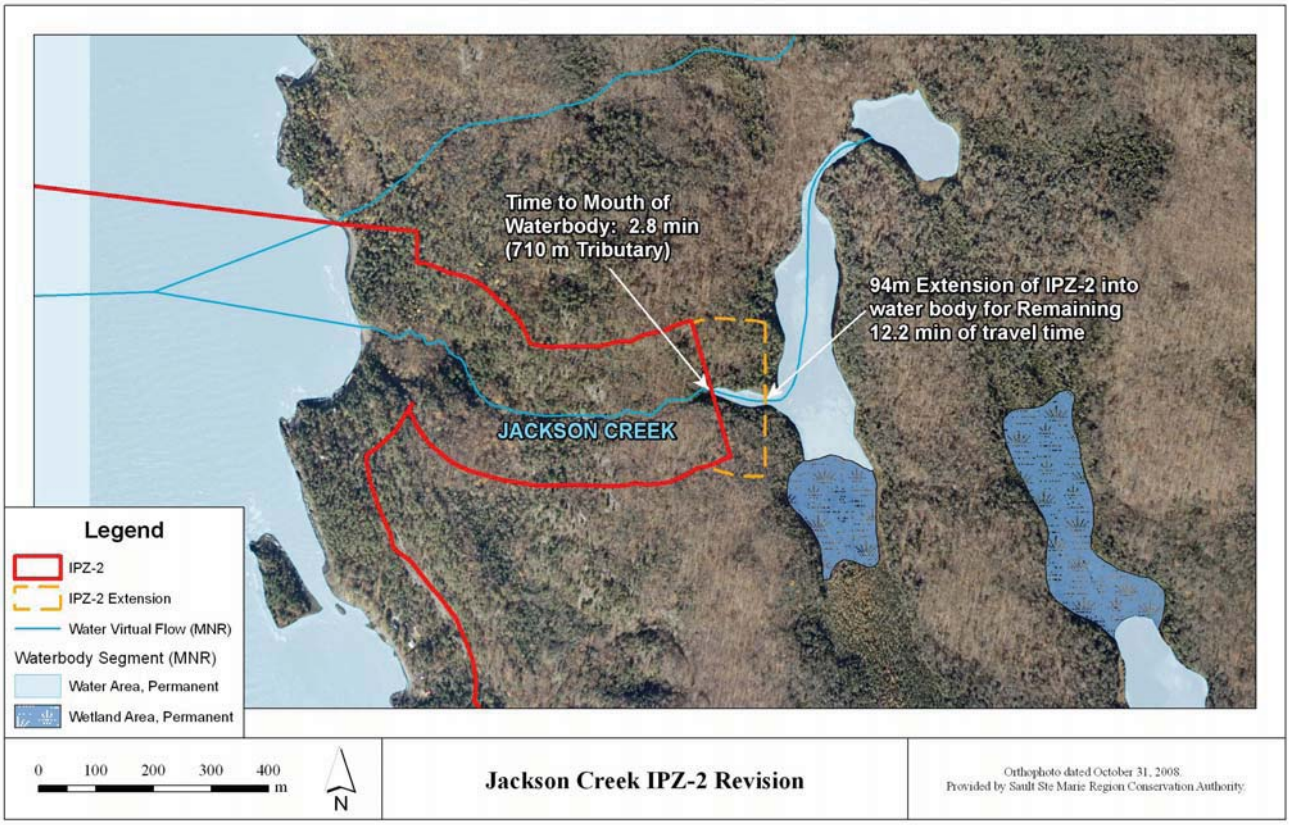


Figure 3.2 Detail showing IZP-2 Extension in Jackson Creek and Upstream Waterbody

The un-named tributary is located 2 hours travel time from the Gros Cap intake. The remaining travel time is therefore 1 hour. The un-named tributary divides at the confluence of the east and west branches, approximately 1.29 km upstream of where it enters Lake Superior (see Figure 3.3). The east branch terminates 0.59 km upstream of the confluence. The west branch flows from a series of wetlands and lakes located 0.6 km upstream of the confluence. With an estimated bankfull velocity of 2.10 m/s, the travel time upstream along the un-named tributary and west branch is 15.0 minutes to the wetland on the east side of the lake (therefore, 45.0 minutes of travel time remain). Analysis of the 2008-Oct-31 orthophoto indicates that the wetland contains emergent vegetation. Using a velocity of 0.128 m/s for emergent wetlands (Stern et al., 2001) and a GIS-measured wetland length of 148 m, travel time was estimated to be 19.3 min (148 m/0.128 m/s/60

s). Therefore, 25.7 minutes of travel time remain. The velocity though the lake was estimated to be 0.58 m/s, which is 3% of the 10 year return period wind speed of 19.2 m/s for W to E direction. The lake was measured to have a length of 258 m. Travel time though the lake was determined to be 7.4 min (258 m/0.58 m/s / 60 s), therefore, 18.3 minutes of travel time remain. For the wetland on the west side of the lake, a velocity of 0.128 m/s was used (similar type to east side wetland). The wetland was measured in GIS to have a length of 111 m. Travel time though the wetland was estimated was determined to be 14.5 min (111 m /0.128 m/s /60 s), therefore, 3.8 minutes of travel time remain. Adjacent to the west-side wetland is a 56 m length of the west branch tributary. A bankfull velocity of 2.10 m/s was assumed for this segment of tributary. The travel time along this segment was estimated to be 0.5 minutes (56 m / 2.10 m/s / 60 s), therefore, approximately 3.3 minutes still remain. Upstream of the short tributary segment is a larger waterbody, with a measured length of approximately 325 m and a northwest orientation. The velocity though the lake was estimated to be 0.6 m/s, which is 3 % of the 10 year return period wind speed of 19.9 m/s for NW to SE direction. The travel distance in the lake is 119 m in the time remaining (3.3 min *60 s /0.6 m/s). The actual travel distance from the mouth of the Unnamed Tributary along the west branch is 2,582 m.

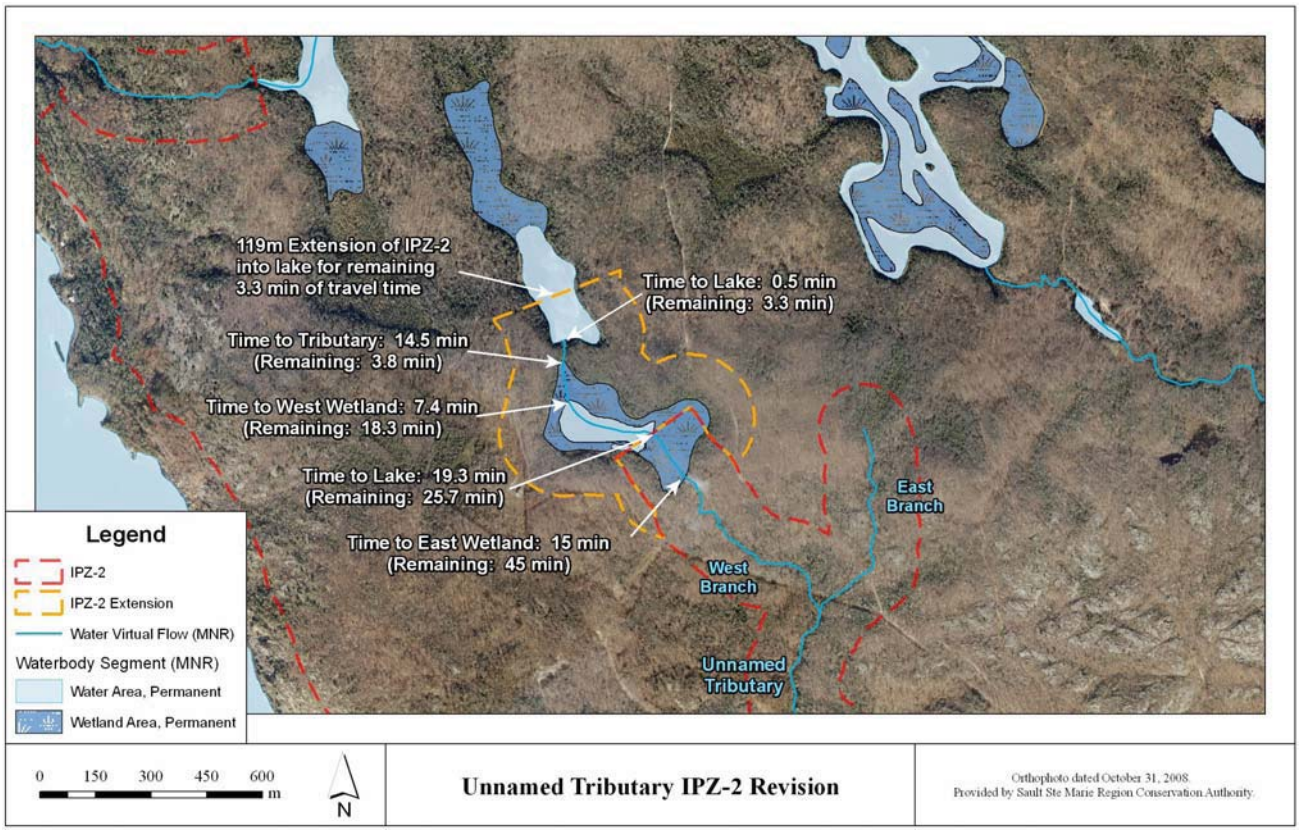


Figure 3.3 Detail showing IZP-2 Extension in Un-named Tributary and Upstream Wetland

It is important to recognize that the delineation of the IPZ-2 is based on a 3-hour travel time to the intake. There are a number of tributaries that lie beyond the 3-hour travel time that may potentially impact water quality at the intake if longer time periods are considered. These may be addressed in future phases as part of the IPZ-3.

3.2.3 Inland Extent of IPZ-2

Where the IPZ-2 abuts land, it includes a setback of not more than 120 m inland along the abutted land measured from the high water mark of the surface water body that encompasses the area where overland flow drains into the surface water body. If a Conservation Authority Regulation Limit is in effect in the IPZ-2, the IPZ-2 includes the area of land that is within the Conservation Authority Regulation Limit [Rule 65; MOE, 2009a). As discussed in Section 3.1, no Regulation Limit meeting MOE's requirements has been developed for the study area and the default value of 120 m from the HWM was therefore applied [Rule 61(2)(a); MOE, 2009a]. Although MOE (2009a) does not provide guidance on the specific definition of high water mark (which is open to interpretation), the more recent MOE Liaison Officer Program Update (MOE, 2009c) defines the high water mark for water bodies where a long term water level record exists, as the 80th percentile for the month within which the highest water level occurs. A value of 183.69 m IGLD 1985 is defined for Lake Superior (DFO, 2004). The vertical datum for the DEM provided by SSMRCA is not specified and is unknown. To complete the delineation, it was assumed that the vertical datum for the DEM is IGLD 1985. This must be confirmed. The inland limit of the IPZ-2 is shown in Figure 3.1.

3.2.4 Transport Pathways

Where an area that is an IPZ-2 includes a setback from a surface water body delineated in accordance with Rule 65(1) (MOE, 2009a), the area may be extended to include an area that contributes water to the IPZ-2 through a natural or anthropogenic transport pathway [Rule 72; MOE, 2009a]. The following factors are used to determine the extent to which the IPZ-2 shall be extended [Rule 73 (MOE, 2009b):

(1) The hydrological and hydrogeological conditions in the area where the transport pathway is located.

(2) Where a transport pathway is anthropogenic in origin, the type and design of the pathway.

(3) In respect of an IPZ-2, the time of travel for water to enter into and pass through the transport pathway.

Rule 74 states that a transport pathway that is part of an IPZ-2 shall not include an area of land or water that lies within an IPZ-1.

Transport pathways were included in the IPZ-2 delineations based on Rules 72 to 74. A complete description of the methodology, analysis and transport pathway delineation is provided in Appendix B.

4.0 VULNERABILITY ANALYSIS

The Technical Rules require that vulnerability scores be assigned to the vulnerable areas. The Technical Rules (MOE, 2009a) that relate to the vulnerability analyses undertaken for this study include:

- Rules 86 and 87 Vulnerability scores
- Rule 88 Area vulnerability factor for IPZ-1
- Rules 89 and 93 Area vulnerability factor for IPZ-2
- Rules 90 to 93 Area vulnerability factor for IPZ-3
- Rule 94 to 96 Source vulnerability factor

The recommendations for the vulnerability factors and scores are provided in this section.

4.1 Overview of Vulnerability Scoring

A vulnerability score is assigned to each IPZ-1 and IPZ-2 associated with a Type A intake [Rule 86; MOE, 2009a]. The vulnerability score ranks the relative vulnerability of the intake to contaminants. It considers the water body the intake is located in, the hydrological, land use and environmental characteristics of the watershed, the attributes of the intake (length, depth) and the history of water quality concerns. The vulnerability score (V) is defined in Rule 87 (MOE, 2009a):

$$V = B \times C$$

where V = vulnerability score;

B = area vulnerability factor; and

C = source vulnerability factor.

MOE (2009a) has defined acceptable ranges for the vulnerability factors for each IPZ. These vary with the intake type. The range for Type A intakes is listed in Table 4.1.

Table 4.1
Vulnerability Score Range for Type A Surface Water Intakes (MOE, 2009a)

Intake Type	Area Vulnerability Factor (B)			Source Vulnerability Factor (C)	Range of Vulnerability Score (V)		
	IPZ-1	IPZ-2	IPZ-3		IPZ-1	IPZ-2	IPZ-3
Type A	10	7 to 9	n/a	0.5 to 0.7	5 to 7	3.5 to 6.3	n/a

Note: Vulnerability scores are not calculated for the IPZ-3 for Type A intakes.

