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Surface Water Vulnerability Analysis for Goderich Intake

Addendum: Numerical Modeling in Support of IPZ-2 Delineation

May 21, 2010
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Navigating New Horizons

Surface Water Vulnerability Analysis for Goderich Intake

Addendum: Numerical Modeling in Support of IPZ-2 Delineation

Prepared for

Town of Goderich

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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 October 2006, the Town of Goderich in partnership with the Ausable Bayfield Conservation Authority (as lead authority for the Ausable Bayfield Maitland Source Protection Region) retained the team of Baird & Associates in association with BMROSS to undertake a surface water vulnerability analysis for their intake on Lake Huron. The results of that study are provided in our report, *Surface Water Vulnerability Analysis for Goderich Intake* completed in August 2007.

The Town of Goderich applied for and received additional funding in March 2007, to complete the surface water vulnerability analysis. The Town retained BMROSS with Baird as sub-consultan. This Addendum describes the additional work undertaken to complete the numerical modeling initiated in the first phase of the studies and to refine the IPZ-2 based on the results of the modeling. A draft report was issued in May 2008. After receiving comments from BMROSS, a final Phase 1 report was issued in June 2009. Additional comments were received from the peer reviewer in April 2010. The comments have been addressed in this revision to the report. It is noted several versions of the Technical Rules have been issued since this report was finalized in June 2009, with the most recent version dated November 16, 2009. This report has been updated for consistency with MOE (2009a).

As further background, key findings from the August 2007 report, 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 *Surface Water Vulnerability Analysis for Goderich Intake*, completed in August 2007 follows the methodology outlined in Assessment Report: Draft Guidance Module 4 (MOE, 2006), and largely addresses the requirements of that Module. Numerical modeling was undertaken in support of the preliminary IPZ-2 delineation using the Lake Huron Operational Forecast System (LHOFS) applied by the National Oceanic and Atmospheric Administration (NOAA) to define boundary conditions for the Delft3D model, used to define the hydrodynamic conditions at the site. The LHOFS is an application of the Princeton Ocean Model (POM).

Reverse particle tracking was used to delineate the preliminary IPZs for the intake. The model was run for the two, 3-week periods including the most severe storms in 2003. Neutrally buoyant particles were introduced at the intake. 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 2-hour travel time (defined by the WTP Operator as the required time to shut down the plant in the event of a spill or threat to the drinking water).

A number of recommendations were made in that report, relating to additional numerical modeling requirements, to better define the level of uncertainty in the modeling results and the IPZ-2 delineation. It was recommended that the model should be validated with measured current data. Furthermore, it was recommended that a statistical analysis be undertaken to define extreme events and associated return periods, and that additional runs be completed to refine the IPZ-2.

1.3 Scope of Work

The focus of the Addendum work was to complete the modeling initiated in Phase 1, to improve the level of confidence in the in-water IPZ-2 delineation, and to better define the level of uncertainty associated with this work. Specifically, this included:

- Assessment of the level of uncertainty in the modeling, through a comparison of modeled results with measured current data collected by MOE at two ADCP stations in 2003;
- Statistical analysis of measured wind data to define return period events;
- Additional numerical model runs using reverse particle tracking with the 10-year return period wind for 8 compass point directions, combined with a 2-year return period flow in the Maitland River;
- Refinement of in-water IPZ-2 based on additional model runs; and
- Refinement of Vulnerability Scores and Uncertainty Analysis

2.0 COMPARISON OF MEASURED DATA AND MODEL RESULTS

The current velocities predicted by the Delft 3D model were compared with measured current data, to assess the accuracy of the model results. This was not intended to be a calibration/validation exercise and was tailored to available funding. The comparison provides a measure of the level of uncertainty of the in-water IPZ-2 delineation, as required for MOE (2009a).

The Ministry of the Environment (MOE) deployed ADCPs at two locations as shown in Figure 2.1, from May to November of 2003. The location of the intake is also shown in Figure 2.1. The measured data included current magnitudes and directions recorded at 0.5 hour intervals. Currents were measured at one metre intervals from the surface to the lakebed.

The model was run for the period coinciding with the measured current data. The data used as input to the model is described in Baird and BMROSS (2007). Measured flow data from the Maitland River and wind data extracted from the POM model (LHOFS) were used in the model run.

Figure 2.1 Locations of ADCPs used for Model Validation

The measured and modeled current speeds and directions, for the two ADCP stations are shown in Figures 2.2 and 2.3 and summarized in Table 2.1 for three elevations in the water column (surface, mid depth and near lakebed). In general, the comparison shows reasonable agreement between the measured and modelled current speeds, however the model tends to over-predict the current velocities near the lakebed and under-predict the current velocities at the surface.

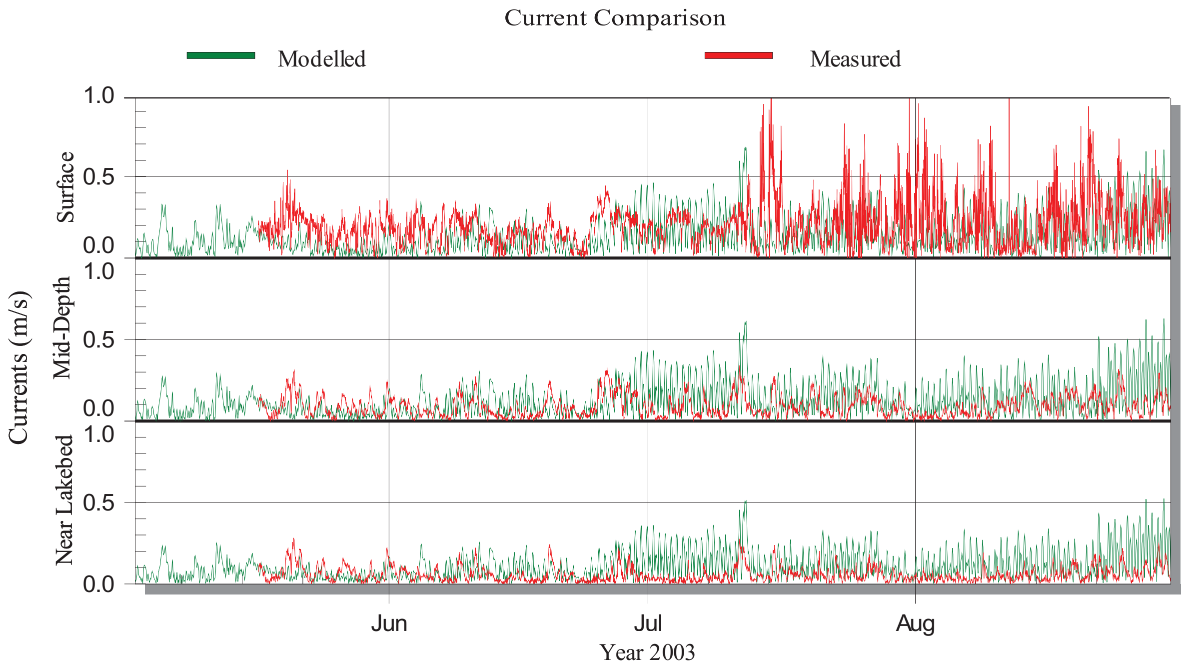


Figure 2.2a Comparison of the Modeled and Measured Current Speed at ADCP #3501

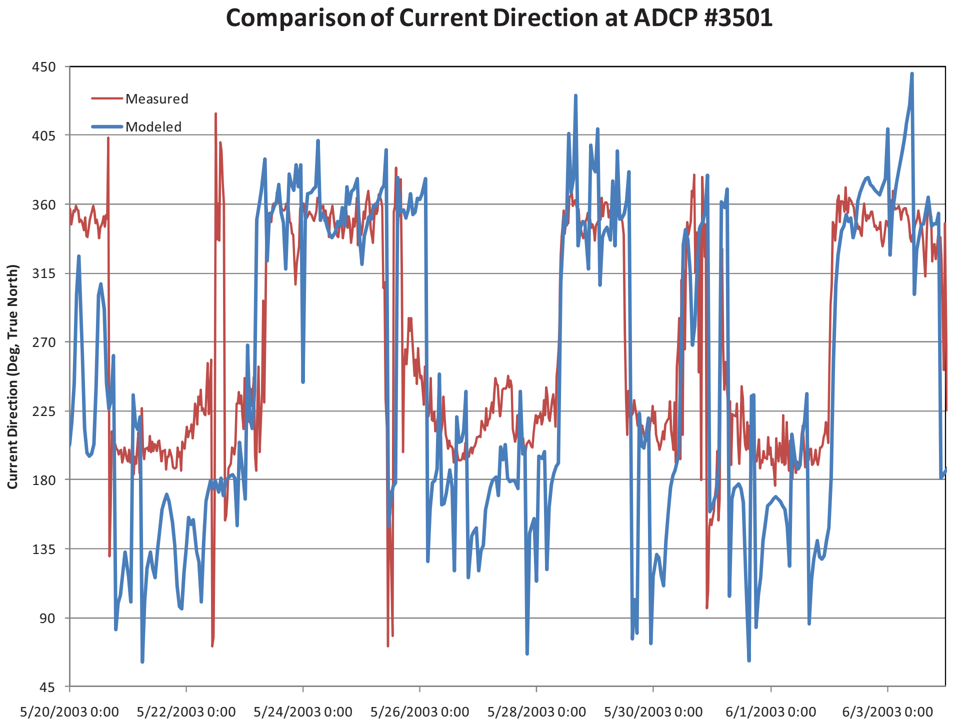


Figure 2.2b Comparison of the Modeled and Measured Current Direction at ADCP #3501

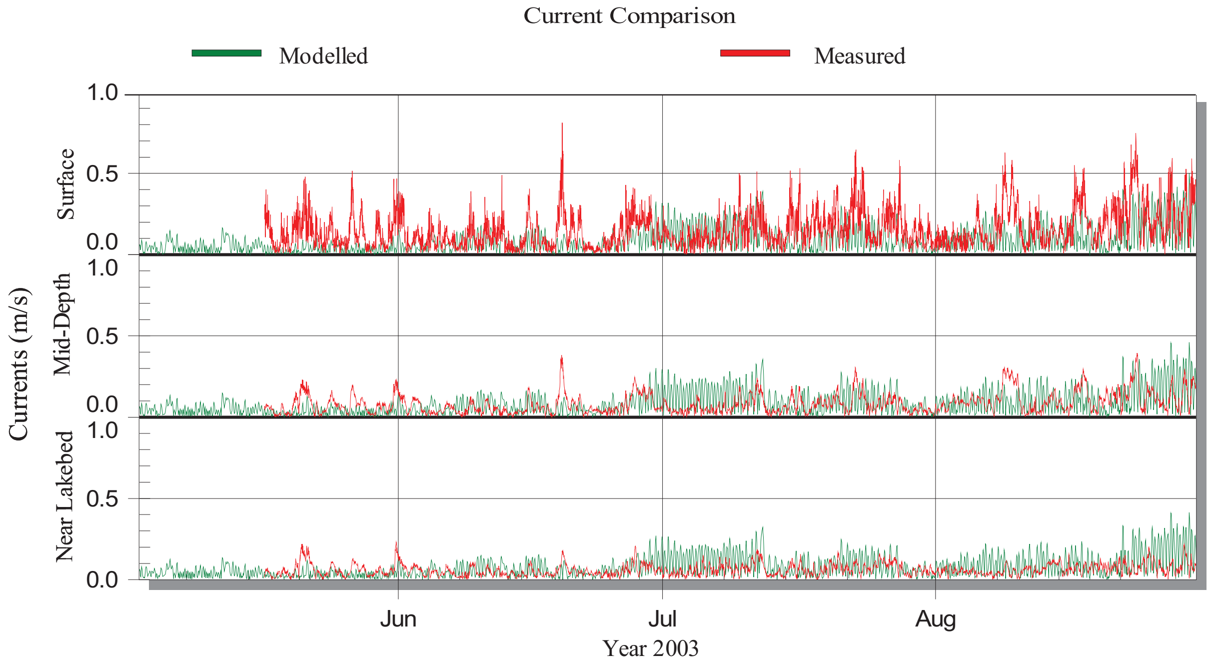


Figure 2.3a Comparison of the Modeled and Measured Current Speed at ADCP #3223

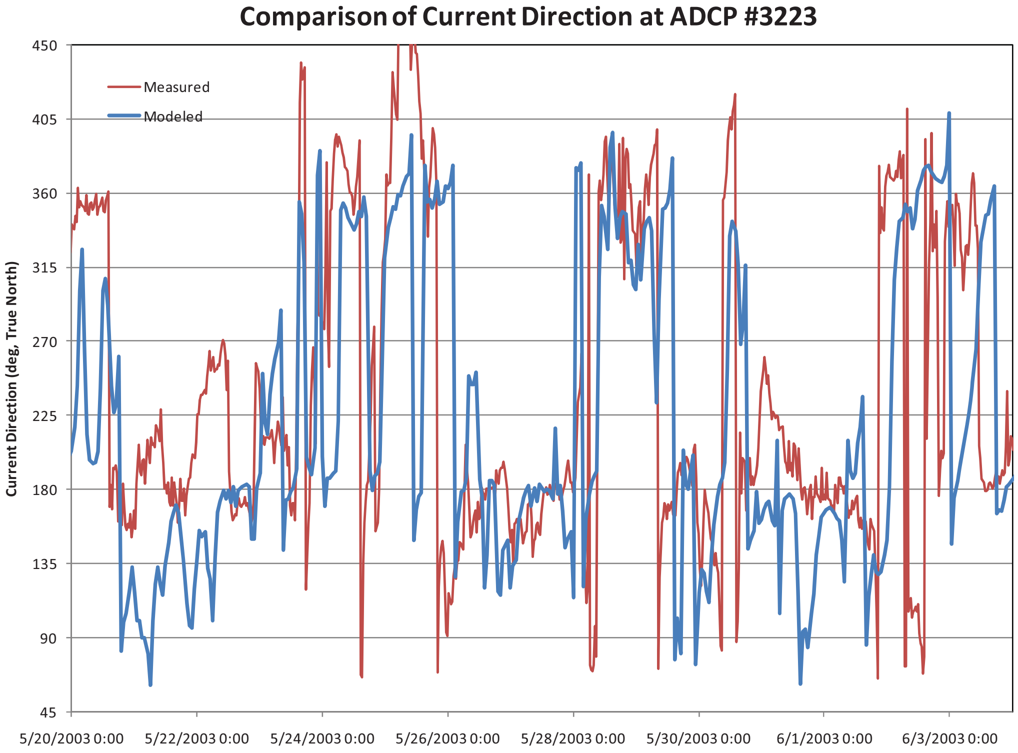


Figure 2.3b Comparison of the Modeled and Measured Direction at ADCP #3223

Table 2.1 Comparison of Average Modelled and Measured Current Velocities (m/s)

	#3501 (nearshore)		#3223 (offshore)	
Layer	Modelled	Measured	Modelled	Measured
Surface	0.15	0.21	0.11	0.18
Mid-Depth	0.14	0.10	0.10	0.09
Near Lakebed	0.12	0.07	0.08	0.07

The under-prediction at the surface may be partially explained by the way the model calculates velocities for the different depth layers. The model output for a given layer represents the vertically averaged velocity through the layer. The current speed is highest at the surface and decreases rapidly with depth as shown in Figure 2.4. Therefore, although the measured values for the surface comparison are truly at the surface, the modeled values are an averaged value through the top layer (which is 1.0 m thick at ADCP 3501 and 1.5 m thick at ADCP 3223). This does not explain the over-predictions by the model at mid-depth and near the lakebed.