Source vulnerability factors and vulnerability scores were developed for the Gros Cap intake using the methodologies described below.

4.2 Area Vulnerability Factor

The IPZ-1 and IPZ-2 are assigned an area vulnerability factor (B), with the IPZs closest to the intake having the highest factor (Rules, 88 to 96; MOE, 2009a]. The acceptable values for the area vulnerability factors (B) are listed in Table 4.1. Rule 93 (MOE, 2009a) states that the area vulnerability factor shall be expressed as a whole number.

An IPZ-1 is assigned an area vulnerability factor of 10 due to its close proximity to the intake [Rule 88; MOE, 2009a).

An IPZ-2 is assigned an area vulnerability factor that is not less than 7 and not more than 9 based on the vulnerability of the area, where a higher factor corresponds to a higher vulnerability [Rule 89; MOE, 2009a]. The following factors are considered in selecting the area vulnerability factor for an IPZ-2 [Rule 92; MOE, 2009a]:

1) the percentage of the area of the IPZ-2 that is composed of land;
2) the land cover, soil type, permeability of the land and the slope of any setbacks; and
3) the hydrological and hydrogeological conditions in the area where the transport pathway is located;

The area vulnerability factor was calculated based on the criteria listed below, considering the three sub-factors listed above. Each of the sub-factors was given equal waiting.

Percentage of Area Composed of Land

The first area vulnerability sub-factor is determined based on the land-water ratio in the IPZ-2. This represents the percentage of the IPZ-2 that is composed of land [Rule 92 (1); MOE, 2009a]. It is assumed that a higher percentage of land is likely to indicate more land based activities and a higher vulnerability. As a result, a higher score is given when the percentage land is higher. Waterways inland of the shoreline were considered to be part of the land percentage. This analysis is based on the MNR Provincial Land Cover Database (PLC 2000). The area vulnerability factor was assigned as follows: low (<33 % land = 7), moderate (33-66 % land = 8) or high (>66 % land = 9) The Gros Cap IPZ-2 was 5% land and sub-factor of 7 was therefore assigned.

Land Characteristics

The land characteristics sub-factor requires an evaluation of the following factors: land cover, soil type, permeability and slope (Rule 92(2); MOE, 2009a]. Each of these characteristics was evaluated as follows, with equal weighting given to each factor:

a) U.S. Soil Conservation Service (SCS) Curve Number (CN), representing runoff generation potential based on land cover and soil permeability. The SCS CN was based on SSMRCA (2008). The SCS CN sub-factor was then assigned a value as

follows: low (<55 = 7); moderate (55-80 = 8); or high (>80 = 9). These divisions in general represent forested, rural/agricultural and urban land uses respectively, and sand, loam and clay soil types respectively. A low CN value indicates highly permeable soils and natural land uses, where rainfall (or a spilled contaminant) would readily soak into the ground. A high CN value reflects highly impermeable surface conditions that would generate considerable runoff. Note that the CN score was counted twice in the calculation of the vulnerability score associated with [Rule 92-2; MOE, 2009] because it represents both land cover and soil type. The mean CN in the Gros Cap IPZ-2 was 44, and a score of 7 was therefore assigned.

b) The permeability of the area was evaluated based on the impervious area within the landbase of the IPZ-2 expressed as a percentage of the total area of the landbase within the IPZ-2. The impervious area of the landbase was estimated from the MNR Provincial Land Cover Database (PLC 2000). A score was assigned as follows: 7 (0-20 %); 8 (20-50 %) or 9 (>50 %). These divisions broadly reflect the degree of development of an area between, undeveloped, rural development, and urban development. The percentage impervious of the Gros Cap was 16.6 %, and a score of 7 was therefore assigned.

c) The slope of the land was evaluated using the watershed relief-length ratio, a surrogate for watershed slope, indicative of the speed at which contaminants may be transported along a watercourse. This analysis was based on the data from the 20 m SSMRCA Digitial Elevation Model. The relief-length ratio essentially reflects the mean slope of a subwatershed. A score was assigned based on the following divisions: low (<2 % = 7); moderate (2-5 % = 8) and high (>5% = 9). The relief-length ratio of the Gros Cap IPZ-2 was 5.11 %, and a score of 9 was therefore assigned.

Hydrological and Hydrogeological Conditions

The hydrological and hydrogeological conditions in the area where the transport pathway is located [Rule 92(3); MOE, 2009a] were evaluated by considering the presence of transport pathways in the subwatershed, along with the drainage density of the subwatershed as follows:

a) Transport pathways were classified considering the presence and proximity of outfalls to the intake, in the IPZ-2. A score was assigned as follows: low or 7 (no outfalls in the IPZ-2); moderate or 8 (outfalls within 1-3 hours of the intake) and high or 9 (outfalls within 1 hour of the intake). This factor is an indicator of the degree of human modification to the hydrological regime within the IPZ-2. The travel times to outfalls were based on the travel time contours developed from the reverse particle tracking, and the locations of outfalls presented in Baird (2008). At Gros Cap, an outfall was located beyond the 1 hour contour, but within the 3 hour contour, and a score of 8 was therefore assigned.

b) Drainage density is the total length of streams in an area divided by the area. A higher density corresponds to a higher likelihood that a contaminant could be

transported to the intake through tributaries. Total stream length was measured along the water virtual flow polyline from the MNR LIO Water Virtual Flow - Seamless Provincial Dataset. The drainage density score was assigned as follows: low or 7 (<1 km/km^2); moderate or 8 (1-3 km/km^2) and high or 9 (>3 km/km^2). A higher value indicates a higher density of streams in a given area, and faster routing of water through the area, resulting in a hgiher vulnerability. Drainage density values vary with regional factors, including relief, geology, soils and climate. The divisions between the categories were loosely based on regional values for North America (e.g. Horton, 1932; Langbein, 1947). The drainage density in the Gros Cap IPZ-2 was 2.3 km/km^2, and a score of 8 was therefore assigned.

The area vulnerability factor was calculated by averaging the sub-factors discussed above. An equal weighting was given to each of the sub-factors. The derivation of the area vulnerability factor for the IPZ-2 is summarized in Table 4.2.

Table 4.2

Derivation of Area Vulnerability Factor for Gros Cap IPZ-2

Sub-factor and Rule	**Criterion**	**Score**	**Rating**			**Sub-factor Score**
			Low (7)	**Moderate (8)**	**High (9)**	
Percentage Land 92(1)	**Land-Water Ratio %**	5	**<33**	33-66	>66	7
Land Characteristics 92(2)	**SCS CN – Count Twice!**	44	**<55**	55-80	>80	(7+7+7+9)/4=7.5
	% Imperviousness (Permeability)	16.6	**0-20**	20-50	>50	
	Slope %	5.1	<2	2-5	**>5**	
Hydrological & Hydrogeological 92(3)	**Outfalls in Proximity**	Intake within 1-3 hours of intake	No intakes within IPZ-2	**Intake within 1-3 hours of intake**	Intake within 1 hour of intake	(8+8)/2=8
	Drainage Density (km/km^2)	2.3	<1	**1-3**	>3	
Area Vulnerability Factor[1]						(7+7.5+8)/3=7.5 **Rounded to 8**

[1] Area Vulnerability Factor must be an integer and was therefore rounded to nearest integer.

4.3 Source Vulnerability Factor

A source vulnerability factor (C) is assigned to each surface water intake [Rules 94 to 96; MOE, 2009a]. The acceptable range for the source vulnerability factor for Type A intakes is provided in Table 4.1. A source vulnerability factor may be expressed to one decimal place [Rule 96; MOE, 2009a]. The following factors are considered in determining the source vulnerability factor [Rule 95; MOE, 2009b]:

1) The depth of the intake from the top of the water surface.;

2) The distance of the intake from land.

3) The history of water quality concerns at the surface water intake.

Specific guidance on assigning source vulnerability factors based on the considerations listed above is not provided in MOE (2009a). In the interest of providing a level of consistency, the intake and vulnerability categories developed by the Michigan Department of Environmental Quality (MDEQ) for the Michigan source water assessment program were used as a guide (see Table 4.3). The first three rows in Table 4.3 were taken directly from MDEQ (2004), while the bottom row lists the corresponding MOE source vulnerability factor proposed for use on this project.

Table 4.3
Intake Vulnerability Criteria based on Intake Distance from Shore and Depth (adapted from MDEQ, 2004)

Category[1]	Nearshore-Shallow Water	Nearshore-Deep Water	Offshore-Shallow Water	Offshore-Deep Water
Parameters[1]	<300 m offshore <6 m depth	<300 m offshore ≥6 m depth	≥300 m offshore <6 m depth	≥300 m offshore ≥6 m depth
Vulnerability [1] (MDEQ)	High	High to Moderate	High to Moderate	Moderate
Recommended Factor (C) for Type A Intakes	0.7	0.6	0.6	0.5

[1]Category, parameters and vulnerability based on MDEQ (2004).

A lower value within this range is appropriate for intakes located in deeper water, further from shore, and where there are no drinking water issues. If an issue were identified, the source vulnerability factor would be increased from the value determined from Table 4.3, taking into consideration the severity of the threat. The source vulnerability factor must remain within the defined limits as listed in Table 4.1.

The Gros Cap intake is a Type A intake. It is located 830 m from shore, in approximately 15 m water depth (below Chart Datum). The intake is located 2 m above the lakebed, or 13 m below the water surface (Baird, 2008). The WTP operator listed only low level concerns in the interview undertaken during Phase 1 of this study (Baird, 2008). The analysis of limited water quality data did not identify any concerns. A source vulnerability factor (C) of 0.5 is therefore recommended, based on Table 4.3.

4.4 Vulnerability Scores

The vulnerability scores for the Gros Cap intake, calculated with the equation presented in Section 4.1 (V=BxC) and using values determined in Sections 4.2 and 4.3 are summarized in Table 4.4.

Table 4.4
Summary of Vulnerability Scores for Gros Cap

Intake Type	Area Vulnerability Factor (B)		Source Vulnernability Factor (C)	Vulnerability Score (V)	
	IPZ-1	IPZ-2		IPZ-1	IPZ-2
Great Lakes	10	8	0.5	5	4

5.0 LEVEL OF UNCERTAINTY

An analysis of the uncertainty, characterized as "high" or "low" is required in respect of: the delineation of surface water intake protection zones; and the assessment of vulnerability of surface water protection zones [Rule 13; MOE, 2009a]. The factors to be considered in this analysis include [Rule 14; MOE, 2009a]:

1. Distribution, variability, quality and relevance of data;

2. Ability of models to predict the processes;

3. Quality assurance and quality control procedures applied;

4. Extent and level of calibration and validation achieved for model used; and

5. For vulnerability factors, the accuracy to which the area and source vulnerability factors effectively assess the relative vulnerability of the hydrological features.

An uncertainty factor of "high" or "low" is then to be assigned to the vulnerable areas delineated; and the vulnerability scores.

5.1 Data Quality and Gaps

Data gaps and data quality issues identified during the study are listed below:

1. Limited water quality data was available to assess the raw water quality at the WTP. This was a consideration in evaluating the source vulnerability factor. Regular monitoring of the full range of parameters is recommended.

2. The onland extent of the IPZ-1 and IPZ-2 is measured as a setback from the HWM. The DEM provided by SSMRCA for use on this project was not referenced to a vertical datum. It was assumed that the vertical datum is IGLD 1985, however this must be confirmed. The inland extent of the IPZ-1 and IPZ-2 may have to be adjusted if the vertical datum differs from that assumed.

3. Sewershed mapping was not available and could not therefore be used to delineate this portion of the IPZ-2.

4. Tributary flow data was not available for the small tributaries in the IPZ-2s and velocities were therefore estimated. Actual flow data and ground measurements of tributary cross-sections extending up the tributaries would be required to better estimate the extent of the IPZ-2s up tributaries.

5. Flow velocities in the small inland lakes and wetlands were assumed.

6. Estimates and assumptions were required to develop the transport pathways for the IPZ-2 delineations. The data gaps and assumptions are listed in Appendix B.

5.2 Uncertainty in Modeling

The MIKE3 model was used to evaluate current velocities in the vicinity of the intake. The current velocities were then used to delineate the in-lake IPZ-2. A model is a tool that is used to improve our understanding of the physical processes. It is important to understand the model limitations, as well as the limitations of the application, that is how the model was setup, the data that was used as input to the model, the model runs undertaken, and the interpretation of the results. The limitations of the MIKE3 model used in this study are described in Section 2.5.

5.3 Quality Assurance/Quality Control

Baird has an established *Project Quality Control Program (QCP),* which was followed on the project. The QCP includes:

- Preparation of the Project Control Plan (PCP);
- Identification of the Project Manager (PM), Project Team (PT), Quality Control Reviewers (QCRs) and Quality Assurance Manager (QAM);
- Schedule and Budget;
- Description of tasks, project phases and/or deliverables to be reviewed;
- Identification of checklists to be utilized during reviews;
- Discussion of Quality Assurance procedures to be used during the project life cycle.

5.4 Model Calibration and Validation

Current data were measured with an Aquadopp ADCP from July to October 2006. The modeled currents were compared with the ADCP data, to provide a measure of the model's ability to capture general trends in lake hydrodynamics, with particular attention to extreme wind events, as extreme events were used to delineate the IPZ-2. Although recommended, funding was not available for model calibration in this study. The results of the comparison of measured data and model results are presented in Section 2.3.

5.5 Area and Source Vulnerability Factors

The factors considered in assigning the area vulnerability factors include: the percentage of the area of the IPZ-2; the land cover and soil type (relative permeability) of the land and the slope of any subwatersheds; and the hydrological and hydrogeological conditions in the area that contributes water to the area through transport pathways. The data used to evaluate the area vulnerability factors are discussed in Section 4.2.

There is a level of uncertainty associated with the SCS Curve No., which was estimated from datasets provided by SSMRCA (2008). The uncertainty arises from the fact that the SCS Curve No. is a relativistic estimate of the ability of an area to generate surface runoff, based primarily on land cover and soil hydrologic characterization. There is also some uncertainty in the calculation of drainage density, as drainage densities generally apply to natural watersheds, and subwatersheds, whereas the area of the IPZ-2 only represents part of a watershed. There is less uncertainty with the other sub-factor criteria (area, imperviousness, relief) as they were measured directly from GIS data layers.

While there is a relatively low level of uncertainty associated with the datasets used to evaluate the area vulnerability factor, there is a high degree of uncertainty in the methodology used to develop the area vulnerability factor. The methodology developed by Baird is based assigning a relative rating for each criterion in the rules (see Table 4.2). We have endeavored to assign a rating for each criterion (low; moderate; high) based on professional judgment. Other consultants have derived similar methodologies independently of Baird, but their exact choice of criteria, and the divisions between these may vary. This in part stems from the fact that the Rules (MOE, 2009a) do not provide specific guidance regarding the data and methodologies to be applied in evaluating the sub-factors used to derive the area vulnerability factor.

The ratings used to evaluate the area vulnerability factor are relative. This is advantageous because the criteria are easily quantifiable, easy to understand, and can be applied within the scope and budget of source water protection studies. To provide an absolute measure of the area vulnerability factor, a numerically distributed or quasi-distributed hydrologic model would have to be developed, possibly with the inclusion of contaminant transport functions, for each subwatershed within the IPZ-2. This would provide a measure of the likelihood (probability) of a particular contaminant reaching the intake during a storm of a given return period, in a concentration that was sufficient to present a risk to health. However, such an approach is well beyond the scope of this study.

The parameters considered in assigning the source vulnerability factors were the distance of the intake from shore and the depth of water that it is located in. Length and depth values for the intake were provided by the operator (Baird, 2008). These values have been confirmed based on engineering drawings and there is a low level of uncertainty for these values. The WTP operator listed only low level concerns in the interview undertaken during Phase 1 of this study (Baird, 2008) and the analysis of limited water quality data did not identify any concerns. A low level of uncertainty has therefore been assigned to the source vulnerability factor.

5.6 Summary of Uncertainty

MOE requires that an uncertainty rating of "high" or "low" be assigned to the delineation of the IPZs and the vulnerability assessment [Rule 13; MOE, 2009a]. The uncertainty ratings for the IPZ delineation and vulnerability scoring are presented in Table 5.1.

Table 5.1
Summary of Uncertainty Ratings for IPZ Delineation and Vulnerability Scores for Gros Cap WTP

IPZ	Uncertainty for IPZ Delineation		Uncertainty for Vulnerability Scores	
	Evaluation Factor	Rating	Evaluation Factor	Rating
IPZ-1	Data	High	Data	Low
	QA/QC	Low	QA/QC	Low
			Accuracy of Vuln. Factors	Low
	Overall	High	Overall	Low
IPZ-2	Data	High	Data	High
	Modeling	High		
	QA/QC	Low	QA/QC	Low
	Calibration/ Validation	High	Accuracy of Vuln. Factors	High
	Overall	High	Overall	High

The IPZ-1 is delineated as a 1 km radius around the intake, extending onland 120 m. There is a low level of uncertainty in the location of the intake. There is a low level of uncertainty in QA/QC as stated in Section 5.3. No modeling was required, however there is a high level of uncertainty with the inland extent of the IPZ-1 because the vertical datum for the DEM model is unknown.

The IPZ-2 delineation has a high overall rating of uncertainty. Data gaps pertaining to the IPZ-2 delineation are listed in Section 5.1. There is a high level of uncertainty associated with the modeling. This is not a reflection of the modeling undertaken, but rather recognition that a model is a tool that can be used to better understand the currents. It is also important to recognize that the model was not calibrated.

The uncertainty rating for the data used to define the source vulnerability factor (offset from shore, depth and history of water quality concerns) is low. The source vulnerability factor applies to both the IPZ-1 and the IPZ-2. The level of uncertainty for the area vulnerability factor for the IPZ-1 is also low, as it is defined in MOE (2009b) as 10. The level of uncertainty for the area vulnerability for the IPZ-2 is high due to the reasons given in Section 5.5, largely related to the wide range of approaches that could be adopted. An overall rating of low was therefore assigned to the IPZ-1 vulnerability score and a rating of high was assigned to the IPZ-2 vulnerability score.

6.0 SUMMARY AND CONCLUSIONS

1. This Addendum describes additional work undertaken to delineate the IPZ-1 and IPZ-2 for the Sault Ste. Marie Gros Cap intake. The objective of this work was to develop a 3D hydrodynamic model to improve our understanding of current patterns in the vicinity of the intake. Specifically, this included: data collection in support of modeling; model setup; comparison of modeled results with measured current data collected in Phase 1; statistical analysis of measured wind data to define return period events; numerical model runs; delineation of the IPZ-2; and refinement of vulnerability scores and uncertainty analysis.

2. The Danish Hydraulic Institute (DHI) MIKE3 model was used to define the hydrodynamic conditions for the south end of Whitefish Bay on Lake Superior in the vicinity of the raw water intake, and the National Oceanic and Atmospheric Administration (NOAA) lakewide Princeton Ocean Model (POM) was used to provide boundary conditions, initial conditions and external forcing mechanisms, such as wind, for the MIKE3 model.

3. The MIKE3 model results were compared with the measured current data collected in July to October 2006. A review of the Y-component (north-south) of the surface currents showed currents to be predominately to the south. A stronger relationship was evident between the measured data and modelled results in the north-south direction compared to the east-west direction (X-component) as the correlation coefficients were determined to be 0.54 and 0.04, respectively. Similar trends were observed 10 m below the water surface as the dominant flow directions are to the south and east. The correlation coefficients were determined to be 0.49 for the Y-component and 0.14 for the X-component.

4. A directional Peaks-Over-Threshold (POT) analysis was undertaken to define extreme wind events for varying return periods, for the full range of directions on an 8-point compass. The analysis indicates that the most severe events are from the west, northwest and southwest.

5. A matrix of runs was undertaken using the statistical wind conditions. The model was run for the 10-year return period winds for directions N clockwise through NW, at 45 degree intervals.

6. Reverse particle tracking was used to refine the in-lake IPZ-2. Neutrally buoyant particles were introduced at the intake. Particles were introduced near lakebed and at the surface. Although the intake is located near the lakebed, the particles released at both depths were considered in delineating the IPZ-2. The most conservative results were used to delineate the IPZ-2 for the 3 hour travel time specified by the WTP operator in the Phase 1 work. This is a more conservative approach since the currents at the surface are larger than the currents near the lakebed, where the intake is located.

7. Vulnerability scores have been recommended for the IPZs. Vulnerability scores of 5 (IPZ-1) and 4 (IPZ-2) classify this intake as low risk. This is appropriate considering the intake's location and the review of water quality data described in the phase 1 report.

8. There is a high level of uncertainty associated with the IPZ-1 and IPZ-2 delineations. There is a low level of uncertainty associated with the IPZ-1 vulnerability score and a high level of uncertainty associated with the IPZ-2 vulnerability score at this time, due to the factors listed in Section 5.