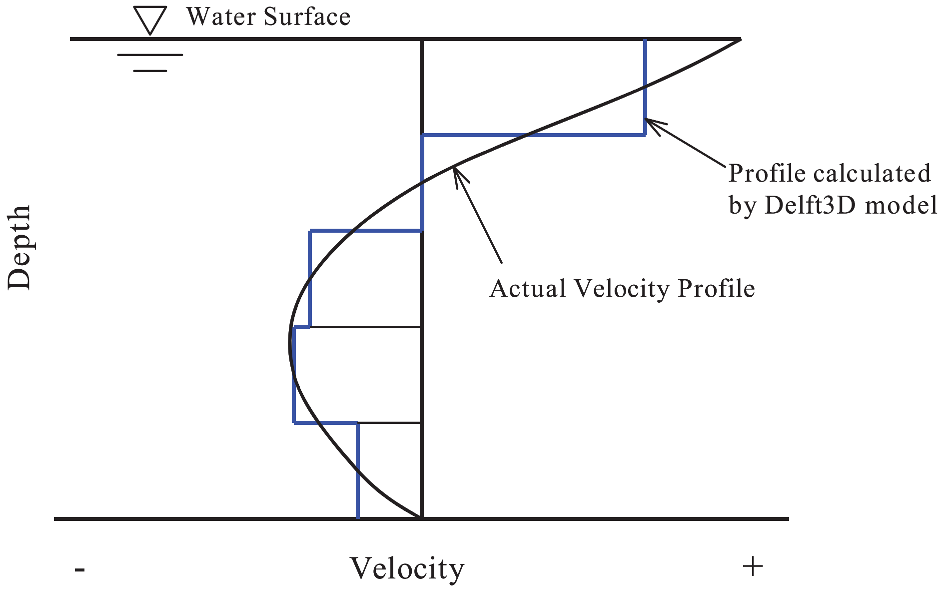


Figure 2.4 Schematic showing Measured and Modeled Current Velocity Profiles

Figure 2.5 shows measured and modeled current speed and direction for the two ADCP locations (3501 and 3223), for three elevations in the water column (surface, mid-depth and near lakebed). This plot shows that there is reasonably good agreement between the measured and modeled current directions at both locations (3501 and 3223). The ability to correctly model current directions is particularly important at this site, where the flow from the Maitland River and the harbour structures have a significant impact on the IPZ-2. As discussed previously and as was shown in Figure 2.5, the modelled results over-predict the current speeds for the mid-depth and bottom layers, and under-predict the current speeds for the surface layers. The model captures the predominance of north-south currents measured at both ADCP locations. Southward flowing currents were more accurately predicted; the model tended to overpredict currents flowing to the north at mid-depth and near the lakebed.

Current direction is directly affected by the wind direction at the surface, extending downward through the water column to near mid depth. Current directions near the lakebed are also affected by bathymetry and are generally in the opposite direction to the surface currents due to reverse flow.

In summary, the validation shows that at the nearshore location (3501), the model over-predicted average current speeds near the lakebed by 0.05 m/s, and at mid-depth the model over-predicted average current speeds by 0.04 m/s. At the surface, the model under-predicted average current speeds by 0.06 m/s. At the offshore location (3223) the model over-predicted average current speeds near the lakebed and at mid-depth by 0.01 m/s. At the surface, the model under-predicted average current speeds by 0.07 m/s. The modelled current directions were generally consistent with the measured values. The results of the validation provide a measurement of the level of uncertainty of the in-water IPZ-2 delineation.

Differences between the modeled and measured current velocities may be in part due to the need to calibrate the model. The wind drag coefficient and vertical eddy viscosity may require adjustment. Some inaccuracies re also introduced by differences between the POM wind data used to define the boundary conditions and the measured wind data (a comparison of the POM and measured data is provided in Figures 3.1 and 3.2). There is also a level of inaccuracy introduced by the currents from the POM model that are used to drive the boundary conditions for the Delft 3D model. The over-prediction of surface currents may also be partially explained by the way the model calculates velocities for the different depth layers as discussed previously.

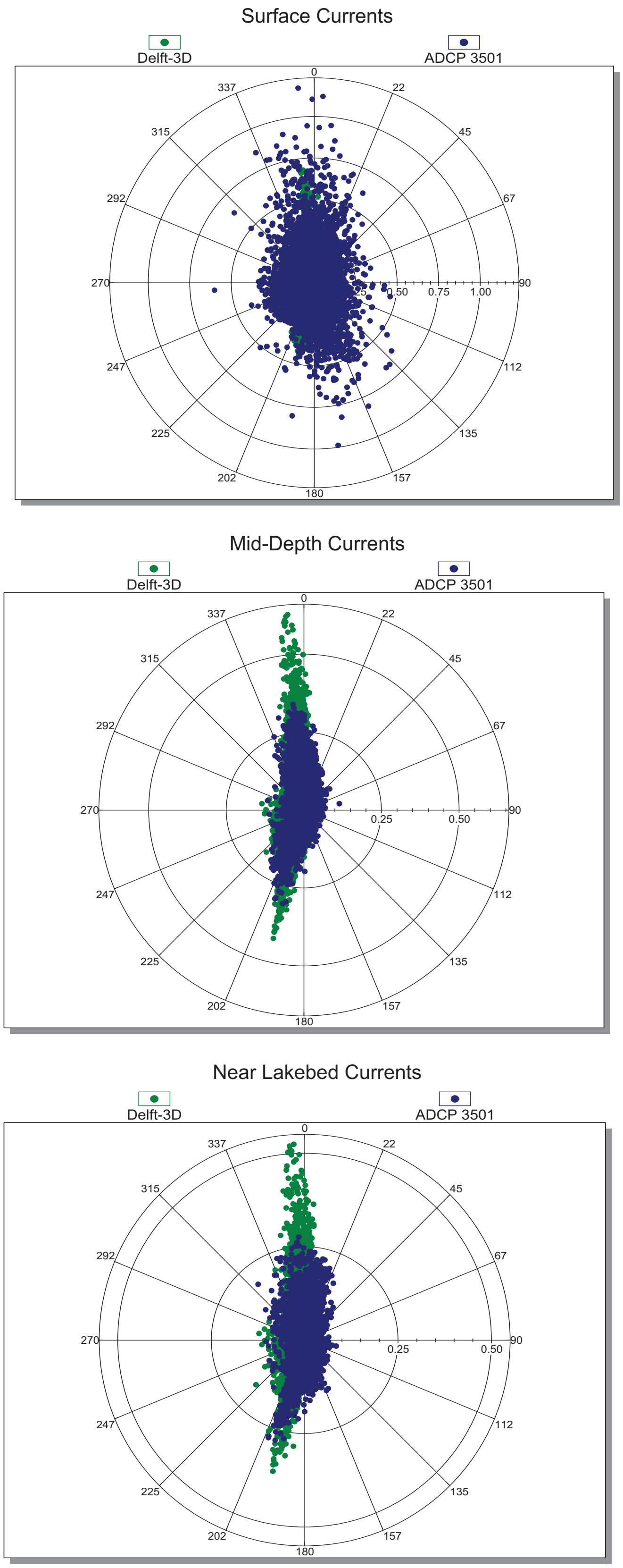
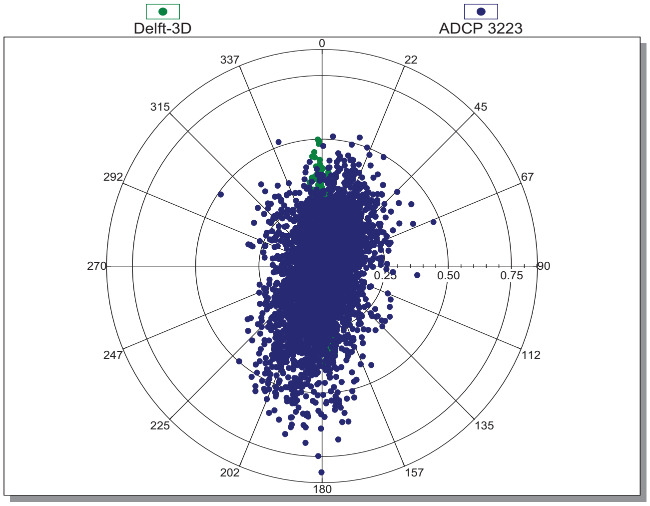
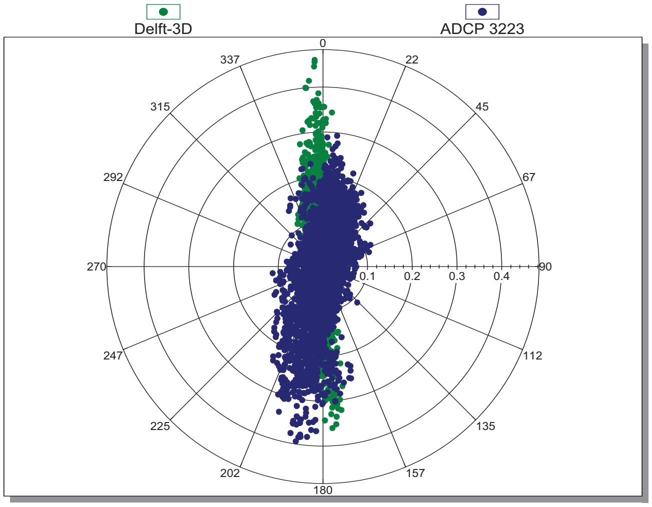


Figure 2.5a Comparison of Modeled (Delft-3D) and Measured (ADCP 3501) Current Speed and Direction

Surface Currents



Mid-Depth Currents



Near Lakebed Currents

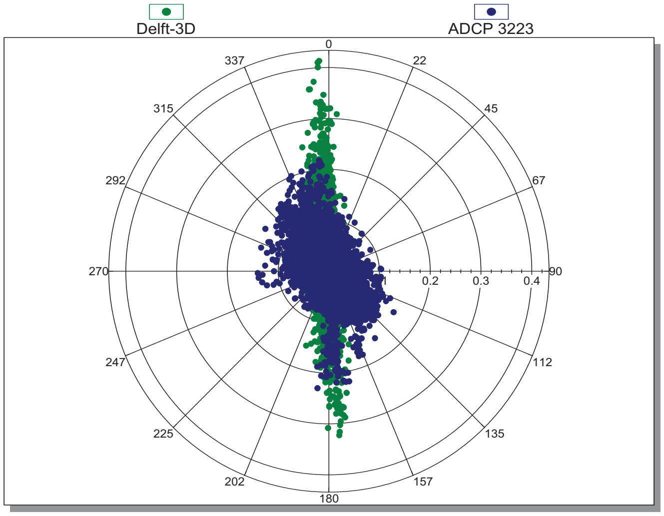


Figure 2.5b Comparison of Modeled (Delft-3D) and Measured (ADCP 3223) Current Speed and Direction

3.0 MODEL RUNS IN SUPPORT OF IN-WATER IPZ-2 DELINEATION

The model setup and runs undertaken in Phase 1 are described in Baird and BMROSS (2007). During that phase of the work, test runs were undertaken for two 3-week periods including the largest storm events observed in 2003, i.e. January 30, 2003 to February 20, 2003 and November 10, 2003 to December 5, 2003, were simulated. These two storm events produced the largest currents in 2003 and therefore represented the most extreme hydrodynamic conditions for that year. The results from the test runs were used to delineate the preliminary IPZ-2. No statistical analysis was undertaken to determine how these events might compare to the storm events in other years. In addition, no analysis was undertaken to define how extreme these events might be, i.e. the return period was undefined.

In this phase, 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 refine the IPZ-2.

3.1 Extreme Value Analysis to Define Matrix Runs

Wind data from the Goderich Municipal Airport, the Southern Lake Huron meteorological buoy (MEDS Station 45149), and the Princeton Ocean Model (POM) were reviewed. The airport data were selected for use in the extreme value analysis due to the longer period of record (1986 to 2007). The buoy data were also not appropriate for use in the extreme value analysis as data were not collected during the winter season, which coincides with the highest wind events.

The airport data were corrected to represent wind speed over water. The data were then compared with the POM data to identify possible data limitations or inconsistencies and required corrections were made. Plots comparing the data from the POM and the airport for 2003 are provided in Figure 3.1 and 3.2. While the airport data included more westerly and easterly events than the POM data, it can be seen that there is reasonable agreement between the airport and the POM data, especially considering that the POM results are not measured – rather they are extracted from a lake-wide model based on measured data at a number of stations.

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 3.1. The analysis indicates that the most severe events are from the east, west and northwest. The 10-year return period winds from Table 3.1 were used as input to the Delft3D model, as described in Section 3.2. Detailed output from the POT analysis is provided in Appendix A.

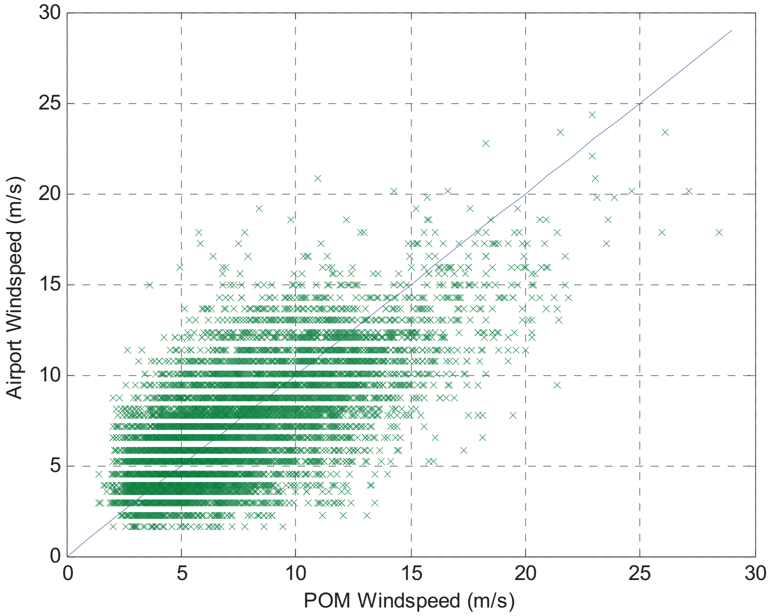


Figure 3.1 Corrected Airport Wind Speed vs. POM Wind Speed (2003)

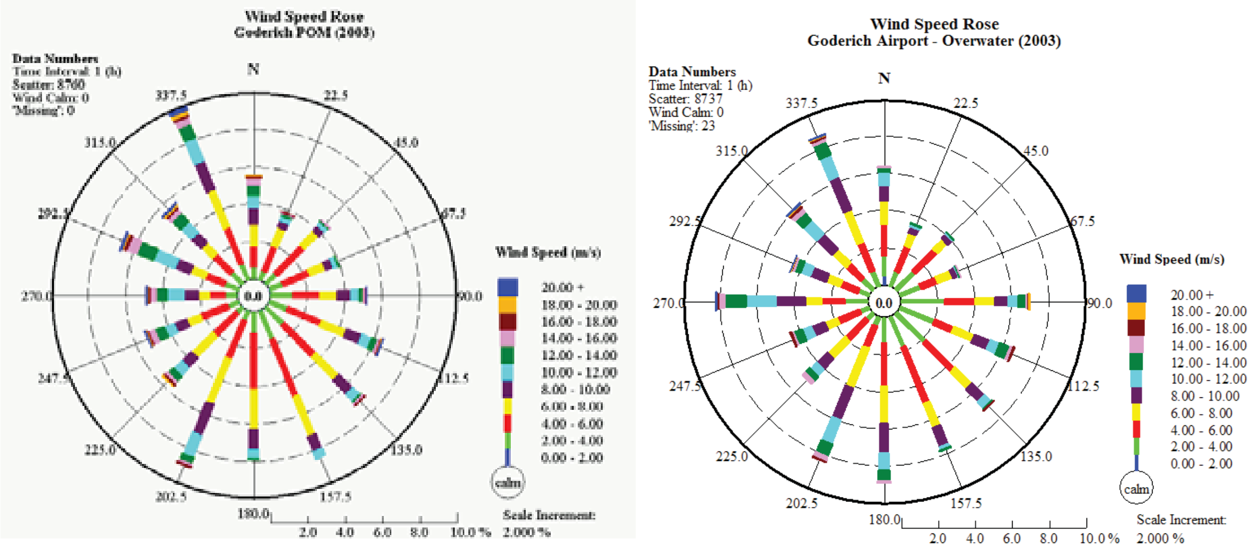


Figure 3.2 Wave Roses showing POM (left) and Airport (right) Wind Data

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Table 3.1
Directional Wind Speeds for Goderich Airport for Varying Return Period

Return Period (years)	Wind Speed (m/s)							
	N	NE	E	SE	S	SW	W	NW
2	17.7	12.7	18.8	15.9	16.5	18.9	19.0	19.2
5	18.9	14.6	20.5	16.9	17.2	20.1	20.5	21.0
10	19.5	15.4	21.6	17.4	17.6	20.7	21.4	22.2
20	20.1	16.1	22.6	17.8	17.9	21.3	22.2	23.3
25	20.3	16.4	22.9	18.0	18.0	21.5	22.5	23.7
50	20.8	17.0	23.8	18.3	18.3	22.0	23.2	24.7

3.2 Model Runs

A matrix of runs was undertaken using the statistical wind conditions described in Section 3.1. The model was run for the 10-year return period winds for directions N clockwise through NW (at 45 degree intervals). The directional wind speeds and return periods are listed in Table 3.1. A constant wind speed and direction was used along the entire model surface boundary. Mean lake levels were used at the offshore model boundary. The model was run to steady state, meaning it was run until current velocities stabilized or remained constant (in each case this occurred within 24 hours). A 2-year return period flow (approximating bank full conditions) was used in the Maitland River for all runs.

Output from the model runs is provided in Appendix B. The figures show the currents in the vicinity of the intake, for each of the eight wind directions run. Currents at the river mouth and around the breakwaters at the harbour entrance are complex, with various eddy formations, depending on the wind direction. For directions N, NE, E and SE, there is an eddy in the vicinity of the intake and the currents are relatively weak in this area. When the wind is from directions S, SW and W the currents at the intake are to the north. During NW winds, currents at the intake are moving in an onshore direction.

3.3 Reverse Particle Tracking to Delineate IPZ-2

Reverse particle tracking was used to refine the in-lake IPZ-2, previously delineated in Phase 1. In Phase 1, the model was run for two, three-week periods including the largest storm events in 2003.

Neutrally buoyant particles were introduced at the intake location. The intake is located in approximately 7 m water depth (see Baird and BMROSS, 2007). Particles were introduced at 3 depths; near lakebed, mid depth and at the surface. 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 2 hour travel time. One particle was released each second. The pathways are indicated by the red particles (near lakebed), purple particles (mid depth) and yellow particles (surface release) in Figure 3.3. Although the intake is located near the lakebed, the particles released at all three 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 mid depth and at the surface are larger than the near lakebed currents.

Figure 3.4 shows the travel distance contours for 0.5 hour intervals from 0.5 hours to 2.0 hours. The lines delineate the time that it would take a particle to reach the intake from the specified contour lines.

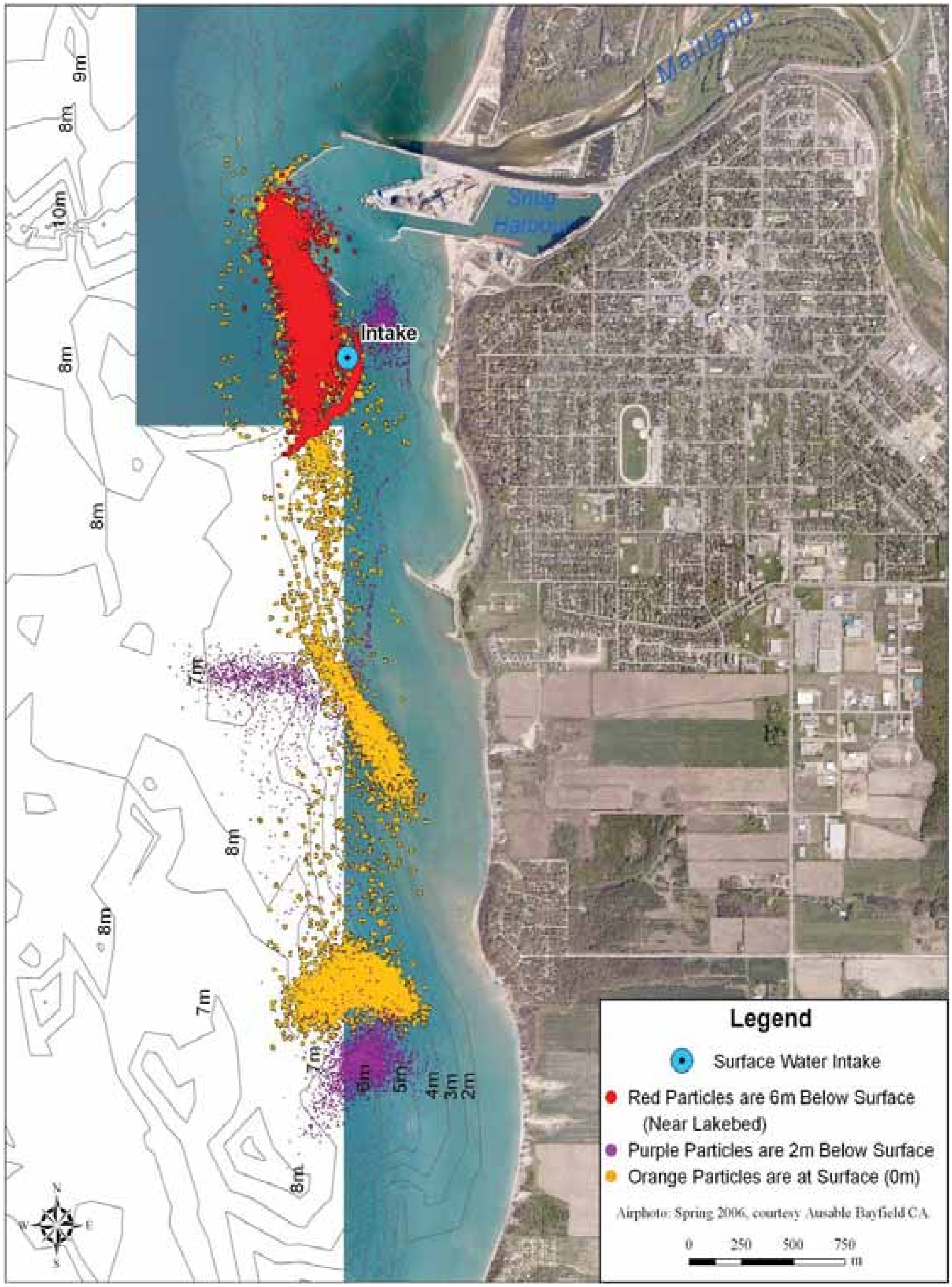
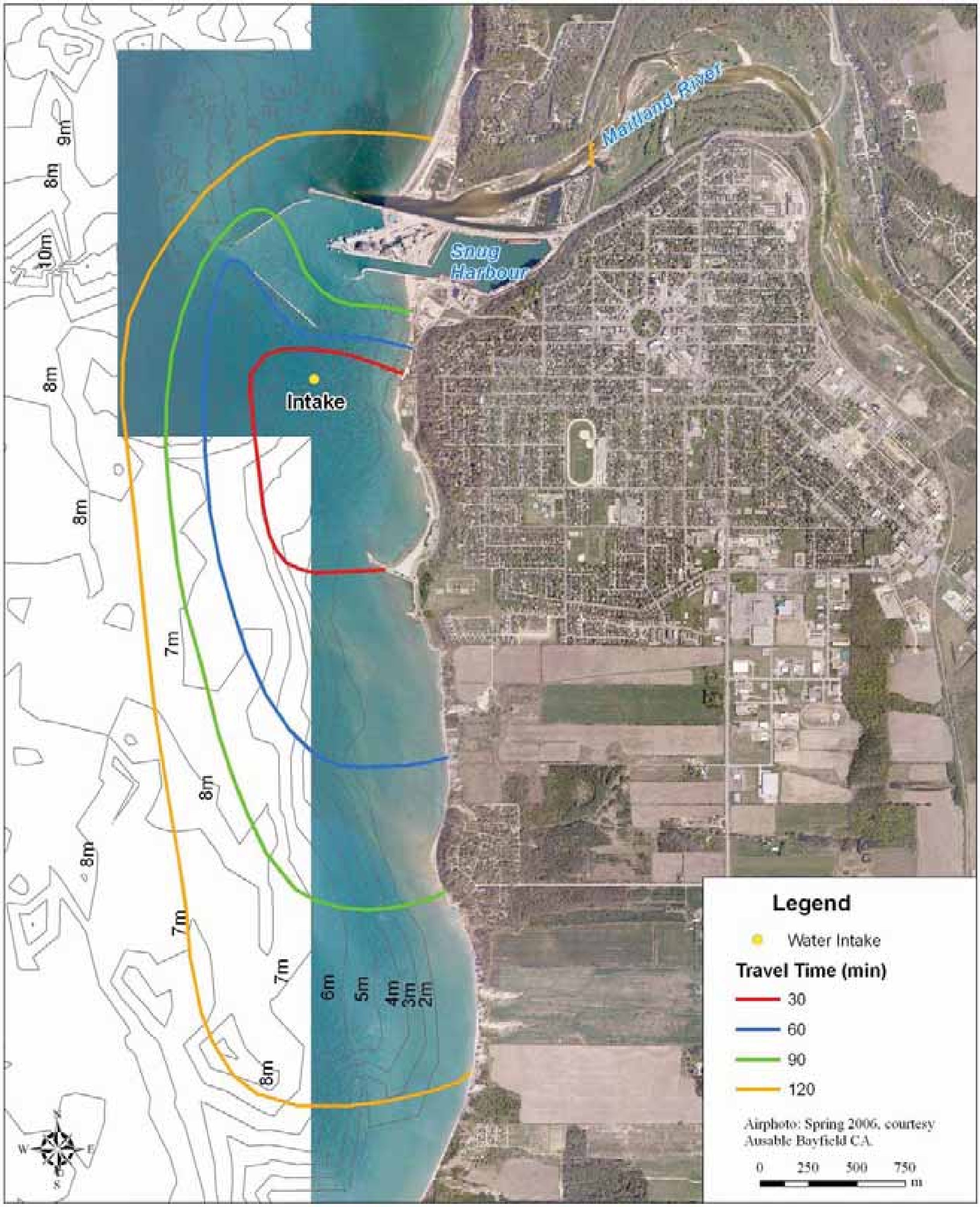


Figure 3.3 Reverse Particle Tracking showing the range of Particle Travel Distances for 2 Hour Model Run



Airphoto: Spring 2006, courtesy Ausable Bayfield CA.

Figure 3.4 Travel Distance Contours at 0.5 Hour Intervals based on Reverse Particle Tracking

When delineating the travel time contours, where the contour intersected the surf zone, the contour was extended in a shore perpendicular direction, through the surf zone, to the shoreline. The particle tracking results and connection to shore for a typical site are shown in Figure 3.4. The assumption is that mixing processes inside the surf zone could transport a contaminant to the offshore limit of the surf zone. This methodology was used to define the shore connection for the IPZ-2s and travel time contours.

The limits of the 2-hour travel distance extend approximately 1.2 km north, 3.6 km south, close to 1.0 km offshore of the intake, and within 100 m from shore at some locations. The in-lake IPZ-2 extends further to the south than to the north, as a result of the large circulation patterns in the lake (which mean that the current direction is not always the same as the wind direction) and localized eddy patterns in the vicinity of the intake. The eddy patterns are a localized effect, created by the harbour and breakwaters. As a result, the currents are predominantly to the north at the intake (this was described in some detail in the Phase 1 report). During winds from the north and east directions, an eddy pattern develops in the vicinity of the intake and currents are weak (see Appendix B, Figures B.1, B.2, B.3, B.4 and B.8). When winds are from the south and west (see Appendix B, Figures B.5, B.6 and B.7), there are strong northward flowing currents, causing the IPZ-2 to extend in a southerly direction. Figure 3.3 shows that similar patterns exist at mid-depth, while the currents at the bottom are smaller.

Based on the runs undertaken, the probability of contaminants from the river reaching the intake within the 2-hour travel time is relatively small. Uncertainties with the model based on the comparison of measured and modeled currents (presented in Section 2) are an important consideration. The presence of the jetties and the offshore breakwaters limit the distance the IPZ-2 extends up the river. Although no particles terminated in the river for the runs undertaken in this phase of the work, the IPZ-2 was extended into the river mouth for two reasons: 1) The runs undertaken in Phase 1 showed some incidence of particles reaching the river mouth; and 2) definition of the river geometry in the model is not well defined due to limited data. It is also important to understand that contaminants in the river could reach the intake if the 2-hour travel time were extended.

3.4 Discussion of Results

The in-water IPZ-2 delineated using the matrix runs which was based on running the model to steady state, for the 10 year return period winds, for eight compass point directions, was very similar to the results from Phase 1. In Phase 1 the delineation was based on running the model for two storm events. The POT analysis undertaken in Phase 2 suggests that Event A (modeled in Phase 1 and sown in Figure 3.5) exceeded the 10 year return period event, and in fact exceeded the 100 year event, albeit, for a limited range of directions and for a limited time. It also included the highest wind in the 22-year record. This provides some explanation for the similarities in results. The return period for Event B (also modeled in Phase 1 and shown in Figure 3.5) was in the 1 to 1.5 year range. The particle tracking results are highly dependent on the shoreline orientation and bathymetry, and the similarity in the Phase 1 and Phase 2 results could not have been predicted with any certainty, without running the model. At Goderich, the breakwater located north of the intake creates an eddy in its lee, and shelters the intake from north currents. This is a fairly unique feature that is reflected in the lack of symmetry in the IPZ-2. Variations in the northern extent of the IPZ-2, with different model runs, are smaller due to this sheltering effect. The fact that the storm events and the matrix runs resulted in similar IPZ-2s, improves our level of confidence in the IPZ-2 delineation.

For scientific defensibility, it is important to use a wind event with a known return period. For consistency, it is also important that a common standard be used to delineate the IPZs. To date, MOE has not provided a standard for the wind events to be used in IPZ-2 delineation for surface water intakes. The Guidance Module (MOE, 2006) states "the travel time in the lake can be calculated using average longshore current velocity during high wind and current period."

There are however some limitations with selecting a defined return period wind speed and running the model to steady state, as we have done for this work. For large lakes such as Lake Huron, the response time for the lake to reflect the given wind conditions is significant. The numerical model test results indicate that it takes several hours for full development of lake circulation driven by a constant wind. In reality, wind conditions will change in most cases, before the full hydrodynamic condition develops in response to the wind. Running the model to steady state is therefore not a realistic condition and in theory, the flow velocities produced using a constant wind in a "steady state" model application may over-predict the currents, when compared to those predicted using event based winds (i.e. actual measured winds). In this case, the IPZ-2s predicted using a storm event and the matrix of runs produced fairly similar results. That would not always be the case. Wind duration is an important consideration when modeling the currents in a large lake such as Lake Huron.

For this reason, it is important to model actual storm events, as well as defined return period events for a full range of directions, as has been done for this project. Further discussions on the model results used to delineate the IPZ-2 based on the preceding discussions are included in Sections 3.5 and 4.