9. Additional work will be required to delineate the IPZ-3 as required by the new Technical Rules (MOE, 2009a).

7.0 REFERENCES

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APPENDIX A: MODEL OUTPUT

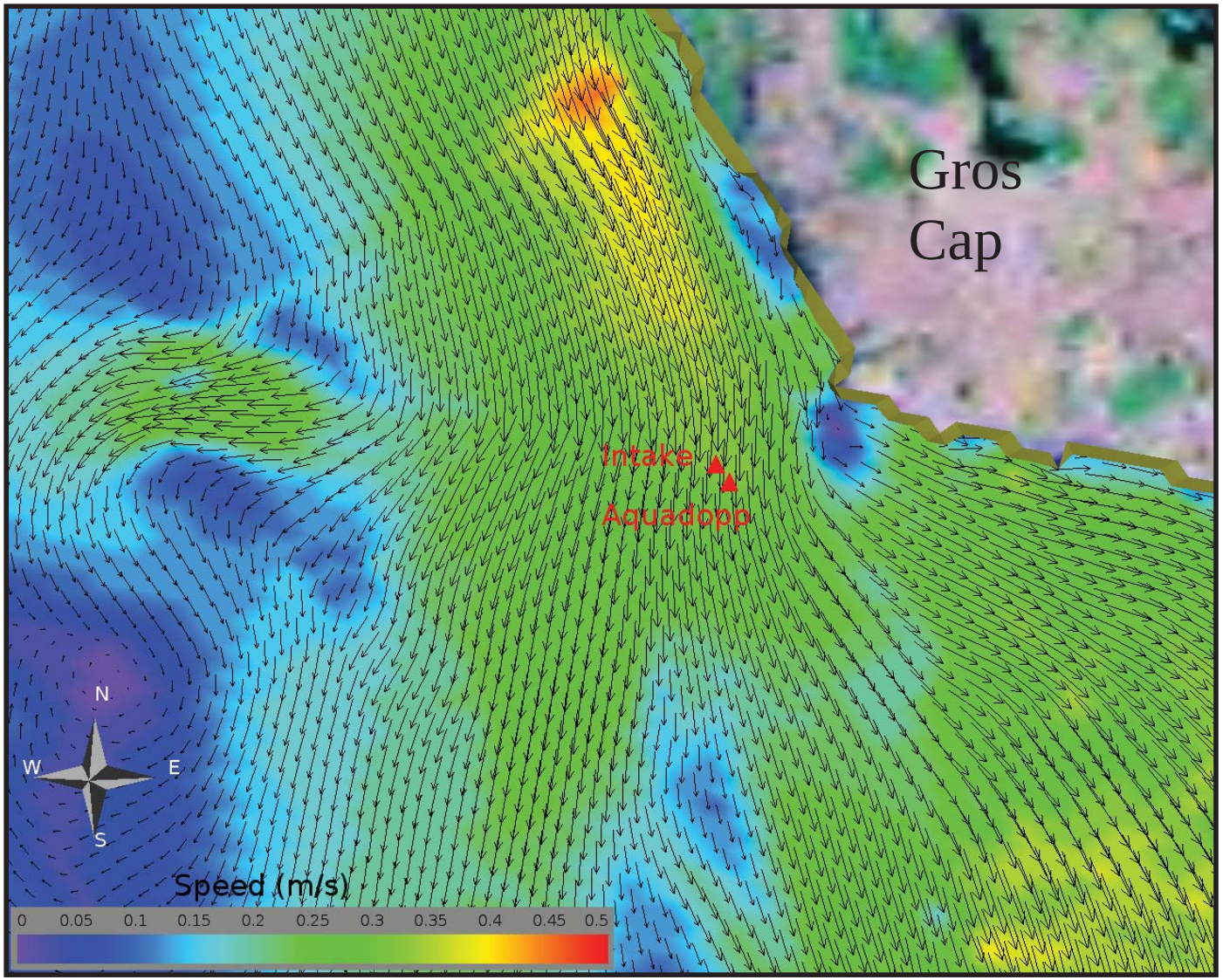


Figure A1 Map of Currents for Constant North Wind of 15m/s

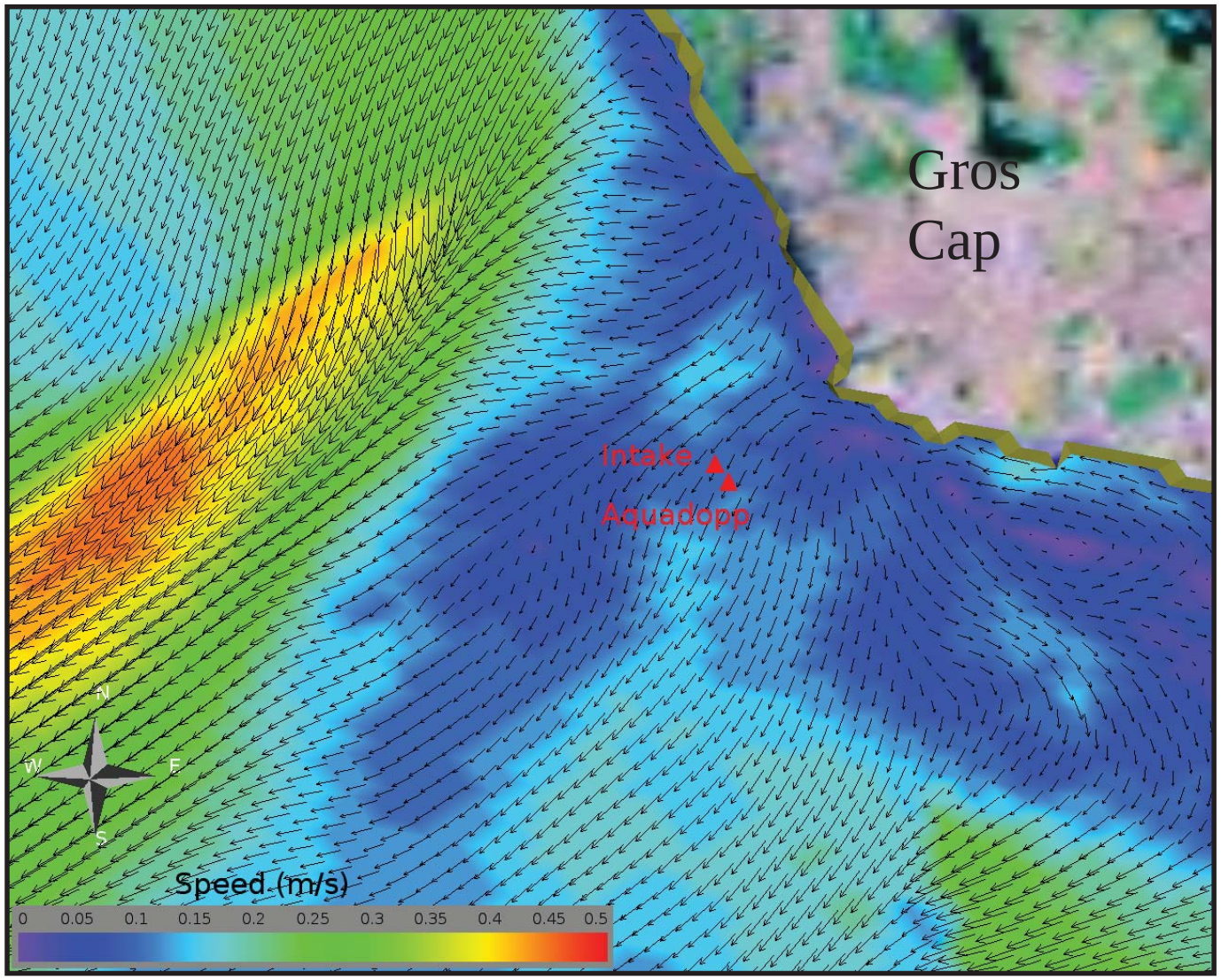


Figure A2 2D Map of Currents for Constant NE Wind of 12.6m/s

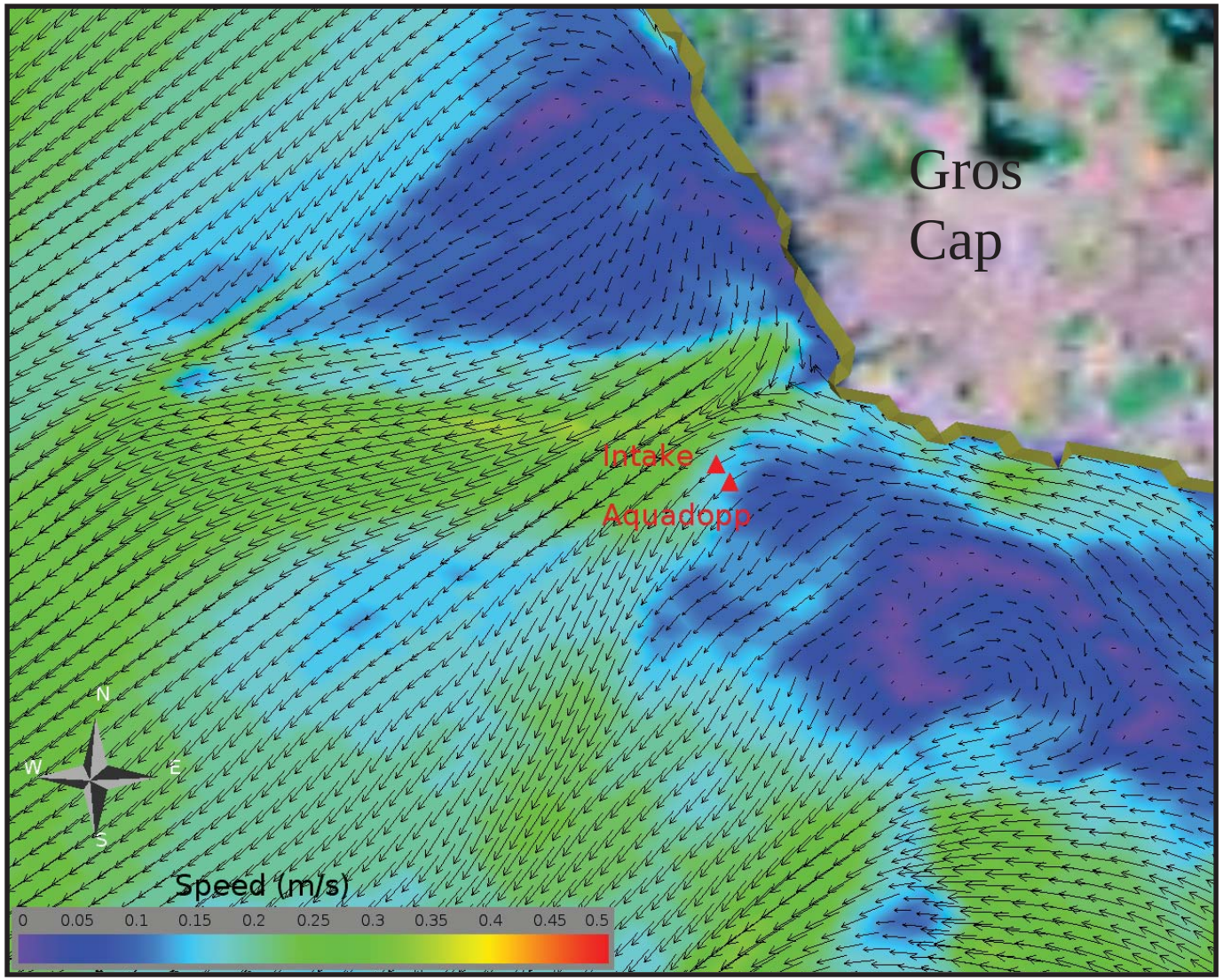


Figure A3 2D Map of Currents for Constant East Wind of 13.8m/s

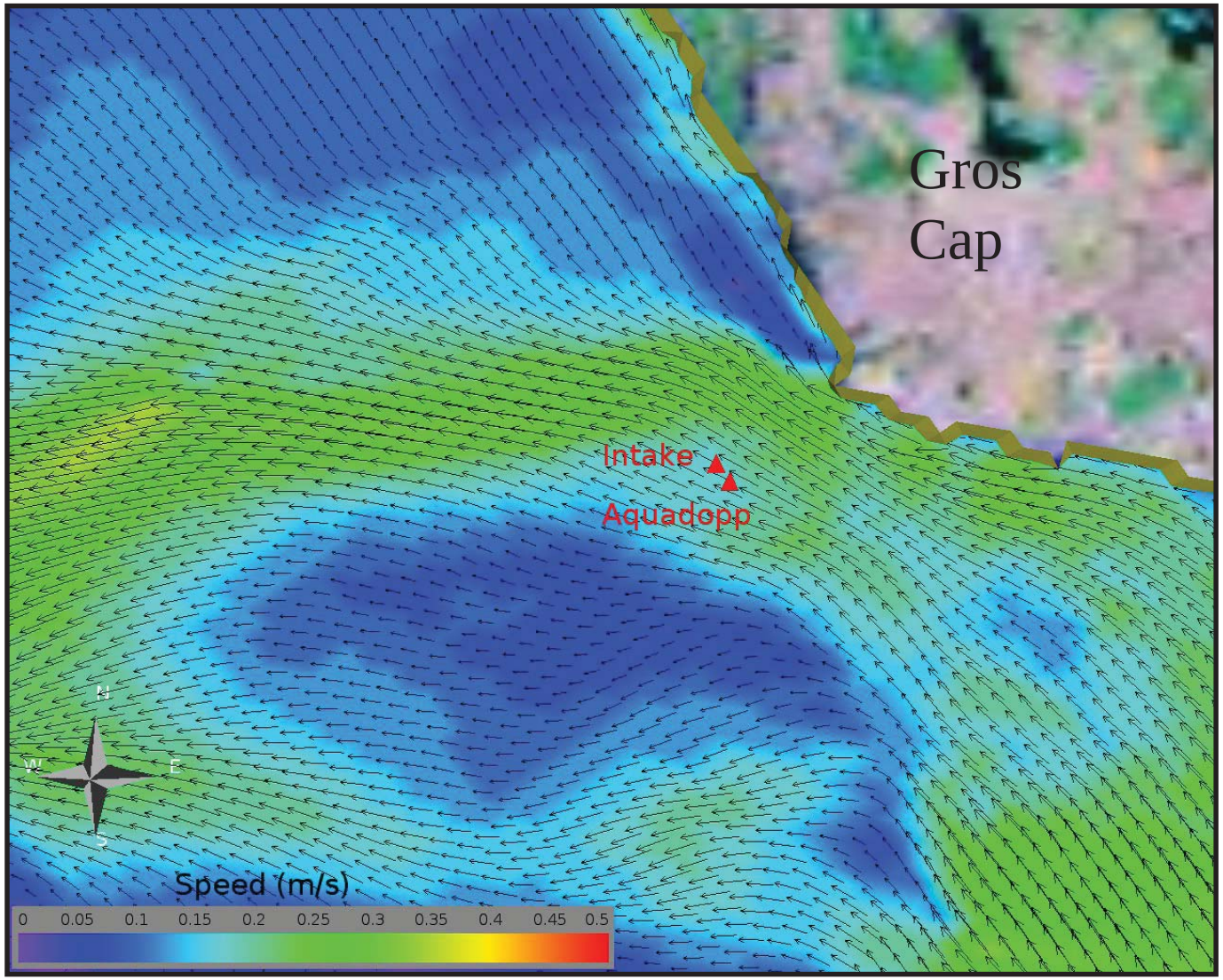


Figure A4 2D Map of Currents for Constant SE Wind of 12.6m/s

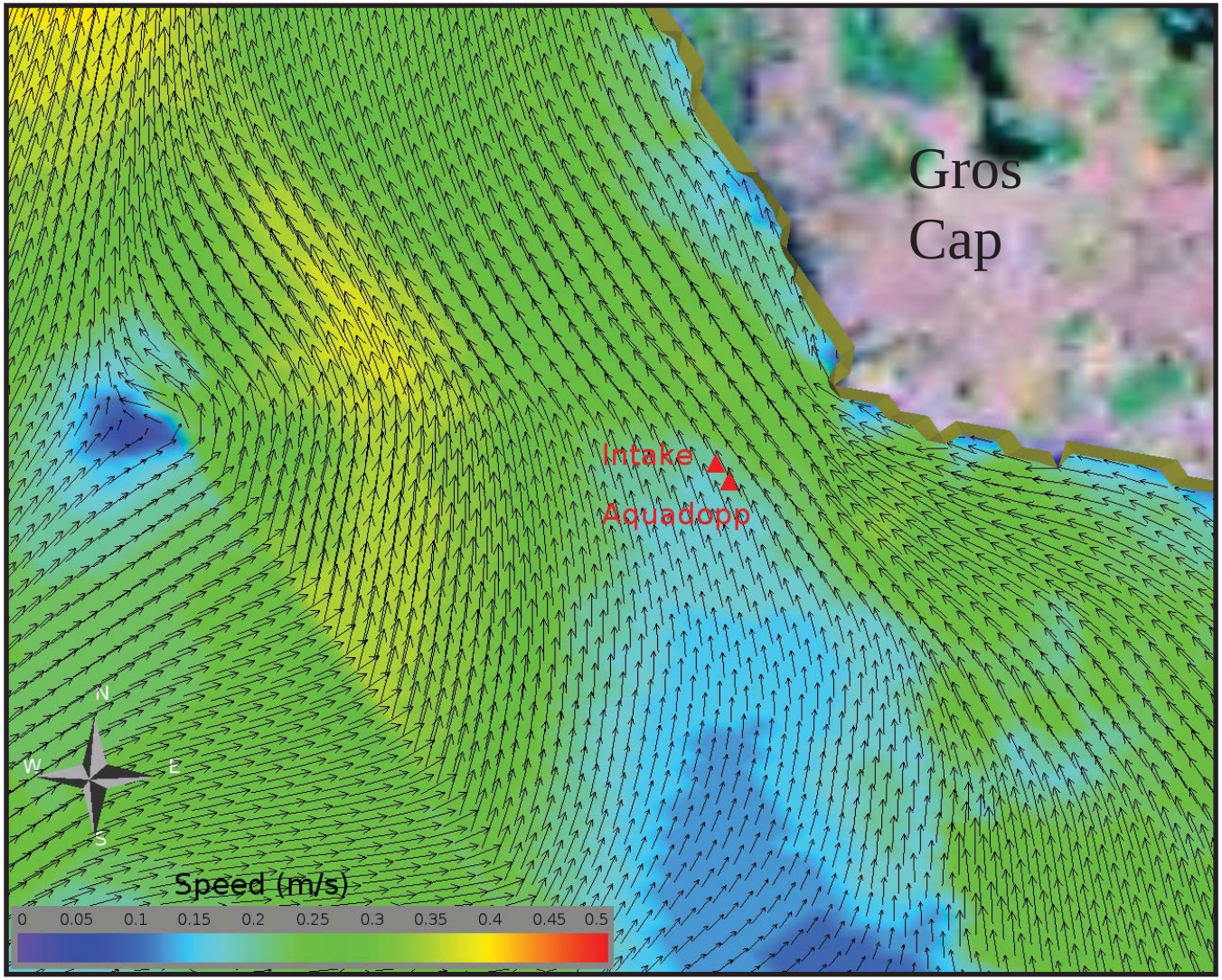


Figure A5 2D Map of Currents for Constant South Wind of 12.1m/s

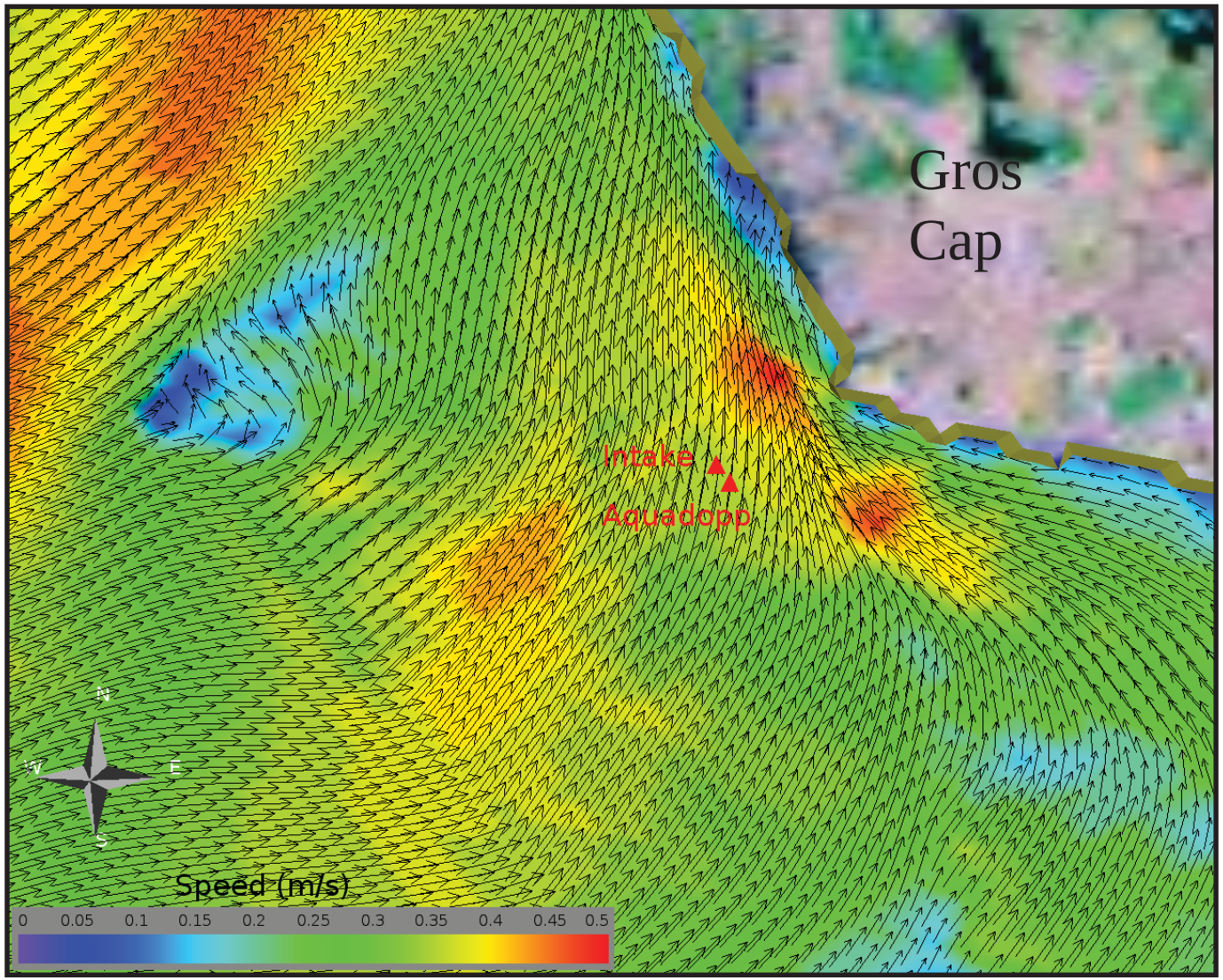


Figure A6 2D Map of Currents for Constant SW Wind of 16.5m/s

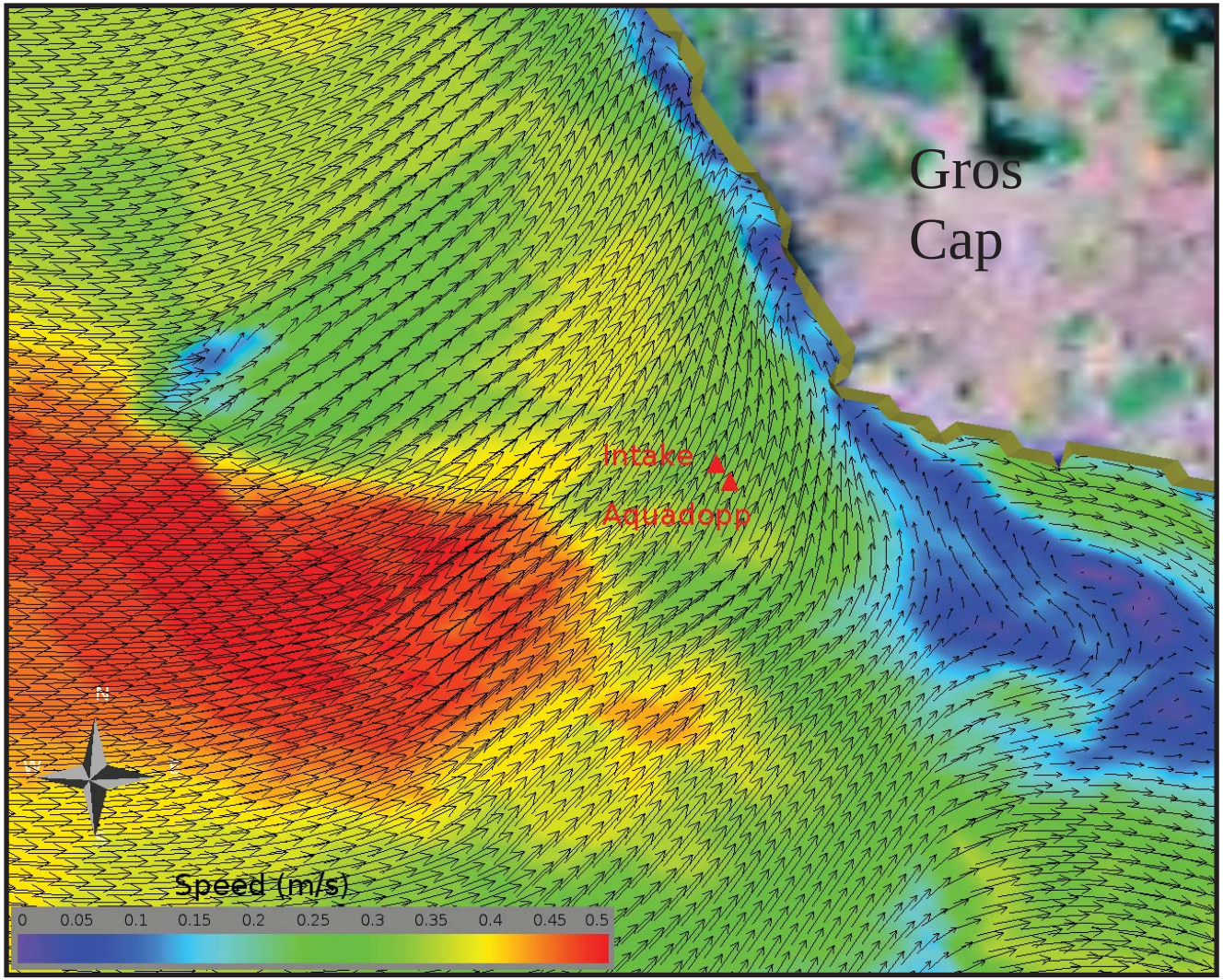


Figure A7 2D Map of Current Conditions under Constant West Wind of 19.2m/s

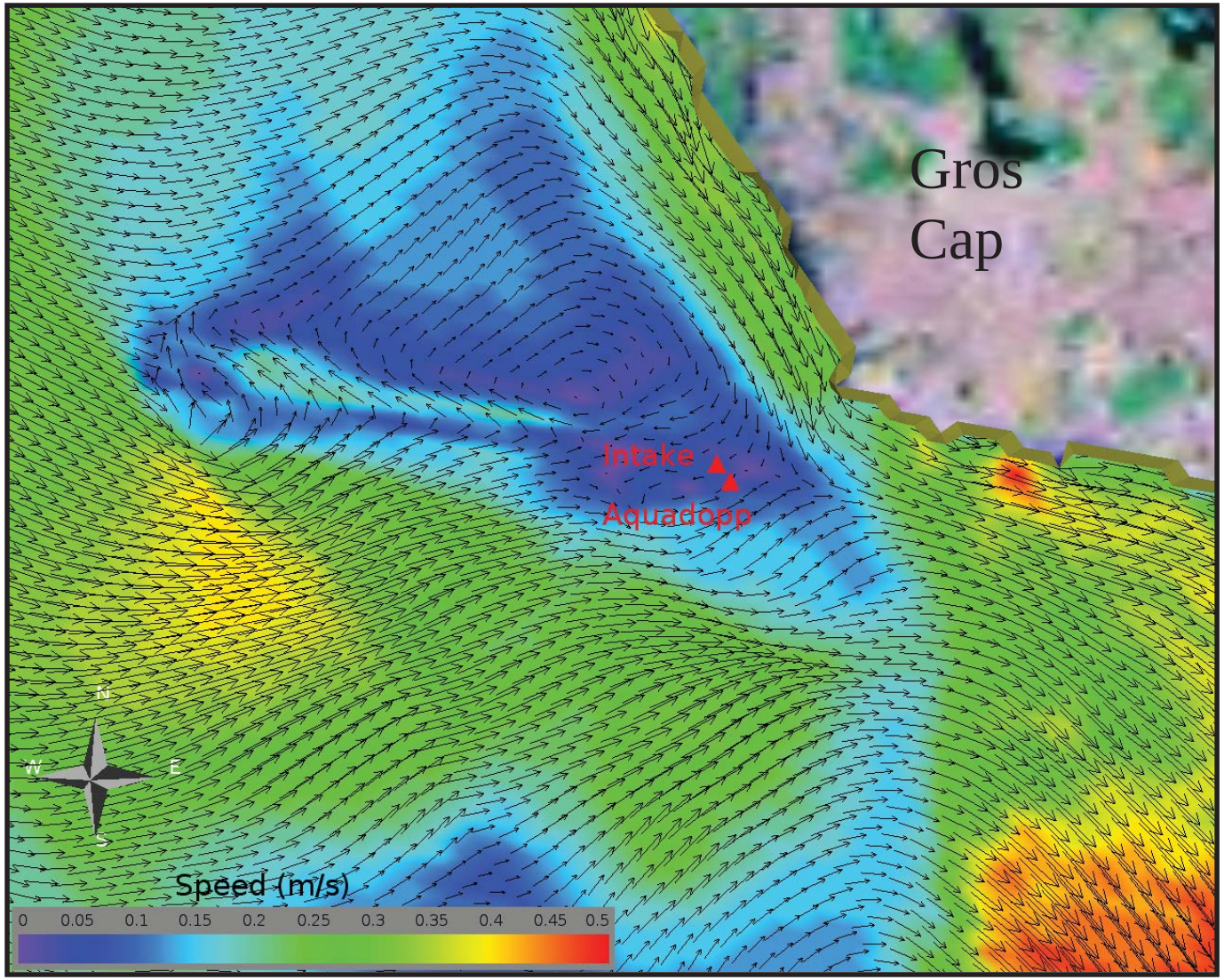


Figure A8 2D Map of Currents for Constant Northwest Wind of16.5 m/s

APPENDIX B: TRANSPORT PATHWAYS

B1.0 Introduction

This appendix presents the methodology and results for delineation of the transport pathways, in support of IPZ-2 delineation.

B2.0 Methodology

B2.1 Data Acquisition and QA/QC