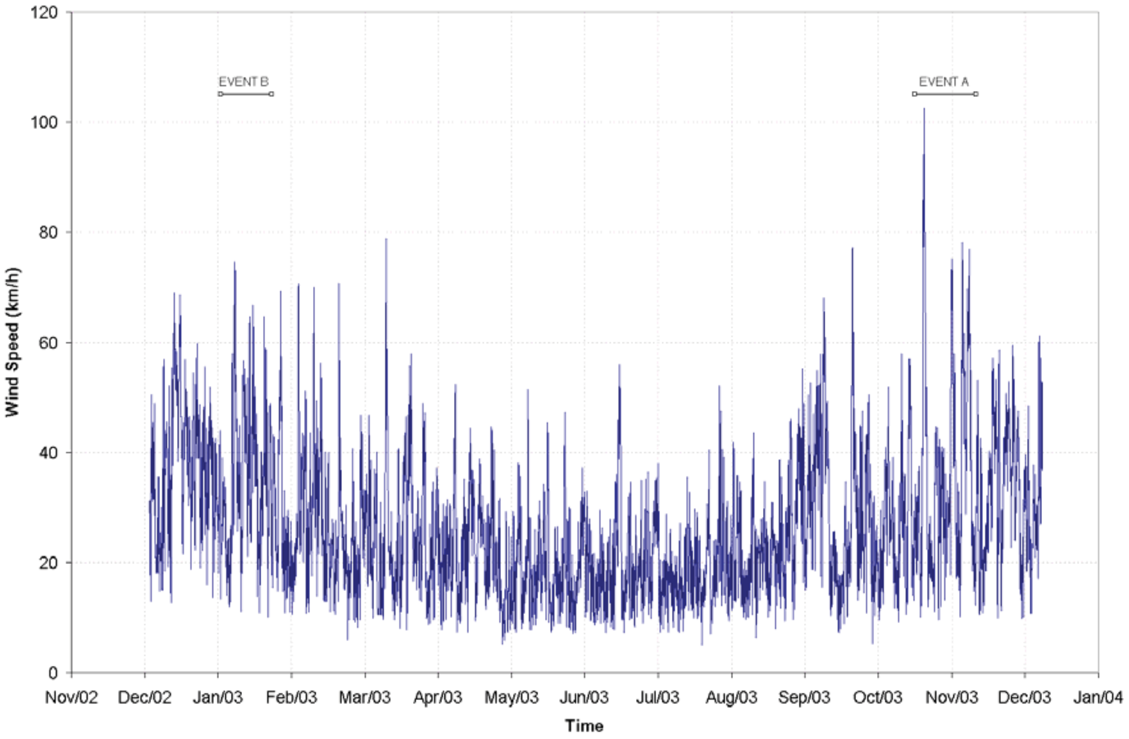


Figure 3.5 Wind Speeds at Goderich for 2003 Showing Extreme Events Modeled in Phase 1

3.5 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 and vulnerability scores in Module 4 (MOE, 2006). The key limitations of the modeling are as follows:

1. Current velocities predicted by the model were compared with measured ADCP data collected by MOE in 2003. This was not intended to be a comprehensive comparison, but rather to provide some measure of the level of uncertainty in the model. For the ADCP location nearest the intake, the model under-predicted the average current velocities at the surface by 40%, and over-predicted average current velocities near the lakebed by 70%. The model captures the predominance of north-south currents measured at both ADCP locations. Southward flowing currents were more accurately predicted; the model tended to overpredict currents flowing to the north at mid-depth and near the lakebed.

2. For the model runs used to delineate the IPZ-2, neutrally buoyant particles were released at the surface, at mid-depth and at the lakebed. Particles were free to move through the water column. The intake is located near the lakebed. The particles released at mid-depth and 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, as noted above, modeled current velocities at the water surface were less than measured values. The level of uncertainty in the model results (which may be partly due to boundary condition inaccuracy) was better defined by the model validation described in Section 2 and this was used in the assessment of the uncertainty of the IPZ-2 delineation as discussed in Section 5.

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 the previous phase, the model was run for two, three-week periods including significant storm events. As discussed previously, 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). The matrix runs predicted a similar IPZ-2 to the storm events modeled in Phase 1 (which exceeded a 10 year return period). This provides a basis for comparison and suggests that the IPZ-2 delineated is reasonable as discussed in Section 3.4.

4. In Phase 1, the model was set-up to include the entire Lake Huron, with the LHOFS model defining the boundary conditions for the more detailed Delft3D model as described in Baird and BMROSS (2007). The LHOFS model is run by the National Oceanic and Atmospheric Administration (NOAA) using actual wind data to produce real time output. The LHOFS model output was obtained by Baird for use on this project. The output is time series data and it therefore, does not include the conditions required to define the boundary conditions for the matrix runs (10-year return period winds blowing at a constant speed and direction, from eight different directions until the model reaches steady state). Furthermore, the LHOFS wind speed and direction varies along the model boundary and it would therefore be necessary to set some subjective criteria for defining 10 year events; and currents at the

boundary reflect currents that have developed over a period of time, and may not relate directly to the present wind condition (i.e. larger circulation patterns in the lake may have developed over the previous days). Therefore, combining the LHOFS winds from a 10 year return period event (if it existed) with the historically developed currents from the LHOFS, may not lead to 10 year return period currents. As a result, it was not possible to use the LHOFS to define the boundary conditions for the matrix runs and the Delft3D model of the study area was used for the matrix runs (i.e. the model did not include the entire Lake Huron). Previous investigations by Baird (Baird, 2007) have shown that some differences in model results can be expected when the model does not include the entire lake.

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 Goderich intake is located in 7 m depth (see Baird and BMROSS, 2007). This is a mid range depth where there would likely be some impact on the IPZ-2.

6. Cross-section data for the Maitland River were taken from the bathymetry field sheet for the lake. The IPZ-2 only extended a short distance into the river mouth, and this would therefore not significantly impact the IPZ-2. However, the data provides an approximation of the river cross-section only. In addition, due to lack of any additional upstream data, it has been assumed that the upstream river cross-sections are the same as the river mouth. This is also an approximation and actual river cross-section data should be collected in future phases to better define the velocities in the river and the IPZ-2 limits, particularly if longer shut-down times are considered, and for the delineation of the IPZ-3.

4.0 REFINEMENTS TO THE IN-WATER 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, 2005).

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]. The two hour minimum response time was used.

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].

This section describes refinements to the in-lake IPZ-2 that was originally delineated in Phase 1. The refinements are based on the reverse particle tracking undertaken in this phase of the work, as described in Section 3. Modifications to the IPZ-1 delineated in the Phase 1 studies were not considered in this phase of the work. Modifications to the extension up tributaries, upstream, on land and up transport pathways are not addressed in this report, as that work is being undertaken by BMROSS as part of the Phase 2 studies.

The currents used to delineate the IPZ-2 were defined based on the results of the numerical modeling described in Section 3, using the 2 hour contour. Figure 4.1 shows the in-water IPZ-2 delineated during Phase 1, along with the in-water IPZ-2 delineated in Phase 2. The changes are small and possible reasons are discussed in Section 3.4. The changes consist of slight modifications to the offshore extent of the IPZ-2 towards the southern end. The IPZ-1 (from Phase 1) and the in-water IPZ-2 from this phase of the work are shown in Figure 4.2. As discussed previously, some revisions to the inland and upstream extent of the IPZ-2 may be recommended by others, based on these modifications to the in-lake IPZ-2 and additional work undertaken in Phase 2.

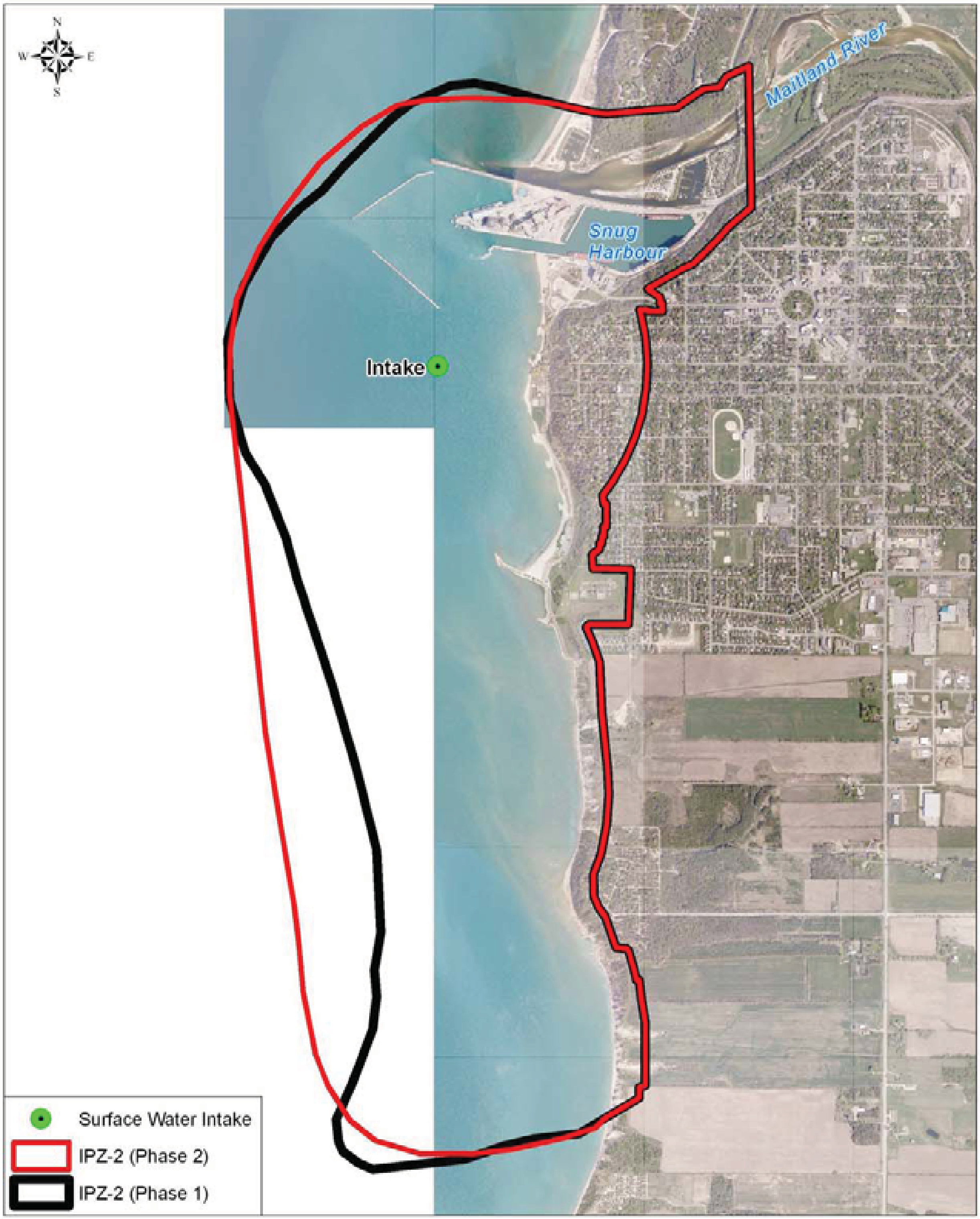


Figure 4.1 Comparison of IPZ-2 Delineations

Airphoto: Spring 2006, courtesy Ausable Bayfield CA.

Baird

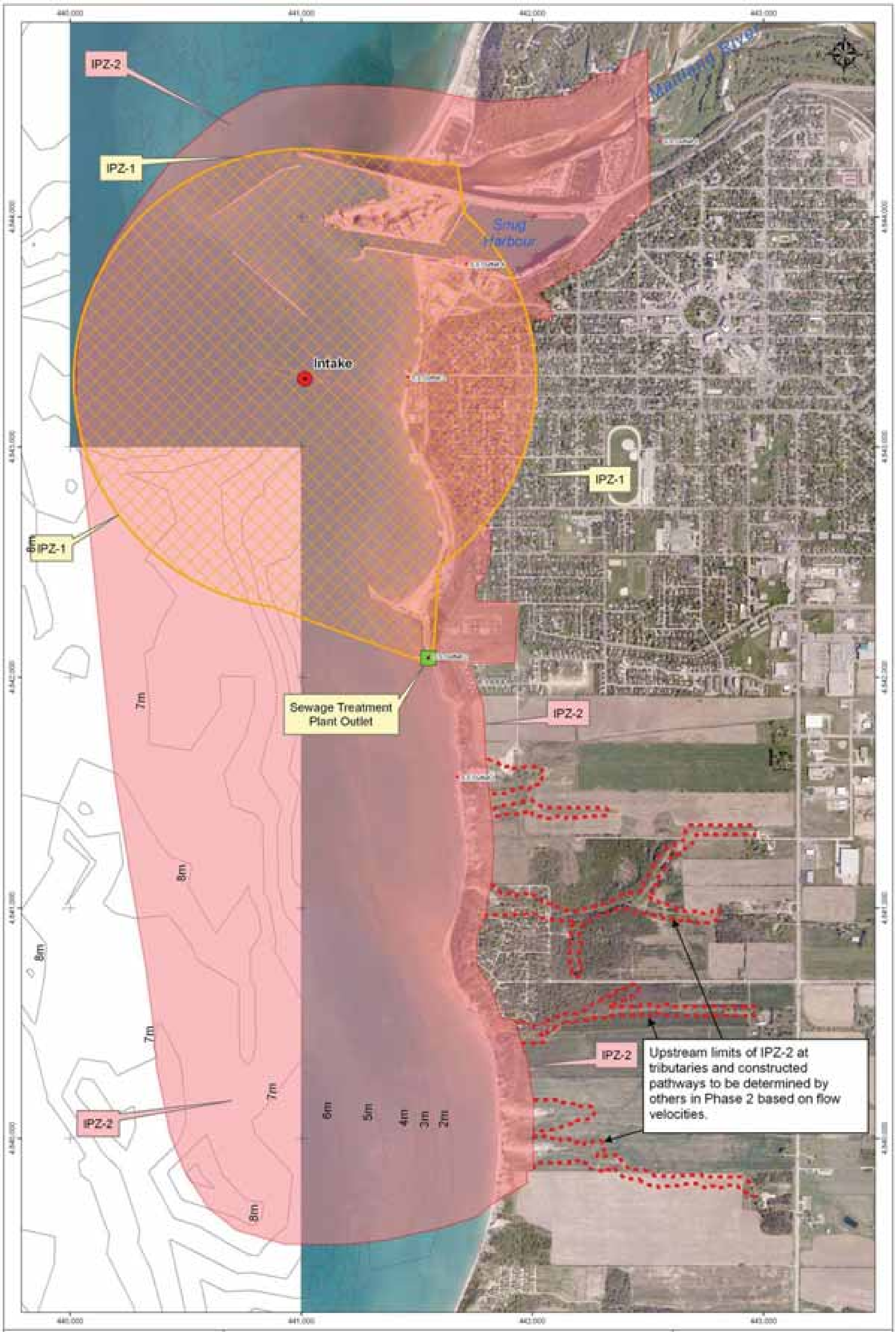


Figure 4.2 Goderich Intake Protection Zone Delineations (IPZ-1 & IPZ-2)

Airphoto: Spring 2006 courtesy Ausable Bayfield CA
Regulated Areas courtesy of Maitland Valley CA
Bathymetry derived from original CHS Field Sheets
Coordinate System: UTM zone 17, NAD83

Baird BMROSS

5.0 VULNERABILITY SCORES AND UNCERTAINTY

This section updates the vulnerability scores and uncertainty assessment provided in Baird and BMROSS (2007), based on the updated Technical Rules (MOE, 2009a).

5.1 General

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, 92 and 93	Area vulnerability factor for IPZ-2
Rule 94 to 96	Source vulnerability factor

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 ranges for Type A intakes are listed in Table 5.1.

Table 5.1
Vulnerability Score Ranges 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 and area vulnerability factors and vulnerability scores were developed using the methodologies described below.

5.2 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, 89, 92 and 93; MOE, 2009a]. The acceptable values for the area vulnerability factors (B) are listed in Table 5.1. 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 SOLARIS data provided by the Conservation Authority. The area vulnerability factor was assigned as follows: low (<33 % land = 7), moderate (33-66 % land = 8) or high (>66 % land = 9). The Goderich IPZ-2 was 64% land and sub-factor of 8 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 compiled from the SOLARIS data provided by the Conservation Authority. The land use data and Hydrologic Soil Group data from SOLARIS were used to determine the Curve Numbers from the curve number table in MOE's IPZ-3 Technical Bulletin (MOE, 2009b). 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, 2009a] because it represents both land cover and soil type. The mean CN in the IPZ-2 was estimated to be greater than 80, so a score of 9 was 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 SOLARIS data provided by the Conservation Authority. 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 Goderich IPZ-2 was 34 %, and a score of 8 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 provincial Digital Elevation Model data. 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 IPZ-2 was 2.6 %, so a score of 8 was 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 on the basis of the presence and proximity of outfalls in the IPZ-2 with respect to the intake. 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). An outfall was observed within the 1 hour travel contour, so a score of 9 was assigned to this factor.

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 higher 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 IPZ-2 was 1.1 km/km^2 (calculated from length of tributaries in IPZ-2 area/IPZ-2 on-land area, 8.54 km/7.77 km^2), and a score of 8 was assigned to this factor.

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 5.2.

Table 5.2

Derivation of Area Vulnerability Factor for Goderich IPZ-2

Rule	Criterion	Score	Rating			Sub-factor Score	Resulting Score
			Low (7)	**Moderate (8)**	**High (9)**		
% Land 92(1)	**Land-Water Ratio %**	64%	**<33**	33-66	>66	8	8
Land Characteristics 92(2)	**SCS CN – Count Twice!**	>80	**<55**	55-80	>80	9	(9+9+8+8)/4=8.5
	% Imperviousness (Permeability)	34	**0-20**	20-50	>50	8	
	Slope %	2.6	<2	2-5	**>5**	8	
Hydrological & Hydrogeological 92(3)	**Outfalls in Proximity**	1 outfall located within 1 hr of intake	No outfalls within IPZ-2	Outfall within 1-3 hours of intake	**Outfall within 1 hour of intake**	9	(9+8)/2=8.5
	Drainage Density (km/km^2)	1.1	<1	**1-3**	>3	8	
Area Vulnerability Factor[1]							(8+8.5+8.5)/3=8.3 **Rounded to 8**

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

5.3 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 5.1. 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, 2009a]:

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 5.3). The first three rows in Table 5.3 were taken directly from MDEQ (2004), while the bottom row lists the corresponding MOE source vulnerability factor proposed for use on this project.

Table 5.3
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 5.3, taking into consideration the severity of the threat. The source vulnerability factor must remain within the defined limits as listed in Table 5.1.

The Goderich intake is a Type A intake. It is located 518 m from shore, in approximately 7 m water depth (below Chart Datum). Based on the drawings, the intake is located approximately 1 m above the lakebed, (approximately 6 m below the water surface). Based on Table 5.3, a source vulnerability factor of 0.6 is recommended. A value of 0.7 was considered, however based on the discrepancies in the reported intake depth (Baird and BMROSS, 2007) and the fact that the depth is at the cutoff value (6 m), a mid range value of 0.6 is recommended. If water quality concerns are reported, the source vulnerability factor can be increased to a maximum of 0.7, to reflect these concerns. The WTP operator noted that the plant has not been shut down within the past 5-6 years and that water quality conditions at the intake have never exceeded the capabilities of the facility (Baird and BMROSS, 2007) and the source vulnerability factor was therefore not increased.

5.4 Vulnerability Scores

The vulnerability scores for the Goderich intake, calculated with the equation presented in Section 5.1 (V=BxC) and using values determined in Sections 5.2 and 5.3 are summarized in Table 5.4.

Table 5.4
Summary of Vulnerability Scores for Goderich

Intake Type	Area Vulnerability Factor (B)		Source Vulnerability Factor (C)	Vulnerability Score (V)	
	IPZ-1	IPZ-2		IPZ-1	IPZ-2
A	10	8	0.6	6	4.8

6.0 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.

6.1 Data Quality and Gaps

Data gaps and data quality issues identified during the study are listed below. It is noted that this listed relates to work undertaken by Baird (in-water delineation of IPZ-1 and IPZ-2). Possible data gaps related to water and sediment quality are not addressed in this report.

1. The data sources provide inconsistent information on the depth of the intake. This should be confirmed by a survey, possibly undertaken during the next scheduled inspection of the intake.
2. Cross-section data for the Maitland River were taken from the bathymetry field sheet for the lake. The data provides an approximation of the river cross-section only. In addition, due to lack of any additional upstream data, it was assumed that the upstream river cross-sections are the same as the river mouth. This is also an approximation and actual river cross-section data should be collected in Phase 2 to better define the velocities in the river and the IPZ-2 limits.
3. As noted in the Phase 1 report, there was a discrepancy in the gauge data for the Maitland River. This should be resolved.

The following provides a list of identified data gaps related to work undertaken by others (IPZ-1 and IPZ-2 delineation beyond in-water).

1. Tributary flow data and cross-section data were not available for the small tributaries flowing into the IPZ-2 is required to calculate flow velocities to delineate the upstream limit of the IPZ-2 at the tributaries. The flow in the tributaries can be estimated using empirical methods.

2. The onland extent of the IPZ-1 and IPZ-2 is measured as a setback from the HWM. As this was completed by others, we are not certain if the HWM used is consistent with the new direction provided by in MOE (2009c). The inland extent of the IPZ-1 and IPZ-2 may have to be adjusted if the vertical datum differs from that assumed.

6.2 Uncertainty in Modeling

The Delft3D 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 Delft3D model used in this study are described in Section 3.5.

6.3 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.

6.4 Model Calibration and Validation

Current data were measured by the Ministry of the Environment (MOE) at two locations from May to November of 2003. 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. The current velocities predicted by the Delft 3D model were compared with measured current data, to assess the accuracy of the model results. This was not intended to be a calibration/validation exercise and was tailored to available funding. Since this work was completed, the Delft3D model of Lake Huron was calibrated for source water studies undertaken on behalf of the Saugeen, Grey Sauble and Northern Bruce Peninsula Source Protection Region. The model calibration is described in Baird (2009). There is an opportunity to update the IPZ-2 using the calibrated model in a future phase.

6.5 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 5.2.

There is a level of uncertainty associated with the SCS Curve No., which was estimated from the SOLARIS landcover and hydrologic soil group datasets provided by the Conservation Authority. The uncertainty arises from the fact that the SCS Curve No. was approximated and 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 5.2). 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 extracted from the sources listed in the Phase 1 report (Baird and BMROSS, 2007). There is some uncertainty with the depth of the intake, as there were discrepancies in the various data sources. A high level of uncertainty has therefore been assigned to the source vulnerability factor.

6.6 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 6.1.

The IPZ-1 is delineated as a 1 km radius around the intake, extending onland 120 m from the high water mark or to the regulation limit. The onland setback was completed by others and confirmation that the high water mark was used to delineate the onland setback is required. The IPZ-1 has been extended to include the waste water treatment plant outfall and parts of the harbor. This is not consistent with MOE (2009a) and a high level of uncertainty has therefore been assigned to the IPZ-1 delineation. There is a low level of uncertainty in QA/QC as stated in Section 6.3. An overall high level of uncertainty has been assigned to the IPZ-1 delineation.

Table 6.1
Summary of Uncertainty Ratings for IPZ Delineation and Vulnerability Scores for Goderich WTP

IPZ	Uncertainty for IPZ Delineation		Uncertainty for Vulnerability Scores	
	Evaluation Factor	Rating	Evaluation Factor	Rating
IPZ-1	Data	High	Data	High
	QA/QC	Low	QA/QC	Low
			Accuracy of Vuln. Factors	High
	Overall	High	Overall	High
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-2 delineation has a high overall rating of uncertainty. Data gaps pertaining to the IPZ-2 delineation are listed in Section 6.1. 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 a detailed calibration of the model was not undertaken.

The uncertainty rating for the data used to define the source vulnerability factor (offset from shore, depth and history of water quality concerns) is high. There is some uncertainty in the depth at which the intake is located and this could affect the source vulnerability score. 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 (2009a) as 10. The level of uncertainty for the area vulnerability for the IPZ-2 is high due to the reasons given in Section 6.5, largely related to the wide range of approaches that could be adopted. An overall rating of high was therefore assigned to the IPZ-1 vulnerability score and to the IPZ-2 vulnerability score.

7.0 SUMMARY AND CONCLUSIONS

1. This Addendum describes additional work undertaken to complete the numerical modeling initiated in the first phase of the studies and to refine the in-water IPZ-2 based on the results of the modeling.

2. The objective of this work was to improve the level of confidence in the in-water IPZ-2 delineation, and to better define the level of uncertainty associated with this work through: comparison of the modeled currents with measured current data; a statistical analysis of measured wind data to define return period events; and additional numerical modeling using reverse particle tracking with the 10 year return period wind for 8 compass point directions, combined with a 2 year return period flow in the Maitland River.

3. The current velocities predicted by the Delft 3D model were compared with measured current data, to assess the accuracy of the model results. This was not intended to be a calibration/validation exercise and was tailored to available funding. In the vicinity of the intake, the model over-predicted average current speeds near the lakebed by 0.05 m/s, and at mid-depth the model over-predicted average current speeds by 0.04 m/s. At the surface, the model under-predicted average current speeds by 0.06 m/s. The model captured the predominance of north-south currents measured at both ADCP locations. The results of the validation provide a measurement of the level of uncertainty of the in-water IPZ-2 delineation.

4. Since this work was completed, the Delft3D model of Lake Huron was calibrated for source water studies undertaken on behalf of the Saugeen, Grey Sauble and Northern Bruce Peninsula Source Protection Region. The model calibration is described in Baird (2009). There is an opportunity to update the IPZ-2 using the calibrated model in a future phase.

5. An extreme value analysis was undertaken to define directional wind speeds for varying return periods using wind data from Goderich Airport. The model was run to steady state, for the 10-year return period winds for directions N clockwise through NW (at 45 degree intervals). A 2-year return period flow (approximating bank full conditions) was used in the Maitland River for all runs.

6. Reverse particle tracking was used to refine the in-lake IPZ-2 delineated in Phase 1. Neutrally buoyant particles were introduced at the intake (in approximately 7 m water depth). Particles were introduced at 3 depths; near lakebed, mid depth and at the surface. Although the intake is located near the lakebed, the particles released at all three 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 mid depth and at the surface are larger than the currents near the lakebed, where the intake is located.

7. The in-water IPZ-2 delineated using the matrix runs was similar to the results from Phase 1 (in Phase 1 the model was run for two periods of three week duration, including the two

largest storm events in 2003). A review of the wind data from Goderich Airport shows that one of the storms modeled in Phase 1 included the highest wind event in the 22-year record, and that it exceeded the 10 year return period wind. This provides some explanation for the similarities in results. The particle tracking results are highly dependent on the shoreline orientation and bathymetry, and the similarity in the Phase 1 and Phase 2 results could not have been predicted with any certainty, without running the model. At Goderich, the breakwater located north of the intake creates an eddy in its lee, and shelters the intake from north currents. This is a fairly unique feature that is reflected in the lack of symmetry in the IPZ-2. Variations in the northern extent of the IPZ-2, with different model runs, are smaller due to this sheltering effect. The fact that the storm events and the matrix runs resulted in similar IPZ-2s, improves our level of confidence in the IPZ-2 delineation.

8. It is important to understand the model limitations as listed in Section 3.5.

9. Vulnerability scores have been recommended for the IPZs. The vulnerability scores for the IPZ-1 and IPZ-2 are 6 and 4.8 respectively.

10. There is a high level of uncertainty associated with the IPZ-1 and IPZ-2 delineations, and with the vulnerability scores for the reasons discussed in Section 6. This is not a reflection of the quality of work, but recognition of the limitations presented. It is our opinion that the level of effort and modeling undertaken meets or exceeds the requirements of MOE as described in MOE (2009a). It is recommended that data gaps and model limitations be considered and addressed as warranted in future phases.

8.0 REFERENCES

Baird and BMROSS, 2007. Surface Water Vulnerability Analysis for Goderich Intake. A report prepared for the Town of Goderich dated August 14, 2007.

Baird, 2007. Intake Protection Zone Delineation for Kincardine and Southampton. A report prepared for Stantec Consulting as part of the Source Water Studies for Saugeen Valley Conservation Authority.

Michigan Department of Environmental Quality, 2004. Michigan Department of Environmental Quality Water Bureau. State of Michigan Source Water Assessment Program Report, December 2004.

Ministry of the Environment. 2006. Assessment Report: Draft Guidance Modules.

Ministry of the Environment. 2009a. Technical Rules: Assessment Report, Clean Water Act, 2006. Dated November 16, 2009.

Ministry of the Environment. 2009b. Technical Bulletin: Delineation of Intake Protection Zone 3 Using the Event Based Approach (EBA). Dated July 2009.

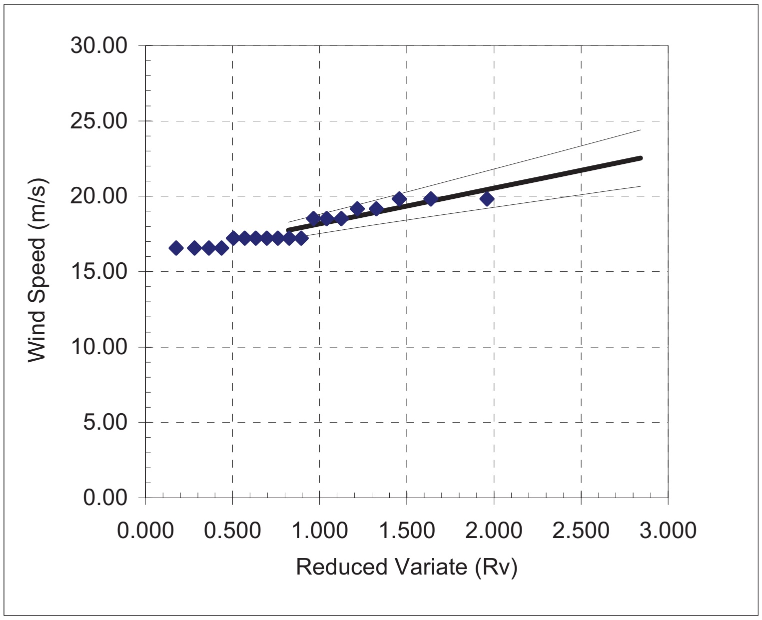
Ministry of the Environment. 2009c. MOE Liaison Officer Program Update. Dated December 18, 2009.

APPENDIX A
POT ANALYSIS FOR GODERICH WIND DATA

Peak over Threshold Extreme Value Analysis

Data Set: Goderich Airport Data - 1986-2008, Winds from North.

Three-Parameter Weibull Distribution



Total Years of Data:	19
Total Storm Events:	19
Total No. Events Selected:	19
Events per year:	1.00

Sample Statistics

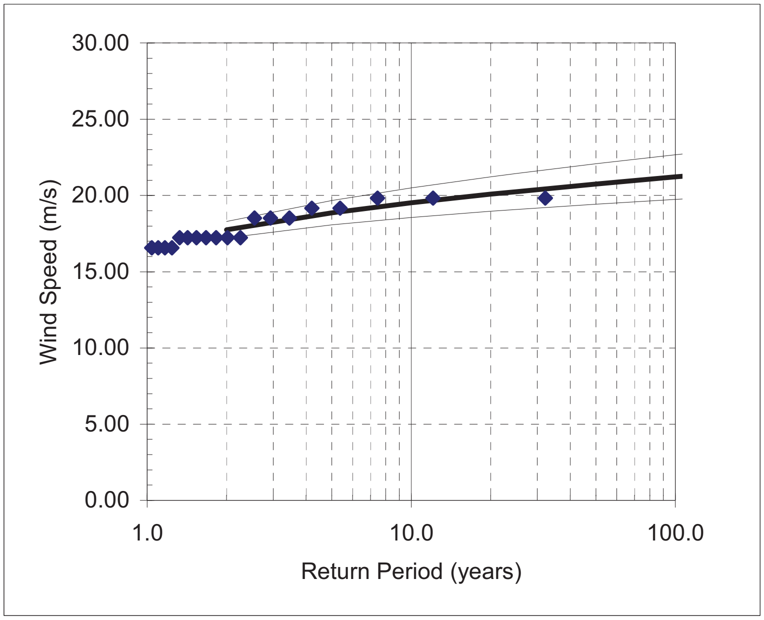
Mean:	17.90
Maximum:	19.82
Minimum:	16.57
s:	1.20
Sample skewness:	-0.43

Weibull Parameters

Shape:	1.85
Scale:	2.368
Location:	15.801

Goodness of Fit

Correlation:	0.950



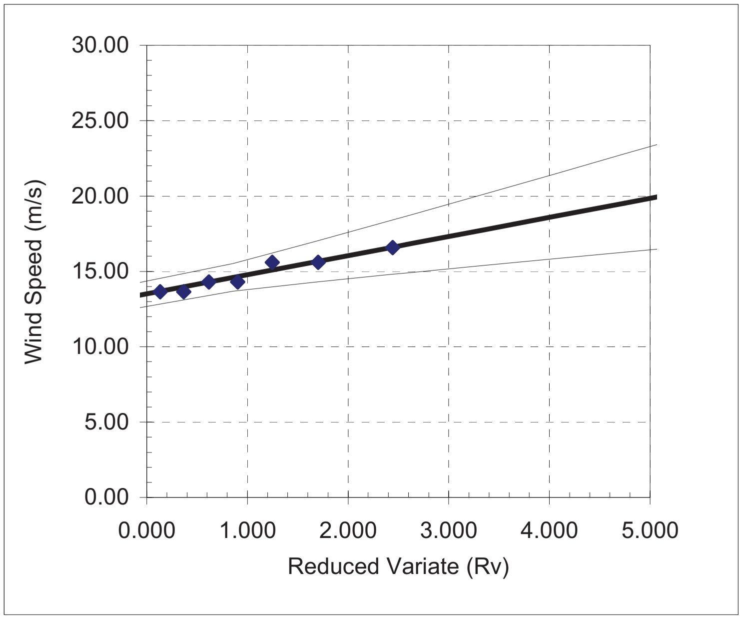
Return Period

		Confidence Limit	
Tr	X(T)	Upper	Lower
1	#NUM!	#NUM!	#NUM!
2	17.74	18.3	17.2
5	18.86	19.7	18.1
10	19.52	20.5	18.5
20	20.09	21.2	19.0
25	20.26	21.4	19.1
50	20.75	22.1	19.4
100	21.21	22.7	19.7
500	22.16	23.9	20.4
1000	22.53	24.4	20.7

Figure A.1 POT Analysis for North Wind

Peak over Threshold Extreme Value Analysis

Data Set: Goderich Airport Data - 1986-2008, Winds from Northeast.