Datasets were obtained from a number of sources, including: Sault Ste. Marie Region Conservation Authority (SSMRCA), Conestoga Rovers & Associates (CRA), and Ministry of Natural Resources Land Information Ontario. Data were collated, catalogued, and imported into a Geographic Information system (GIS), as appropriate, using the following steps:

- Determine datasets to be used in the transport pathways analysis;
- Obtain, visualize and verify that data provided by SSMRCA are appropriate for analysis and obtain feedback as required;
- Catalogue datasets and import into GIS.

Data were acquired by SSMRCA from in-house development, provincial repositories and from the City of Sault Ste. Marie. Field survey data acquired by CRA and documented in Baird (2008) was also leveraged. The Land Information Ontario online data subscription service was utilized. Datasets included (but were not limited to):

- Ditch outlet locations;
- Road networks;
- Digital Elevation Model (DEM);
- SCS Curve Numbers;
- Tributaries and waterbodies;
- Soils and land use data; and
- Ortho-imagery.

Digital data were provided in various formats, including Environmental Systems Research Institute, Inc (ESRI) shapefile, geodatabase, and ArcGrid format, as well as image files (tiff). All data acquired underwent a preliminary review by a GIS Analyst and Geoscientist. See Table B1 for a summary of all data received.

The software used for GIS analysis and geoprocessing was ESRI ArcGIS 9.3 with Spatial Analyst and 3D Analyst extensions.