Fisher-Tippet I (Gumbel)

Total Years of Data:	19
Total Storm Events:	11
Total No. Events Selected:	11
Events per year:	0.58

Sample Statistics

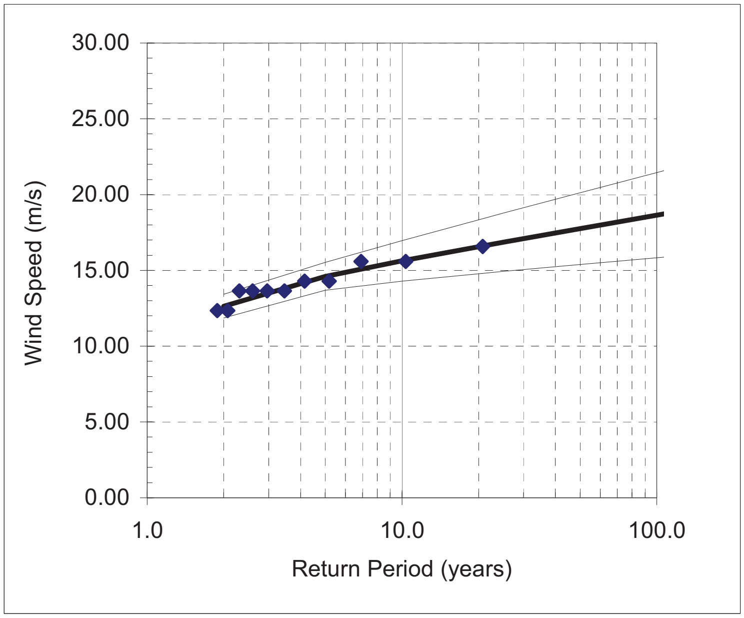
Mean:	14.15
Maximum:	16.57
Minimum:	12.345
s:	1.33
Sample skewness:	-1.49

FT I Parameters

Scale:	1.268
Location:	13.514

Goodness of Fit

Correlation:	0.970



Return Period

		Confidence Limit	
Tr	X(T)	Upper	Lower
2	12.64	13.42	11.85
5	14.60	15.52	13.68
10	15.62	16.96	14.28
20	16.56	18.34	14.78
25	16.86	18.78	14.94
50	17.76	20.12	15.39
100	18.65	21.46	15.84
200	19.53	22.79	16.27
500	20.70	24.55	16.84
1000	21.58	25.89	17.27

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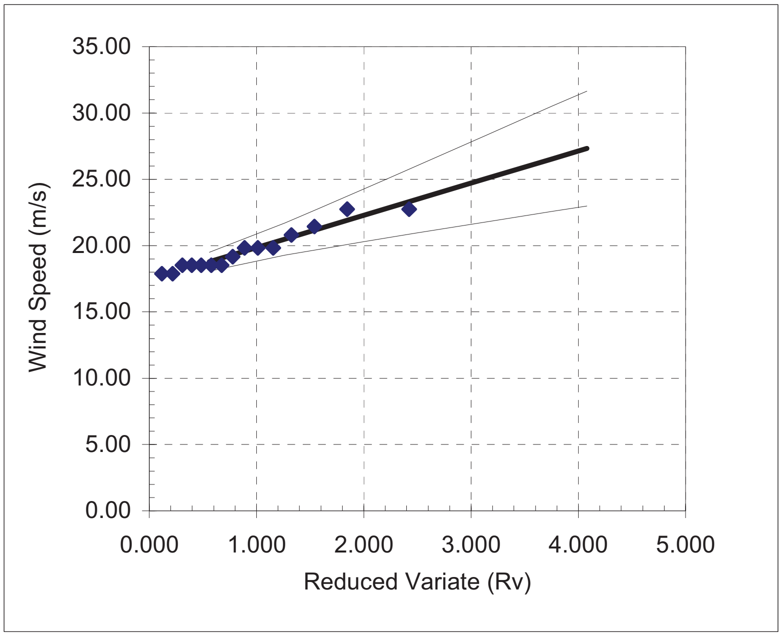
Figure A.2 POT Analysis for Northeast Wind

Peak over Threshold Extreme Value Analysis

Data Set: Goderich Airport Data - 1986-2008, Winds from East.

Three-Parameter Weibull Distribution



Total Years of Data:	19
Total Storm Events:	15
Total No. Events Selected:	15
Events per year:	0.79

Sample Statistics

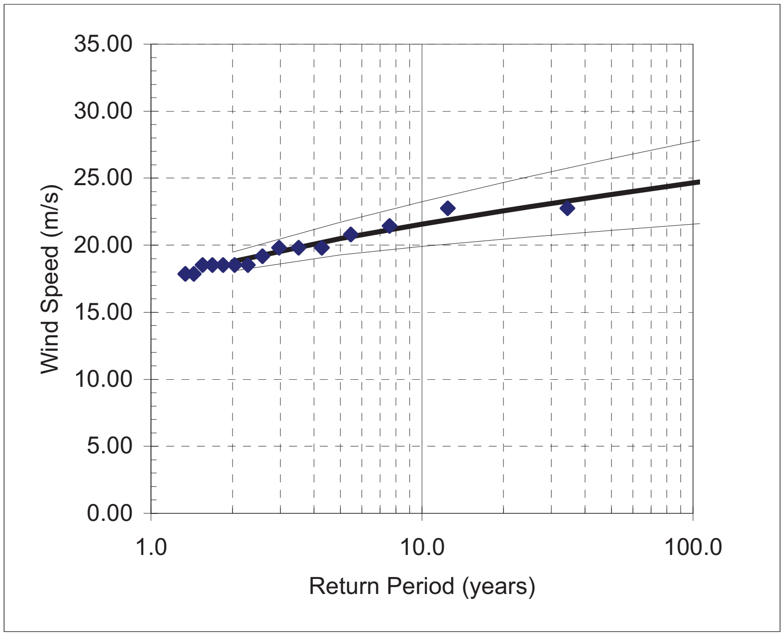
Mean:	19.65
Maximum:	22.75
Minimum:	17.87
s:	1.62
Sample skewness:	-1.40

Weibull Parameters

Shape:	1.35
Scale:	2.428
Location:	17.423

Goodness of Fit

Correlation:	0.973



Return Period

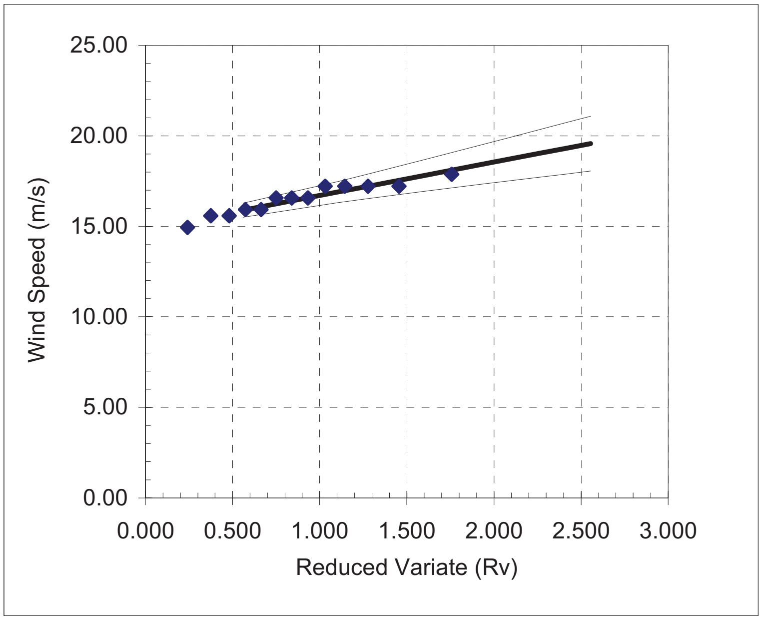
		Confidence Limit	
Tr	X(T)	Upper	Lower
1	#NUM!	#NUM!	#NUM!
2	18.78	19.5	18.1
5	20.49	21.7	19.3
10	21.58	23.3	19.9
20	22.57	24.7	20.5
25	22.88	25.1	20.6
50	23.79	26.5	21.1
100	24.66	27.7	21.6
500	26.55	30.5	22.6
1000	27.33	31.7	23.0

Baird

Figure A.3 POT Analysis for East Wind

Peak over Threshold Extreme Value Analysis

Data Set: Goderich Airport Data - 1986-2008, Winds from Southeast. **Three-Parameter Weibull Distribution**



Total Years of Data:	19
Total Storm Events:	13
Total No. Events Selected:	13
Events per year:	0.68

Sample Statistics

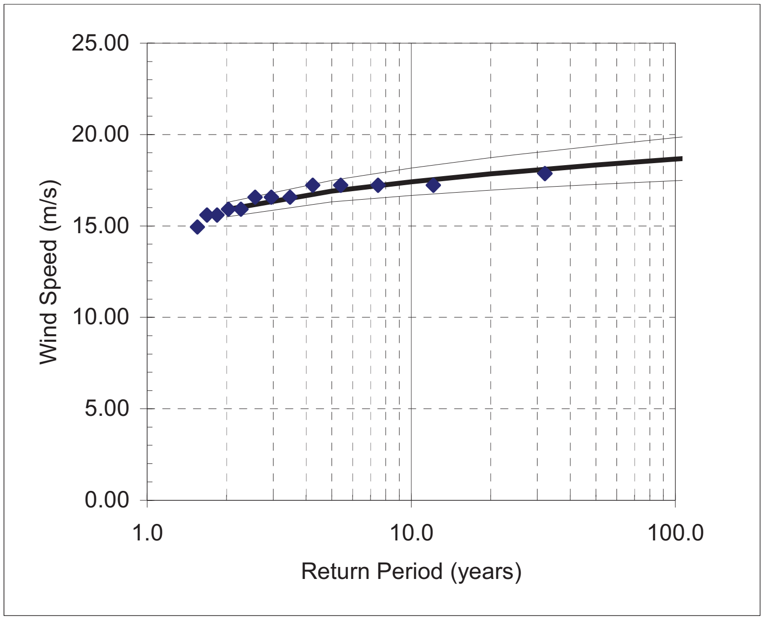
Mean:	16.50
Maximum:	17.87
Minimum:	14.95
s:	0.85
Sample skewness:	-0.47

Weibull Parameters

Shape:	2.00
Scale:	1.845
Location:	14.860

Goodness of Fit

Correlation:	0.956



Return Period

		Confidence Limit	
Tr	X(T)	Upper	Lower
1	#NUM!	#NUM!	#NUM!
2	15.89	16.3	15.5
5	16.91	17.5	16.3
10	17.42	18.2	16.7
20	17.84	18.7	17.0
25	17.97	18.9	17.0
50	18.33	19.4	17.3
100	18.65	19.8	17.5
500	19.32	20.7	17.9
1000	19.57	21.1	18.1

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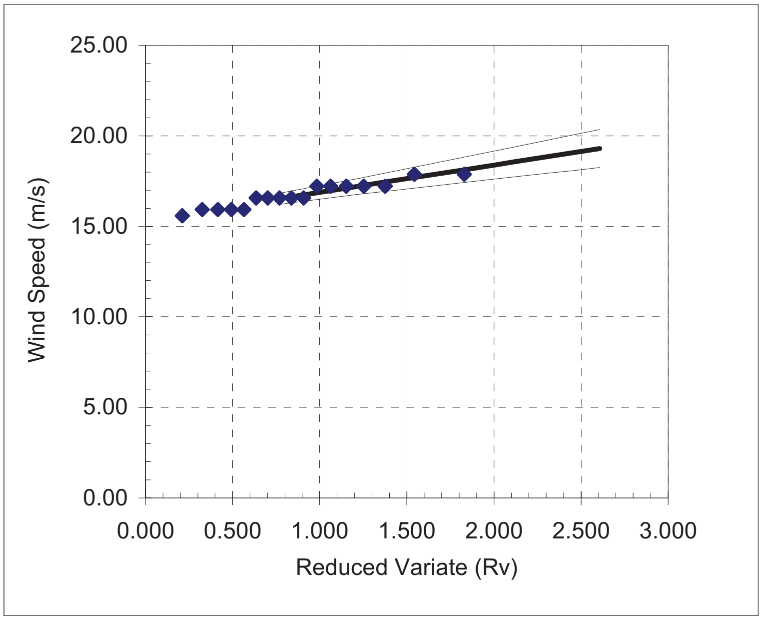
Figure A.4 POT Analysis for Southeast Wind

Peak over Threshold Extreme Value Analysis

Data Set: Goderich Airport Data - 1986-2008, Winds from South.

Three-Parameter Weibull Distribution



Total Years of Data:	19
Total Storm Events:	17
Total No. Events Selected:	17
Events per year:	0.89

Sample Statistics

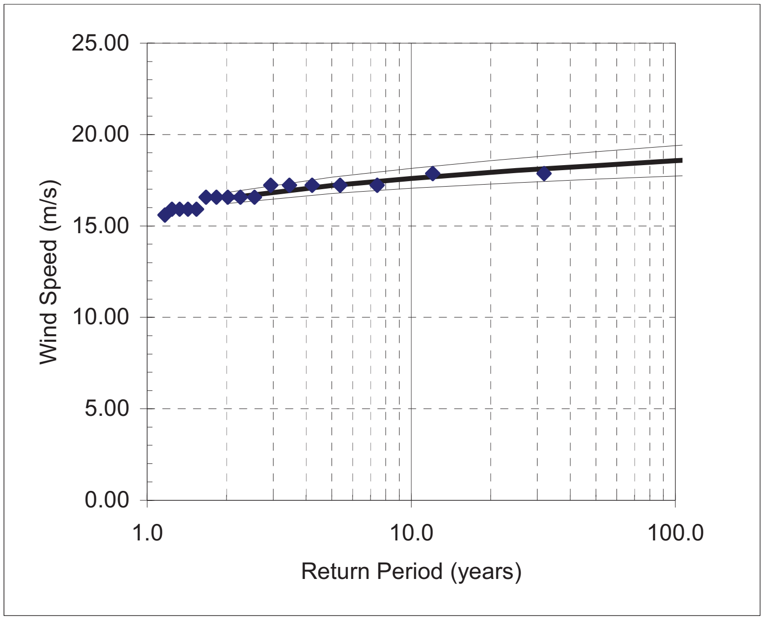
Mean:	16.70
Maximum:	17.87
Minimum:	15.6
s:	0.70
Sample skewness:	-0.19

Weibull Parameters

Shape:	2.00
Scale:	1.508
Location:	15.368

Goodness of Fit

Correlation:	0.960



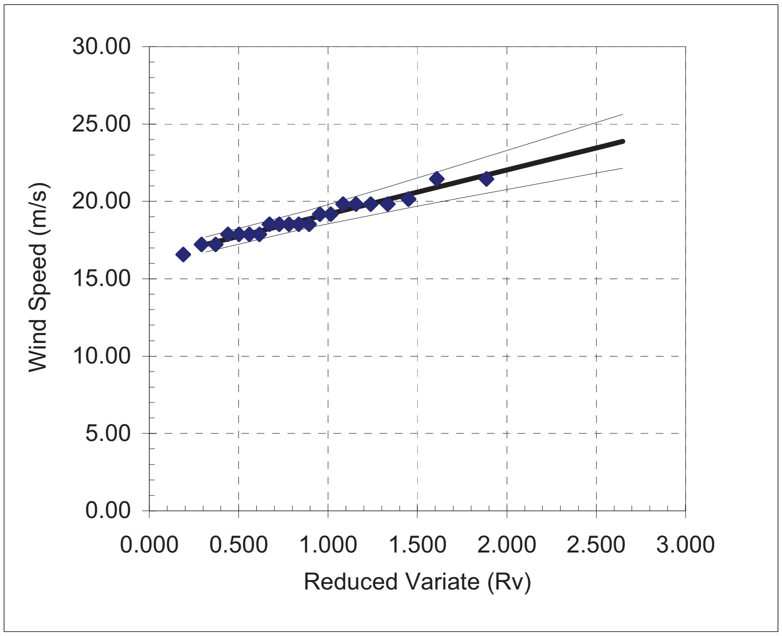
Return Period

		Confidence Limit	
Tr	X(T)	Upper	Lower
1	#NUM!	#NUM!	#NUM!
2	16.52	16.8	16.2
5	17.21	17.7	16.8
10	17.60	18.1	17.1
20	17.93	18.6	17.3
25	18.03	18.7	17.4
50	18.31	19.1	17.6
100	18.56	19.4	17.7
500	19.09	20.1	18.1
1000	19.30	20.4	18.2

Figure A.5 POT Analysis for South Wind

Peak over Threshold Extreme Value Analysis

Data Set: Goderich Airport Data - 1986-2008, Winds from Southwest. **Three-Parameter Weibull Distribution**



Total Years of Data: 19
Total Storm Events: 21
Total No. Events Selected: 21
Events per year: 1.11

Sample Statistics

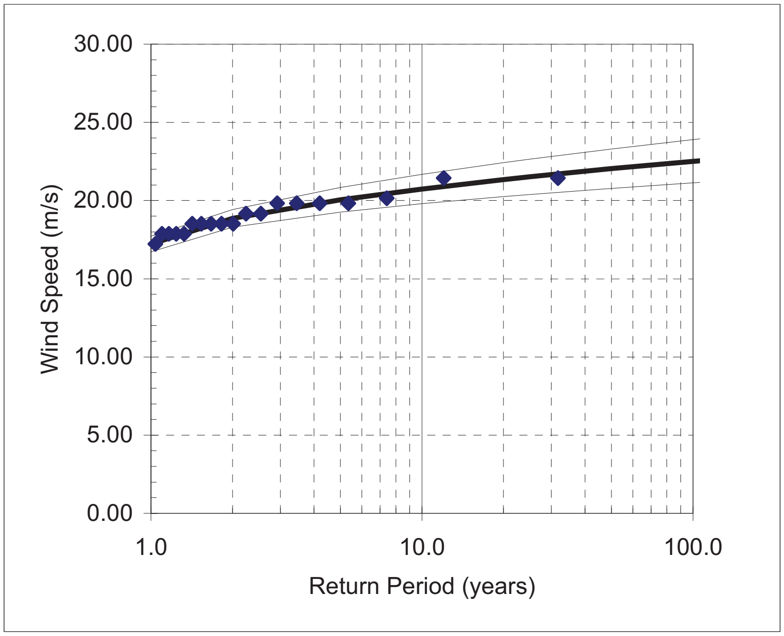
Mean: 18.85
Maximum: 21.45
Minimum: 16.57
s: 1.30
Sample skewness: -1.13

Weibull Parameters

Shape: 2.00
Scale: 2.856
Location: 16.314

Goodness of Fit

Correlation: 0.981



Return Period

		Confidence Limit	
Tr	X(T)	Upper	Lower
1	17.22	17.7	16.7
2	18.86	19.4	18.3
5	20.05	20.8	19.3
10	20.74	21.7	19.8
20	21.34	22.4	20.3
25	21.52	22.7	20.4
50	22.04	23.3	20.8
100	22.51	23.9	21.1
500	23.49	25.1	21.9
1000	23.88	25.6	22.1

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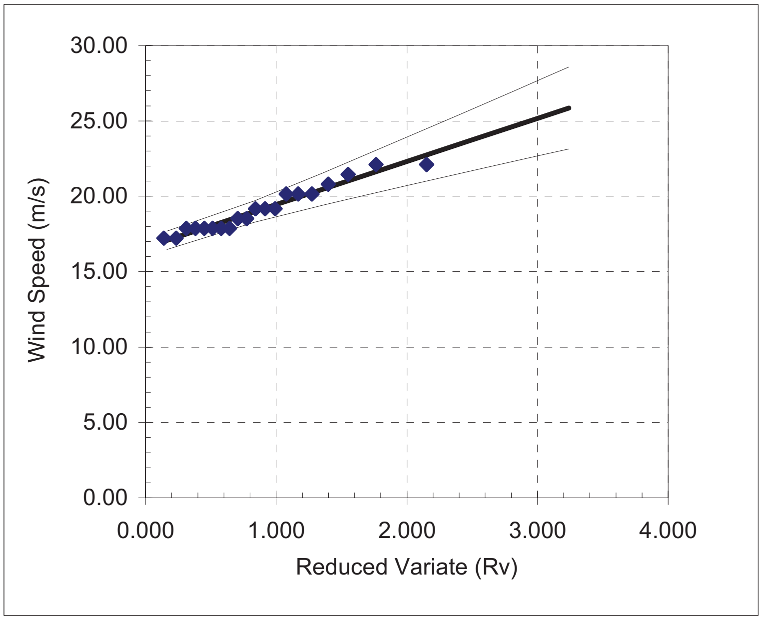
Figure A.6 POT Analysis for Southwest Wind

Peak over Threshold Extreme Value Analysis

Data Set: Goderich Airport Data - 1986-2008, Winds from West.

Three-Parameter Weibull Distribution



Total Years of Data:	19
Total Storm Events:	20
Total No. Events Selected:	20
Events per year:	1.05

Sample Statistics

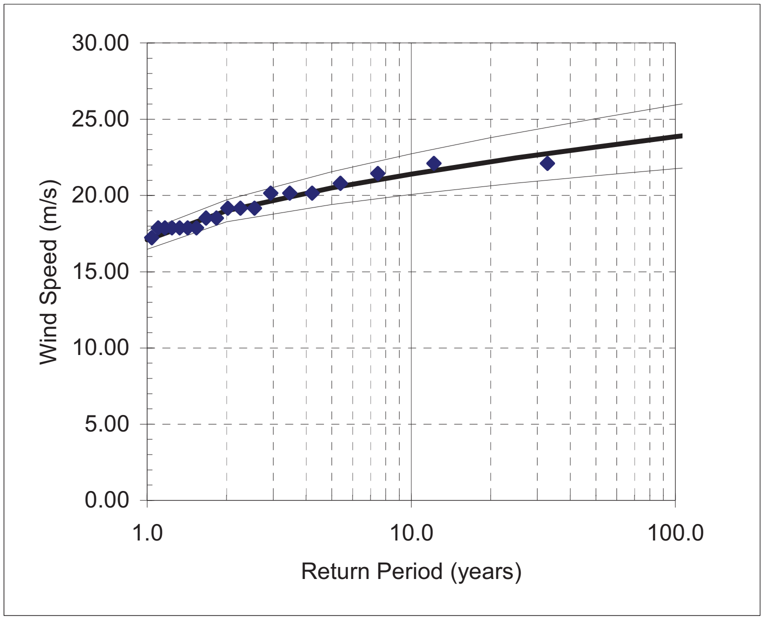
Mean:	19.15
Maximum:	22.1
Minimum:	17.22
s:	1.56
Sample skewness:	-1.19

Weibull Parameters

Shape:	1.65
Scale:	2.854
Location:	16.604

Goodness of Fit

Correlation:	0.978



Return Period

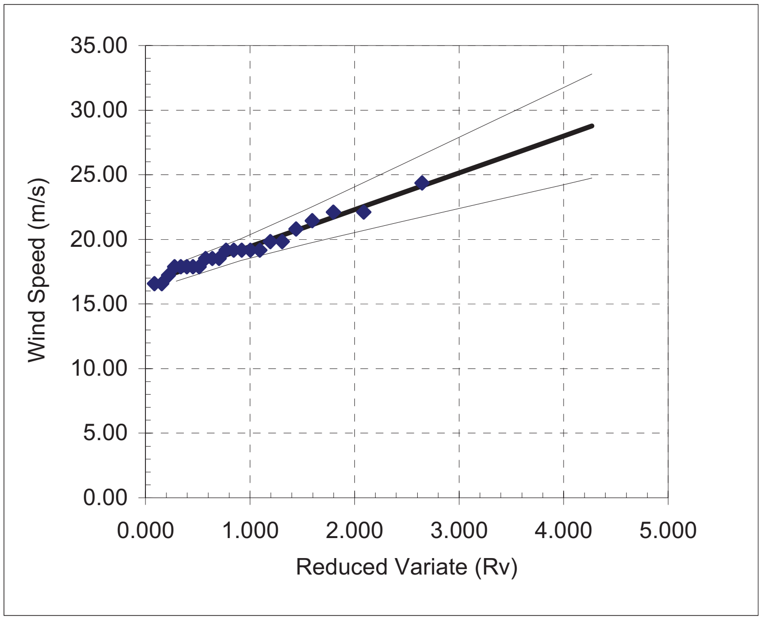
		Confidence Limit	
Tr	X(T)	Upper	Lower
1	17.08	17.7	16.5
2	18.99	19.7	18.3
5	20.48	21.6	19.4
10	21.40	22.7	20.1
20	22.21	23.8	20.6
25	22.46	24.1	20.8
50	23.18	25.1	21.3
100	23.85	25.9	21.8
500	25.28	27.8	22.7
1000	25.85	28.6	23.1

Baird

Figure A.7 POT Analysis for West Wind

Peak over Threshold Extreme Value Analysis

Data Set: Goderich Airport Data - 1986-2008, Winds from Northwest. **Three-Parameter Weibull Distribution**



Total Years of Data:	19
Total Storm Events:	23
Total No. Events Selected:	23
Events per year:	1.21

Sample Statistics

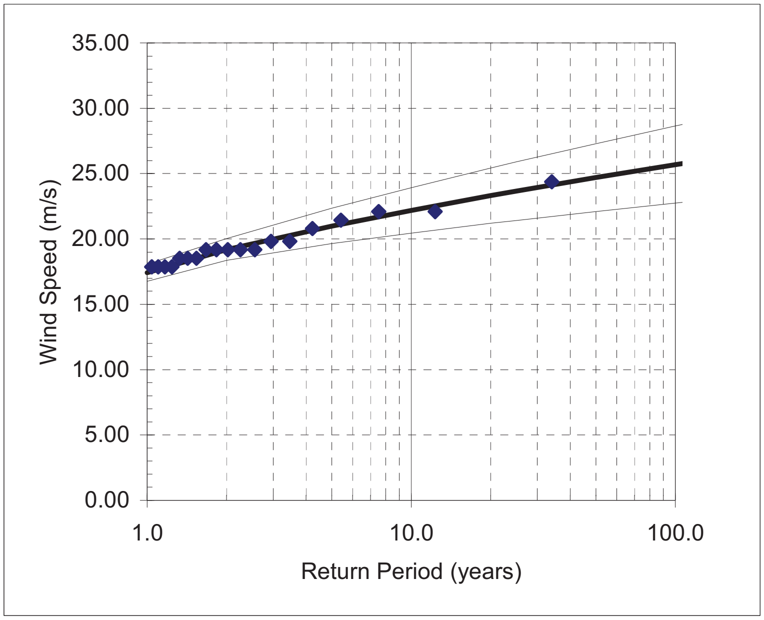
Mean:	19.20
Maximum:	24.37
Minimum:	16.57
s:	1.90
Sample skewness:	-2.03

Weibull Parameters

Shape:	1.35
Scale:	2.852
Location:	16.586

Goodness of Fit

Correlation:	0.987



Return Period

		Confidence Limit	
Tr	X(T)	Upper	Lower
1	17.42	18.1	16.8
2	19.19	20.0	18.4
5	21.00	22.3	19.6
10	22.20	23.9	20.5
20	23.32	25.4	21.2
25	23.66	25.9	21.4
50	24.70	27.3	22.1
100	25.70	28.6	22.7
500	27.88	31.6	24.2
1000	28.77	32.8	24.7

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Figure A.8 POT Analysis for Northwest Wind

APPENDIX B
MODEL OUTPUT

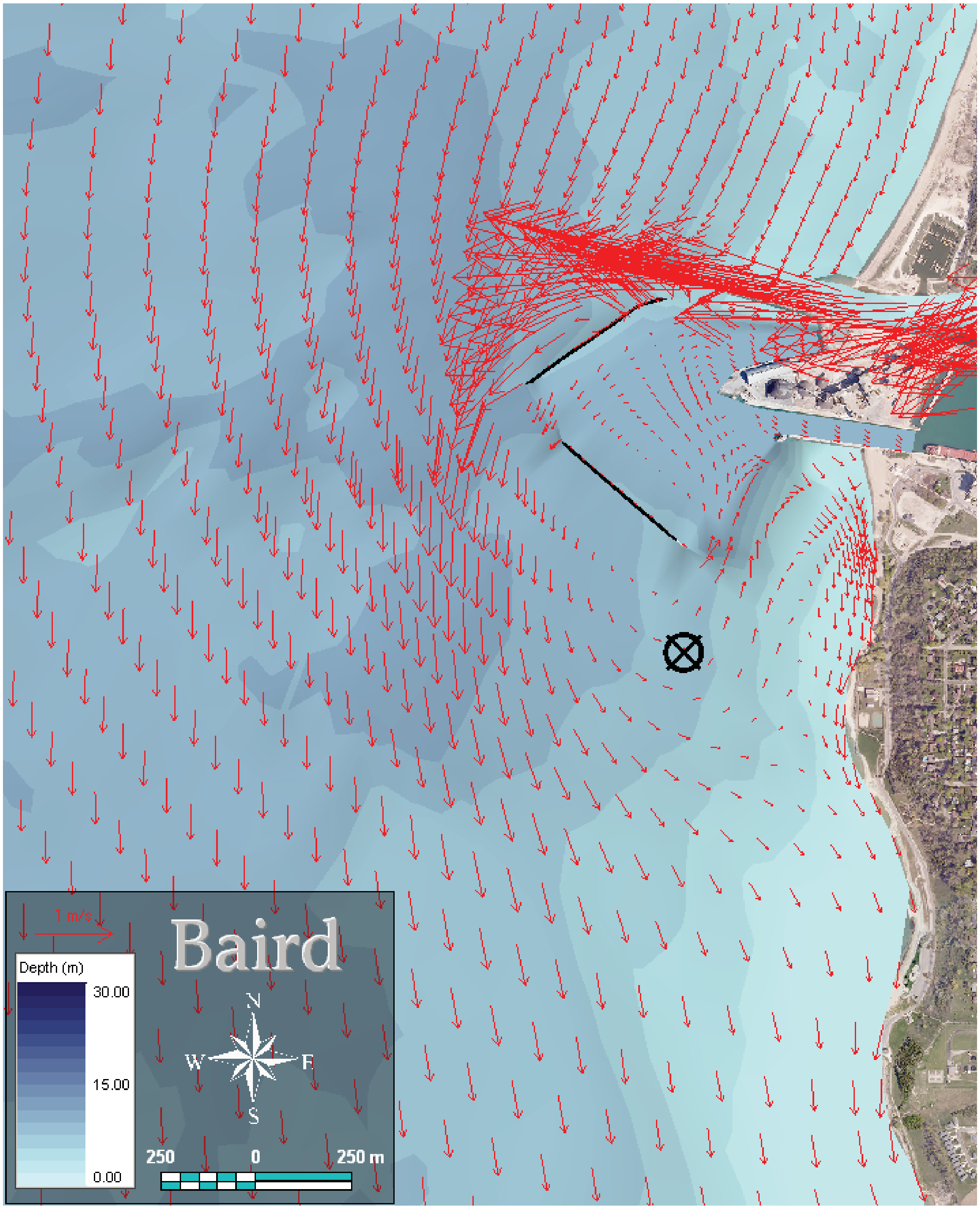

Figure B.1 Surface Currents for 10-Year Return Period Wind from North and 2-Year Return Period Flow in Maitland River