Table B1 Summary of Data Provided and Data Gaps for Transport Pathways Analysis

LEGEND:
Data received
Data not available (Data Gap)

	DATA																	
Intake	Storm Watersheds (Sewersheds)	Storm Water Ponds	Storm Outfalls (Sewershed Outlets)	Outfall/Outlet Diameters	Flow/Velocity Data for Sewers, Ditches, etc.	Ditches	Ditch Cross Sections	Rural Drainage	Hard Surfacing / Impervious Areas	Subsurface Tiling	Watercourses	Engineered Cross Sections (Tributary)	Modeled Cross Sections	Modeled Return Period Flows 2, 10, 100 yr (Tributaries)	Elevation Surface	Soils Classification	Landuse Classification	Orthoimagery
Gros Cap					(Ditches Only)	(Outlets Only)	(measurements only)											

B2.2 Identification of Transport Pathways

Transport pathway features with potential effect on the IPZ-2 were identified primarily through aerial photo interpretation, except for street centerline data, which was provided by SSMRCA. The potential transport pathways are shown in Figure B1. Using a 25 cm resolution orthophoto mosaic dated 2008-Oct-31, features such as ditches and roads were mostly identifiable, though in some instances they were obscured by vegetation. A digital elevation model with 20 m grid cell size was used to derive slope for the transport pathway features.

In Baird (2008), CRA undertook ground reconnaissance to survey all ditches and tributaries that discharged into the lake within the Phase 1 IPZ-2 (5 km radius of intake) and thus, had a potential effect on IPZ-2. Within the revised Phase 2 IPZ-2 extent (based on Director's Rules dated MOE, 2009) there was only 1 ditch outlet identified by CRA as discharging into the lake within the IPZ-2 (SW01)(Figure 1). The SW01 ditch outlet was not surveyed as part of the Spring 2007 reconnaissance, but in Fall 2006 it was surveyed and found to be dry.

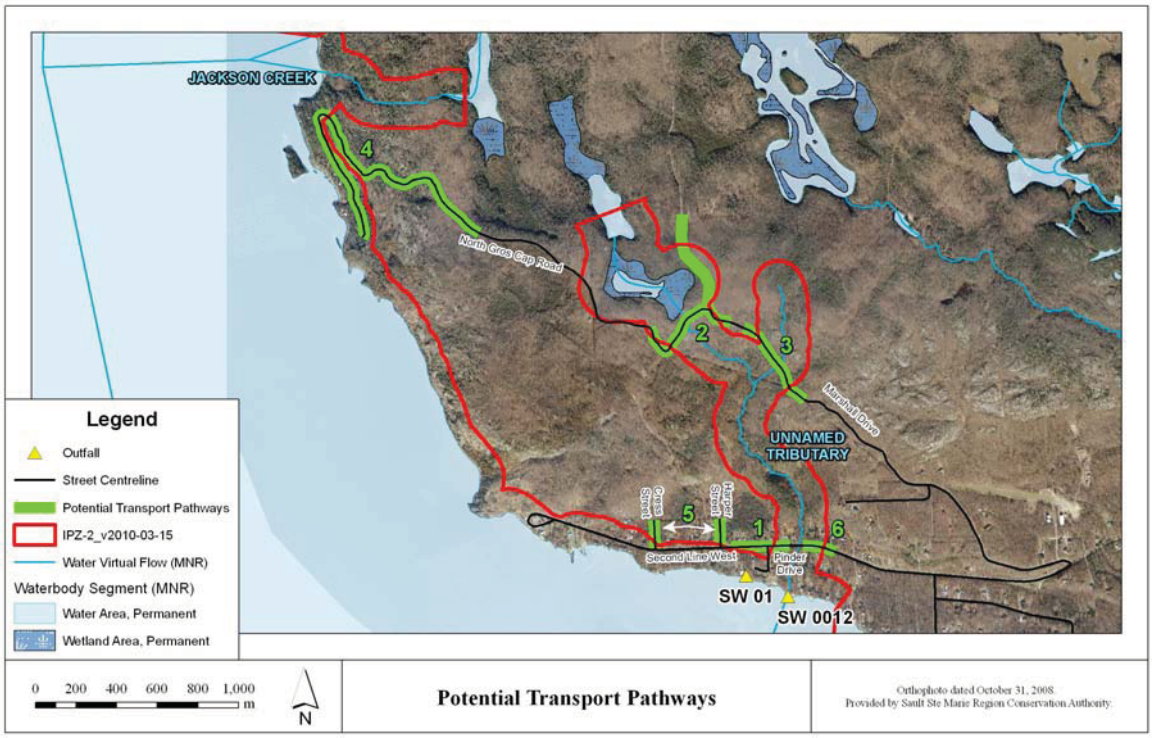


Figure B1 Location of Potential Transport Pathways (Green Highlighting)

B2.3 Determination of Travel Times for Transport Pathways

Each potential transport pathway was assigned a unique identifier. Travel times were calculated for both an in-water component and on-land component. The in-water component is the time from the intake to the point on shore where the transport pathway outlets to the lake. The on-land component only considers time 'upstream' of the point where the transport pathway outlets to the lake. The total travel time is the summation of the in-water and on-land travel time components. A 3-hour maximum time is used (defined by the WTP operator as the time required to shut down the WTP in the event that the water may be compromised).

Potential Transport Pathway #1

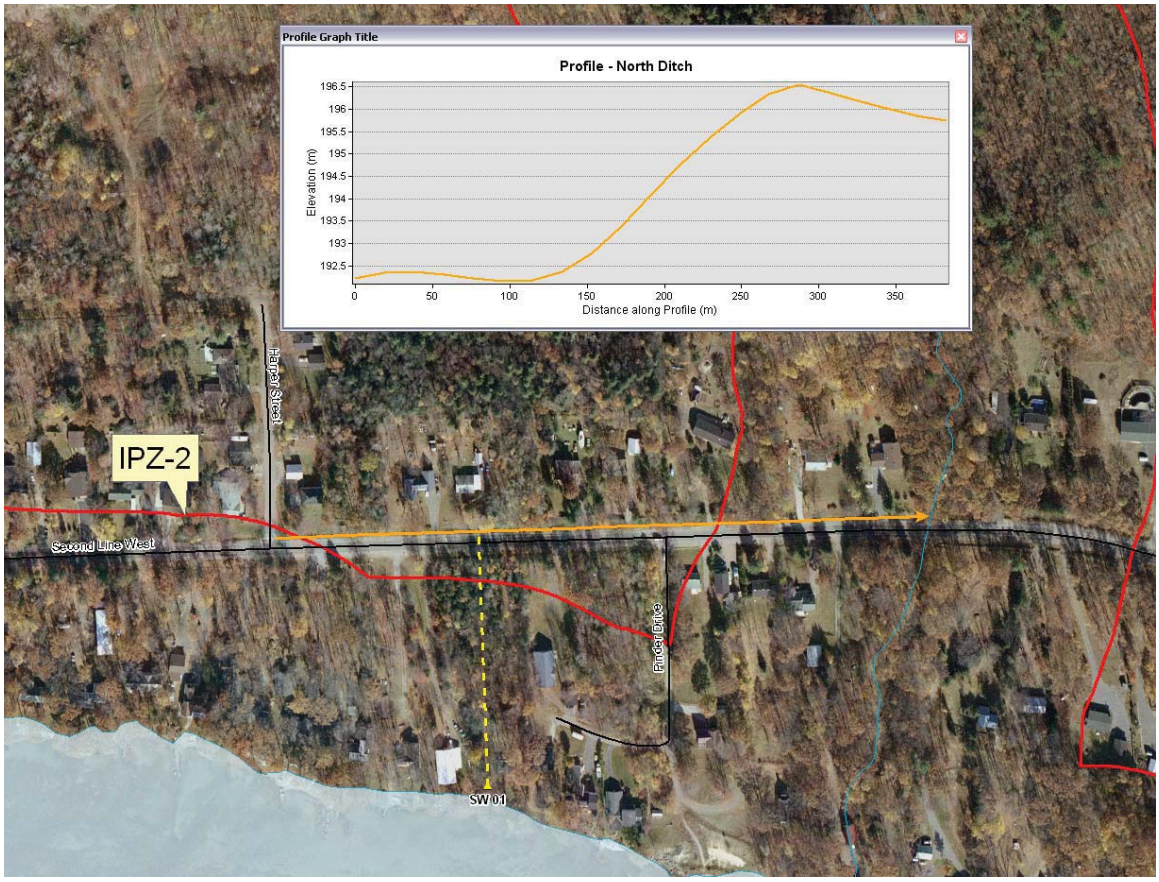
The ditch outlet SW01 is located approximately 1,760 m from the intake. The velocity though the lake was estimated to be 0.4 m/s, which is 3% of the maximum 10 year return period wind speed of 13.8 m/s for an easterly direction. Travel time from the intake to SW01 is calculated to be 73 minutes (1760/0.4/60). Therefore, the remaining travel time up the SW01 ditch is estimated to be 107 minutes.

The ditch draining into the lake through SW01 was surveyed by CRA in Fall 2006 but was not included in the survey in Spring 2007 (Baird, 2008). Slope, soil type, cross-section dimensions and discharges were measured and calculated in 2006. There was no discharge flow during the Fall 2006 survey, and the ditch was noted as 'dry' by CRA. The ditch runs a length of 150 m from the outlet and is assumed connected to the ditch on the north side of Second Line West via a culvert.

The Manning velocity equation was used to calculate a velocity of 1.37 m/s along the north ditch. In absence of a surveyed ditch cross section, a trapezoidal ditch with 45 degree sides was assumed. A Manning roughness coefficient of 0.037 (as used by CRA in Baird (2008) for excavated rock streams) was used. Using a velocity of 1.37 m/s, the time of travel through the ditch is approximately 2 minutes (150/1.37/60). Therefore, the remaining travel time 'upstream' of the SW01 ditch is 105 minutes.

Transport Pathway	Manning's n	Slope (rise/run)	Ditch Depth (m)	Ditch Top Width (m)	Ditch Bottom Width (m)	Ditch Side Angle	Wetted Perimeter (m)	Wetted Area (m2)	Hydraulic Radius (m)	Estimated Velocity (m/s)
SW01 Ditch	0.037	0.062	0.1	2	2	45	2.283	0.210	0.092	1.37

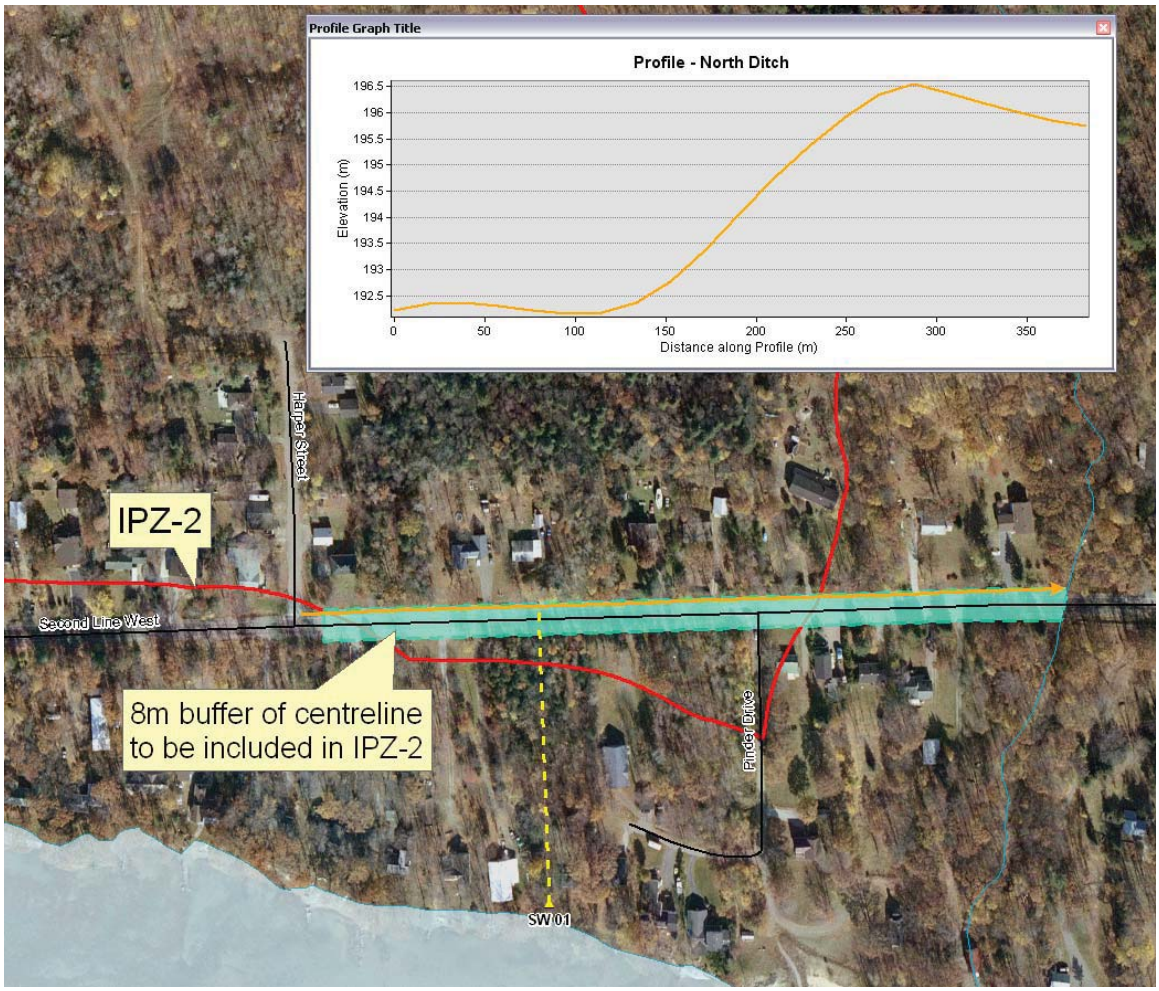
A profile was cut along the north ditch of Second Line West using the DEM. The profile suggests that the SW01 ditch is draining an approximate 75 m segment of ditch from the west of the juncture, and an approximate 190 m segment of ditch from east of the juncture.



The Manning velocity equation was used to calculate a velocity of 0.14 m/s along the north ditch. In absence of a surveyed ditch cross section, a trapezoidal ditch with 45 degree sides was assumed. A Manning roughness coefficient of 0.15 was used, assuming the ditch is densely vegetated with (Chow, 1959).

Transport Pathway	Manning's n	Slope (rise/run)	Ditch Depth (m)	Ditch Top Width (m)	Ditch Bottom Width (m)	Ditch Side Angle	Wetted Perimeter (m)	Wetted Area (m2)	Hydraulic Radius (m)	Estimated Velocity (m/s)
North Ditch (Second Line West)	0.150	0.011	0.1	1.2	1	45	1.283	0.110	0.086	0.14

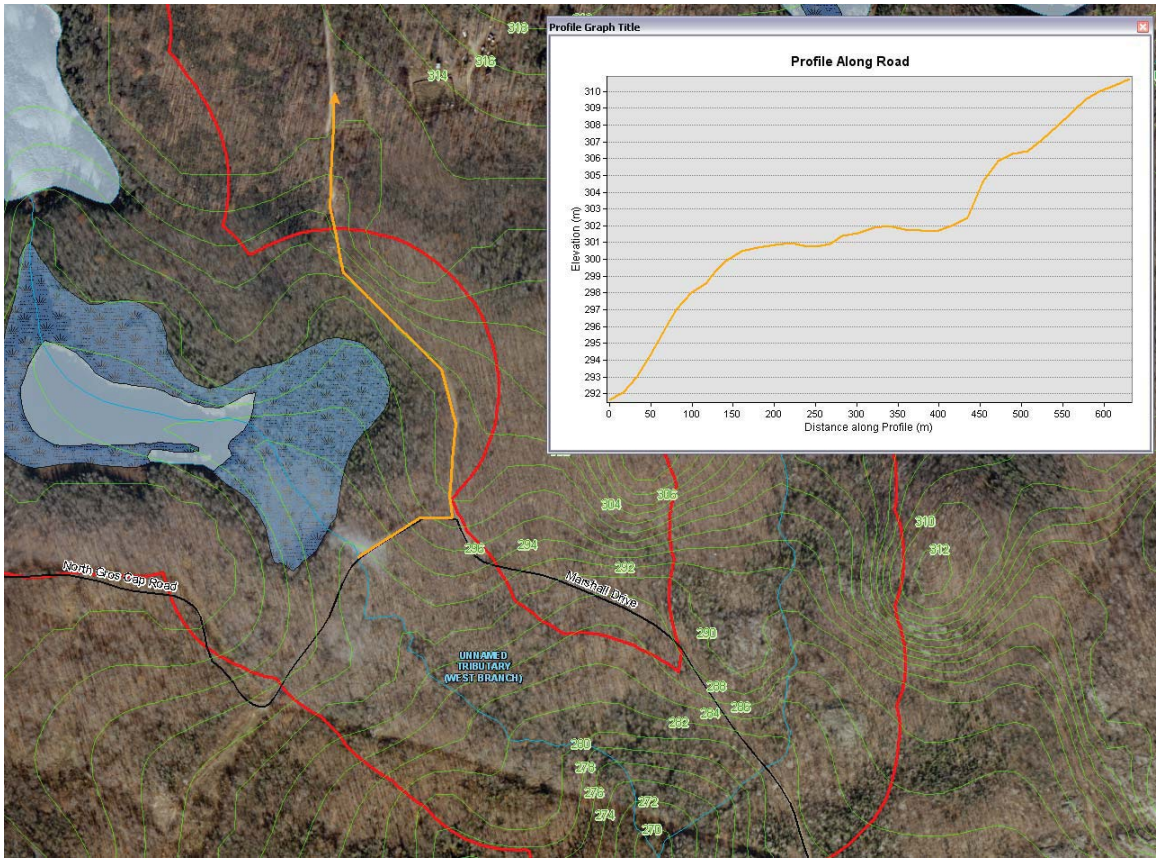
With a remaining travel time of 105 minutes from the juncture of SW01 ditch and the north ditch, there is a potential travel distance 'upstream' along the north ditch of 882 m (105*60*0.14). Therefore, the IPZ-2 should be extended to include the north ditch along Second Line West, for the areas draining toward the SW01 ditch. An 8m buffer was applied to the centreline of the road for inclusion of the transport pathway.



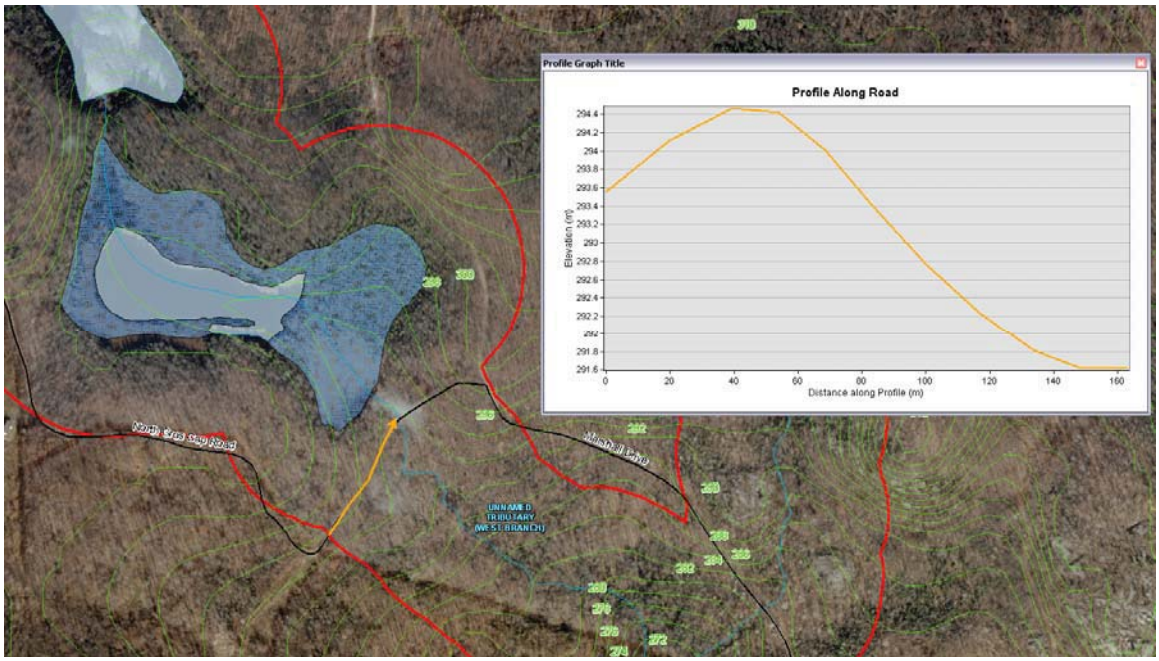
Potential Transport Pathway #2

Marshall Drive crosses the west branch of the Unnamed Tributary at a location approximately 1,839 m upstream from the outlet (SW 0012). With an estimated bankfull velocity of 2.21 m/s, the travel time upstream along the Unnamed Tributary is 13.9 minutes (1839/2.21/60) to this location, and therefore, 46.1 minutes of travel time remain. It is assumed that there is a vegetated (short grass) ditch adjacent to the road, as one is not clearly discernable from the imagery.

A profile was cut along the north side of Marshall Drive and the west side of the unnamed road extending north from Marshall Drive using the DEM. The profile suggests that the road ditch may drain an area approximately 250 m to the north along the unnamed road, which is within the current extent of the IPZ-2. Therefore, this section of Marshall Drive is not considered to be a transport pathway with influence on the IPZ-2.



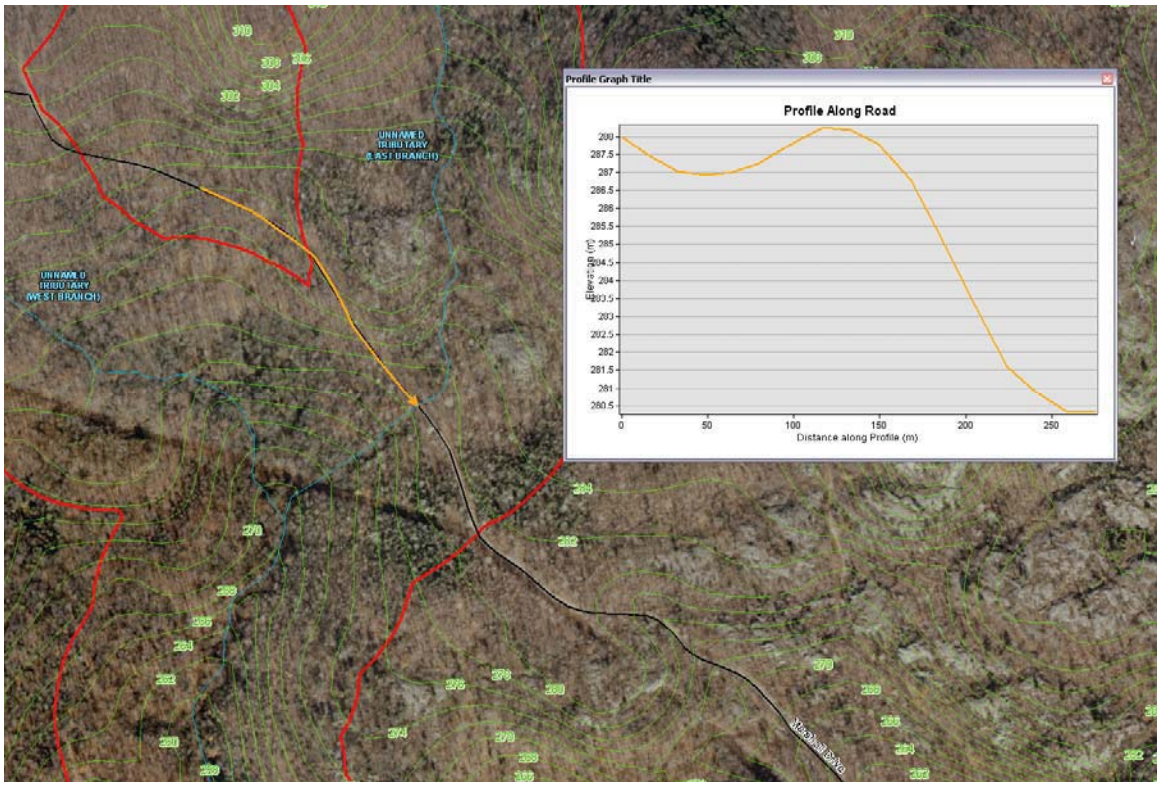
A profile was also cut along Marshall Drive, west of the junction with the Unnamed Tributary. The profile indicates that the road section draining towards the Unnamed Tributary is within the 120 m tributary buffer. Therefore, the section of Marshall Drive located to the west of the junction with the Unnamed Tributary is not considered to be a transport pathway with influence on the IPZ-2.



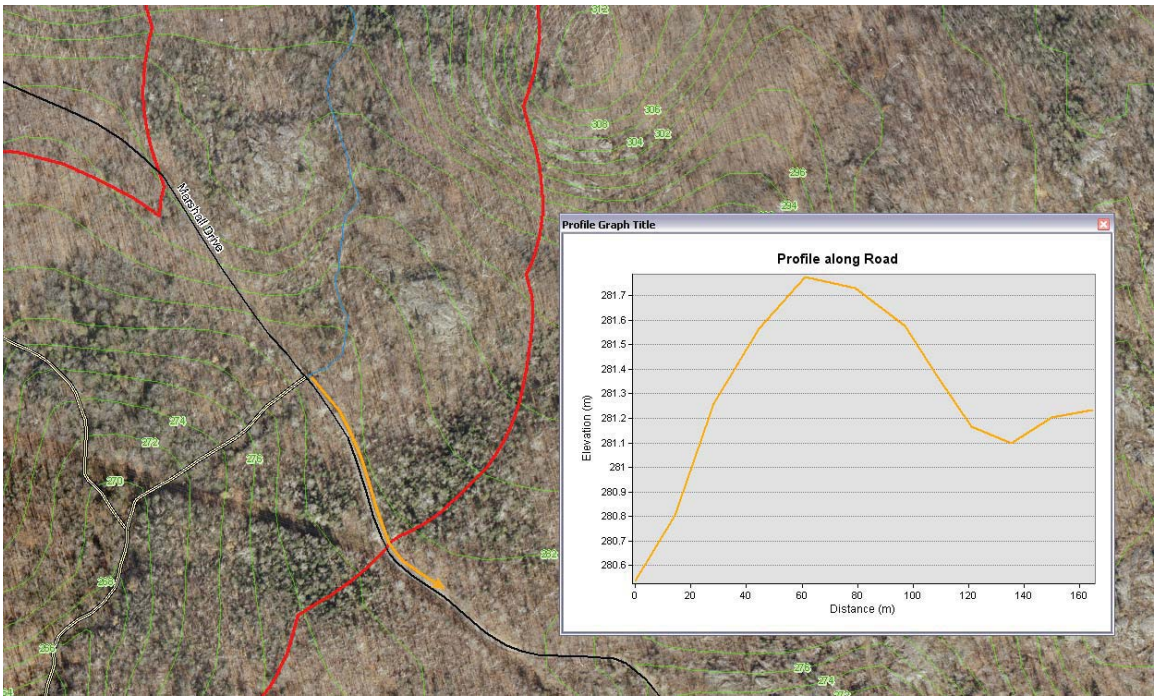
Potential Transport Pathway #3

Marshall Drive crosses the east branch of the Unnamed Tributary at a location approximately 1,445 m upstream from the outlet (SW 0012). With an estimated bankfull velocity of 2.21 m/s, the travel time upstream along the Unnamed Tributary is 10.9 minutes (1445/2.21/60) to this location, therefore, 49.1 minutes of travel time remain). It is evident from the imagery that a ditch is located on the east side of Marshall Drive in this area. It is assumed that this ditch is continuous along the road, as continuity is not clearly discernable from the imagery (obscured by vegetation).

A profile was cut along the east side of Marshall Drive, using the DEM, from the juncture of Marshall Drive and the east branch to the IPZ-2 boundary of the west branch. The profile suggests that the road ditch may drain an area approximately 150 m to the north along Marshall Drive, which is already included in the IPZ-2.



A profile was also cut along the east side of Marshall Drive, using the DEM, from the juncture of Marshall Drive and the east branch to in a southeast direction. The profile indicates that the road section draining towards the Unnamed Tributary is within the 120 m tributary buffer. Therefore, the section of Marshall Drive located to the east of the juncture with the East branch of the Unnamed Tributary is not considered to be a transport pathway with influence on the IPZ-2.



Potential Transport Pathway #4

North Gros Cap Road crosses the IPZ-2 boundary approximately 200 m south of the mouth of Jackson Creek. There is no discernable ditch or outlet to the lake from North Gros Cap Road. Ditch and outlet reconnaissance by CRA in Baird (2008) did not reveal any such ditch or outlet location(s). Therefore, the section of North Gros Cap Road that crosses into the IPZ-2 is not considered to be a transport pathway with influence on the IPZ-2.

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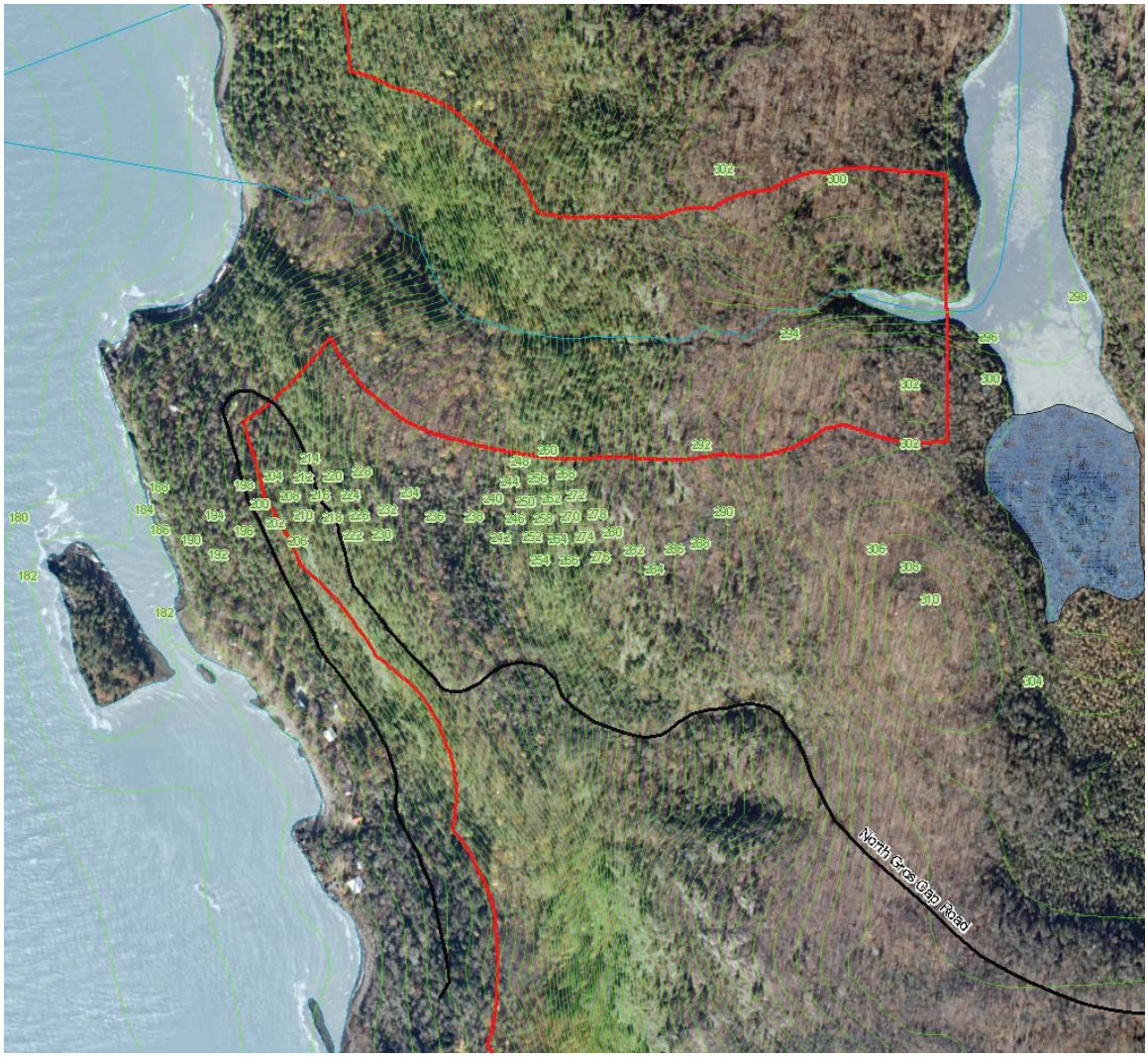


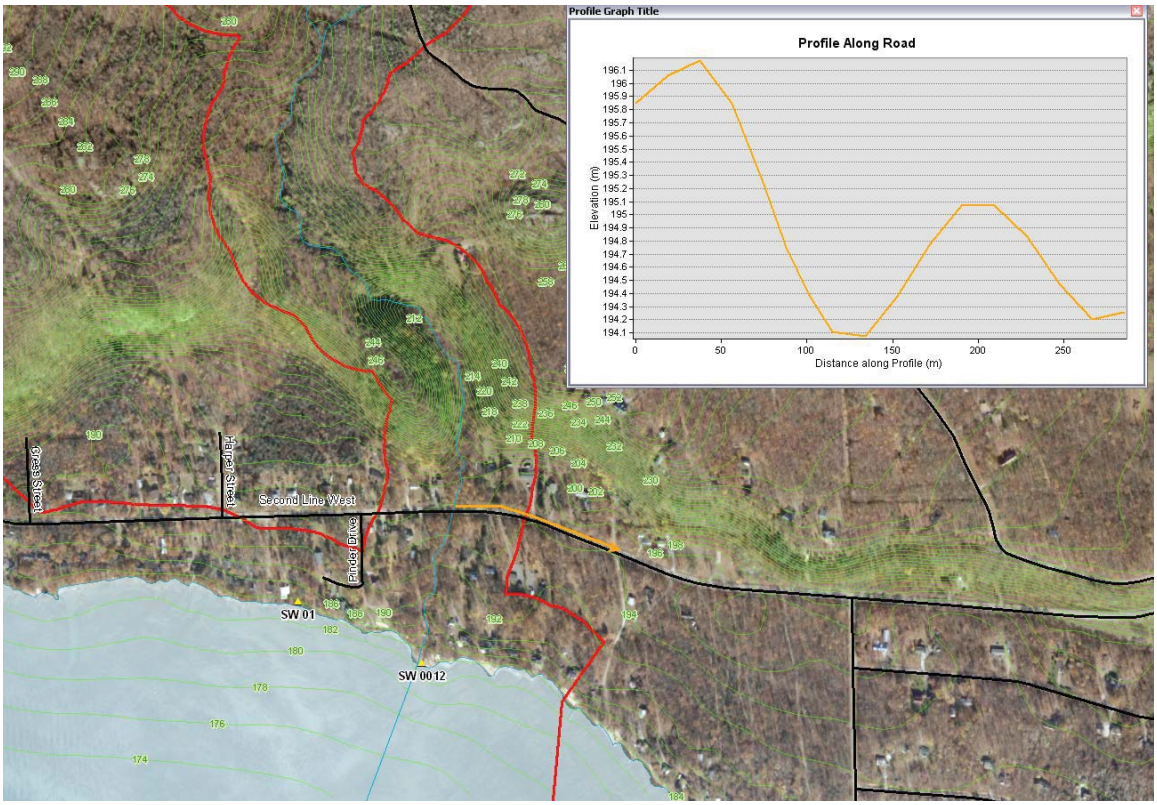
Potential Transport Pathway #5

Along Second Line West, both Cress Street and Harper Street are potential transport pathways. However, the slope of the DEM in this suggests that both Cress and Harper Streets do not drain towards the surveyed ditch outlet SW01. The orange arrows in the graphic below indicate slope direction (arrow indicates downhill slope). The dashed yellow lines indicate potential outlets to the lake based on the slopes obtained from the DEM. However, ditch and outlet reconnaissance by CRA in Baird (2008) did not reveal any such ditches or outlets in these positions. A detailed topographic survey along Second Line West is highly recommended to confirm the flow direction in the ditches. Therefore, Cress Street and Harper Street are not considered to be transport pathways with any influence on the IPZ-2, due to the fact that they do not drain towards outlet SW01 (as deduced from the DEM).


Gress Street
Harper Street
Second Line West
Pinder Drive
SW 01
SW 0012
100 m

Potential Transport Pathway #6

A profile was cut along the north side of Second Line West, east of the juncture between Second Line West and the Unnamed Tributary. The profile indicates that the section of ditch draining towards the Unnamed Tributary is within the 120 m tributary buffer. Therefore, the section of Second Line West located to the east of the juncture with the Unnamed Tributary is not considered to be a transport pathway with influence on the IPZ-2.



Summary of Transport Pathways

Of the six potential transport pathways reviewed, only transport pathway # 1 was considered to have an influence on the IPZ-2. The revised IPZ-2 including transport pathways is shown in Figure B2.

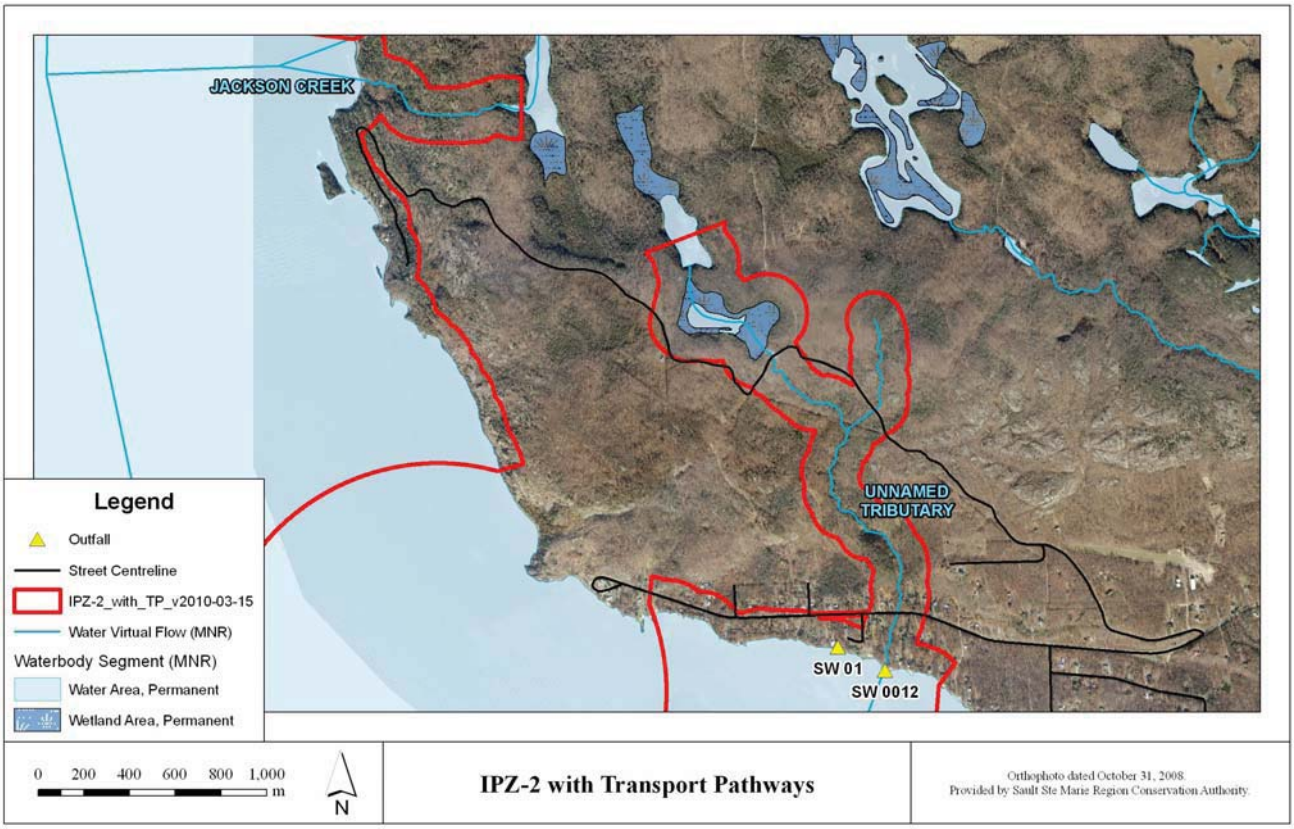


Figure B2 IPZ-2 with Transport Pathways