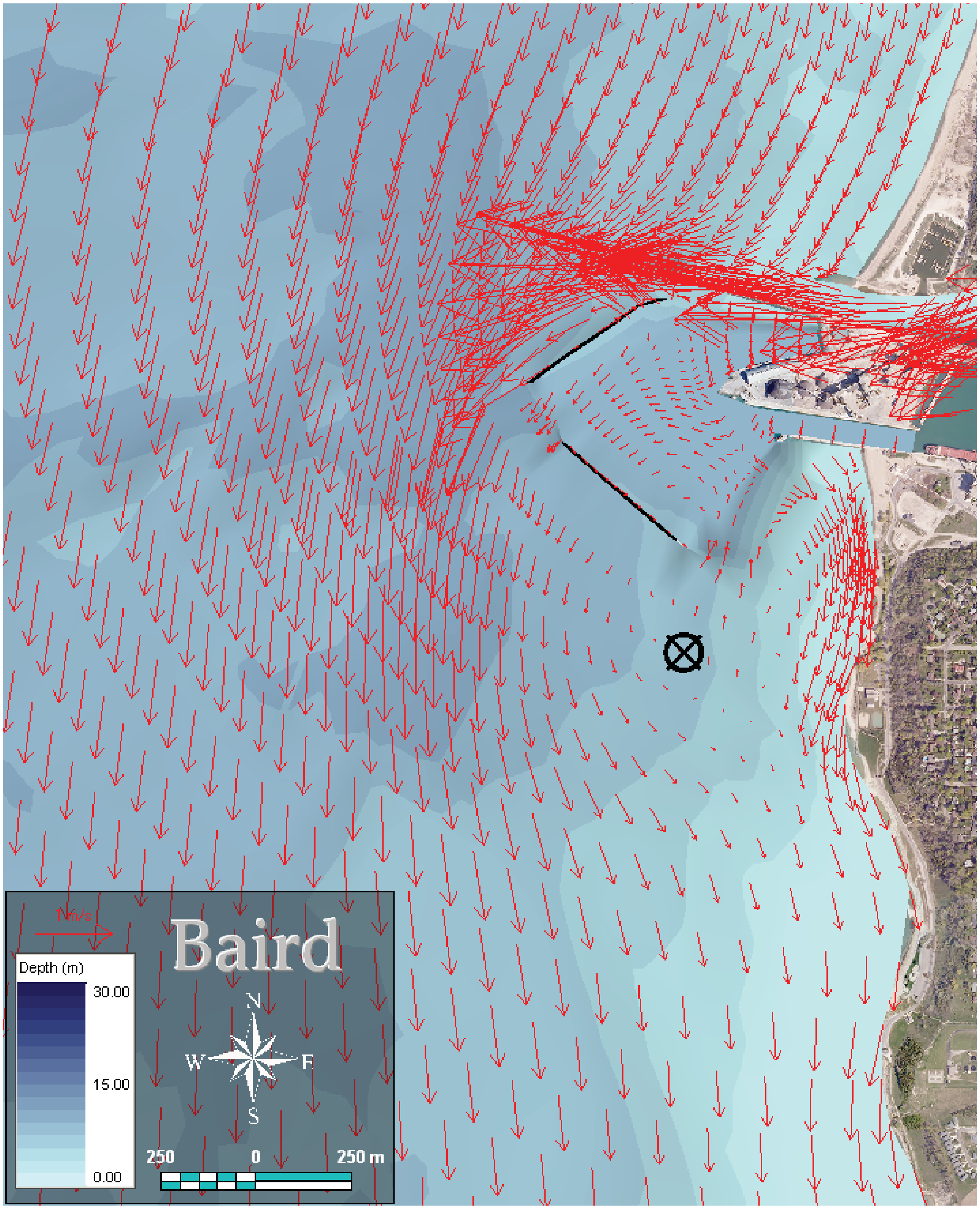

Figure B.2 Surface Currents for 10-Year Return Period Wind from Northeast and 2-Year Return Period Flow in Maitland River

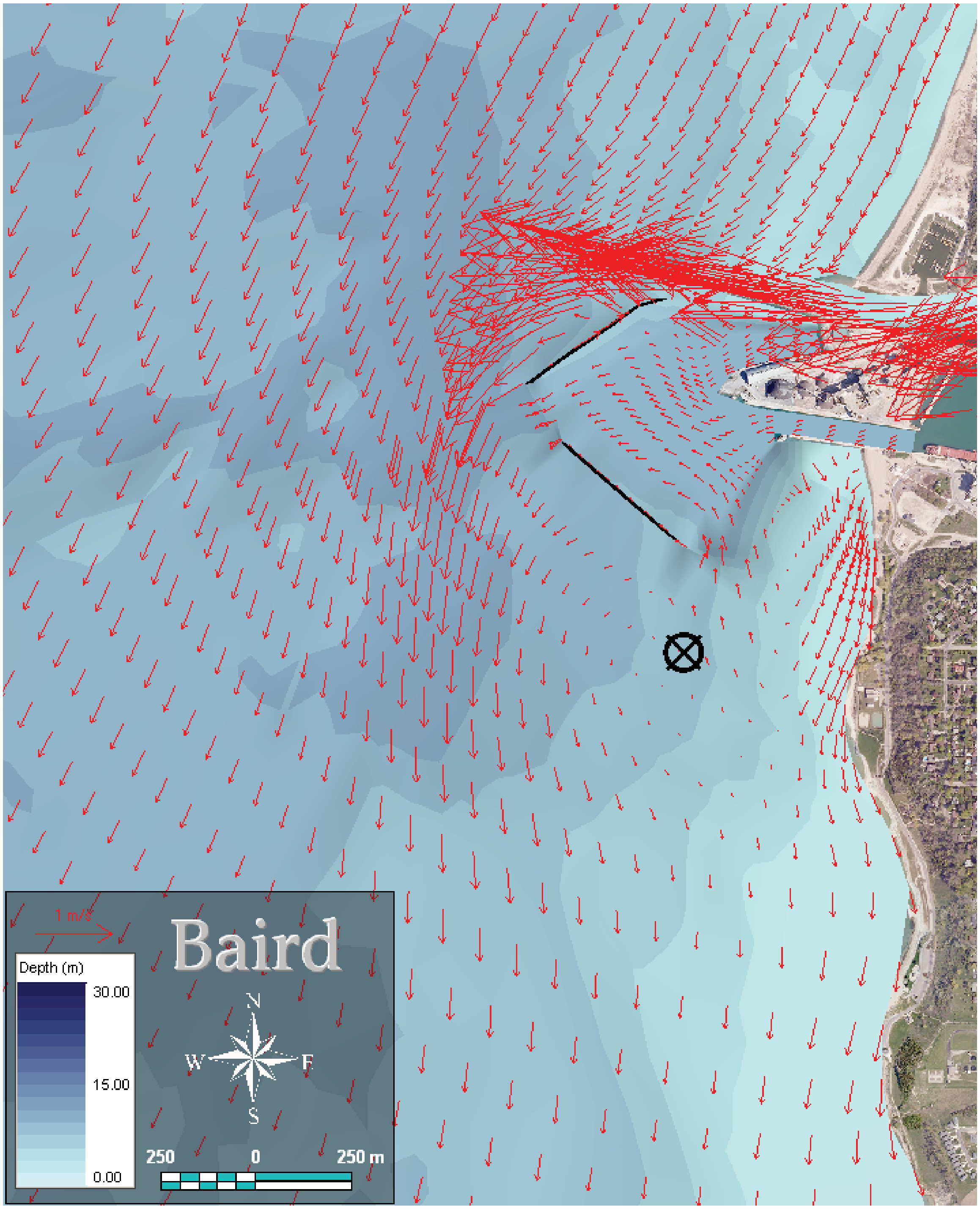

Figure B.3 Surface Currents for 10-Year Return Period Wind from East and 2-Year Return Period Flow in Maitland River

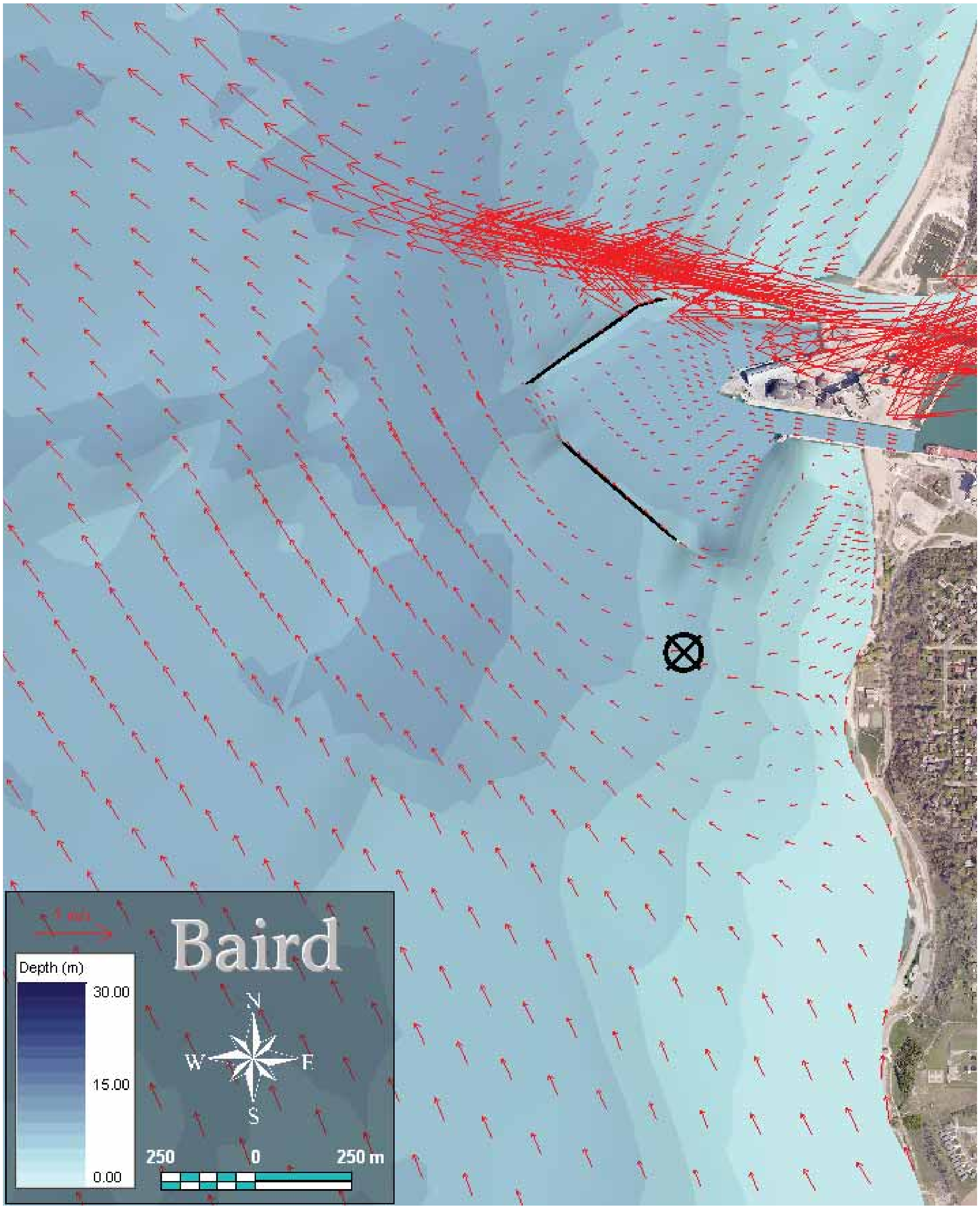

Figure B.4 Surface Currents for 10-Year Return Period Wind from Southeast and 2-Year Return Period Flow in Maitland River

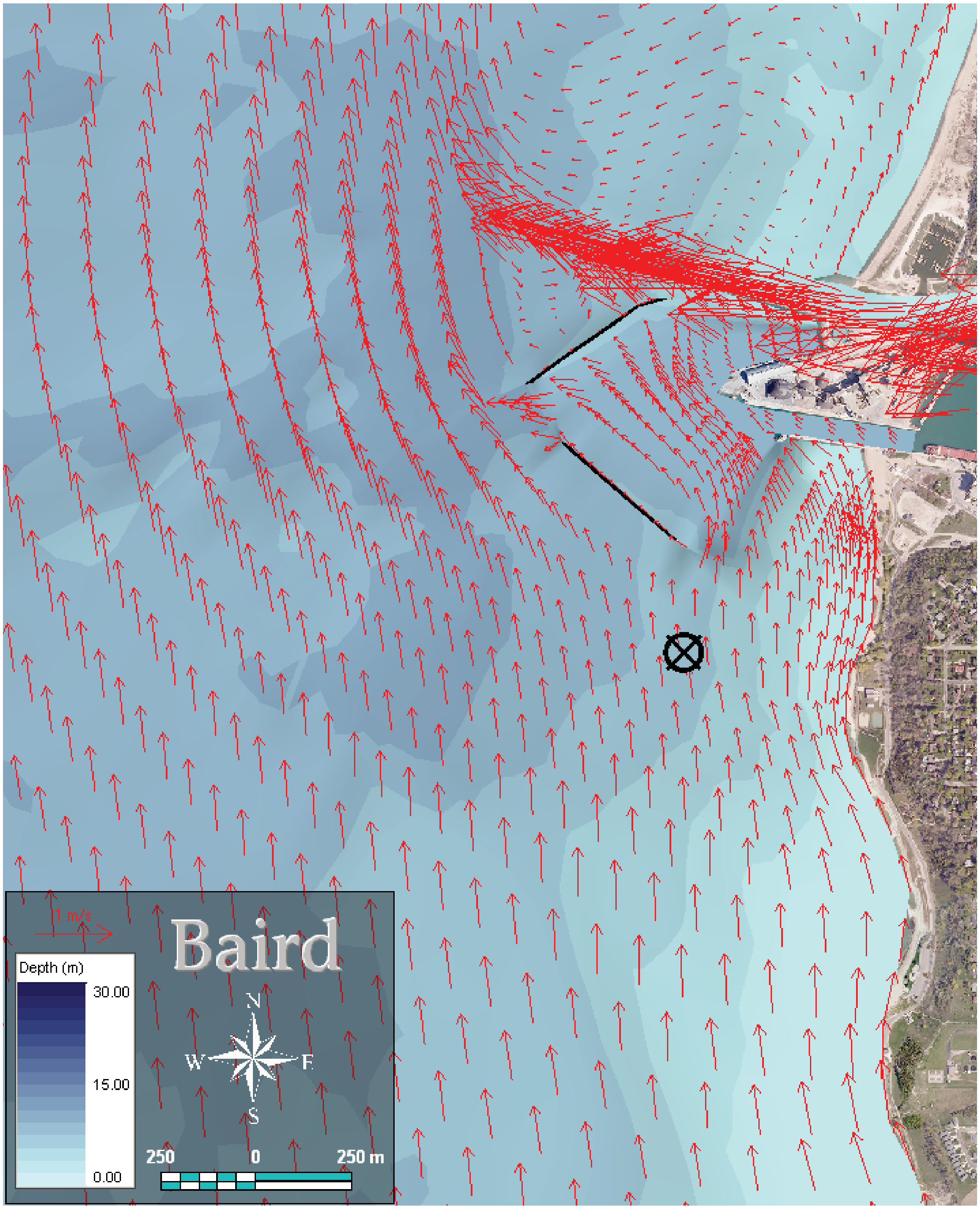

Figure B.5 Surface Currents for 10-Year Return Period Wind from South and 2-Year Return Period Flow in Maitland River

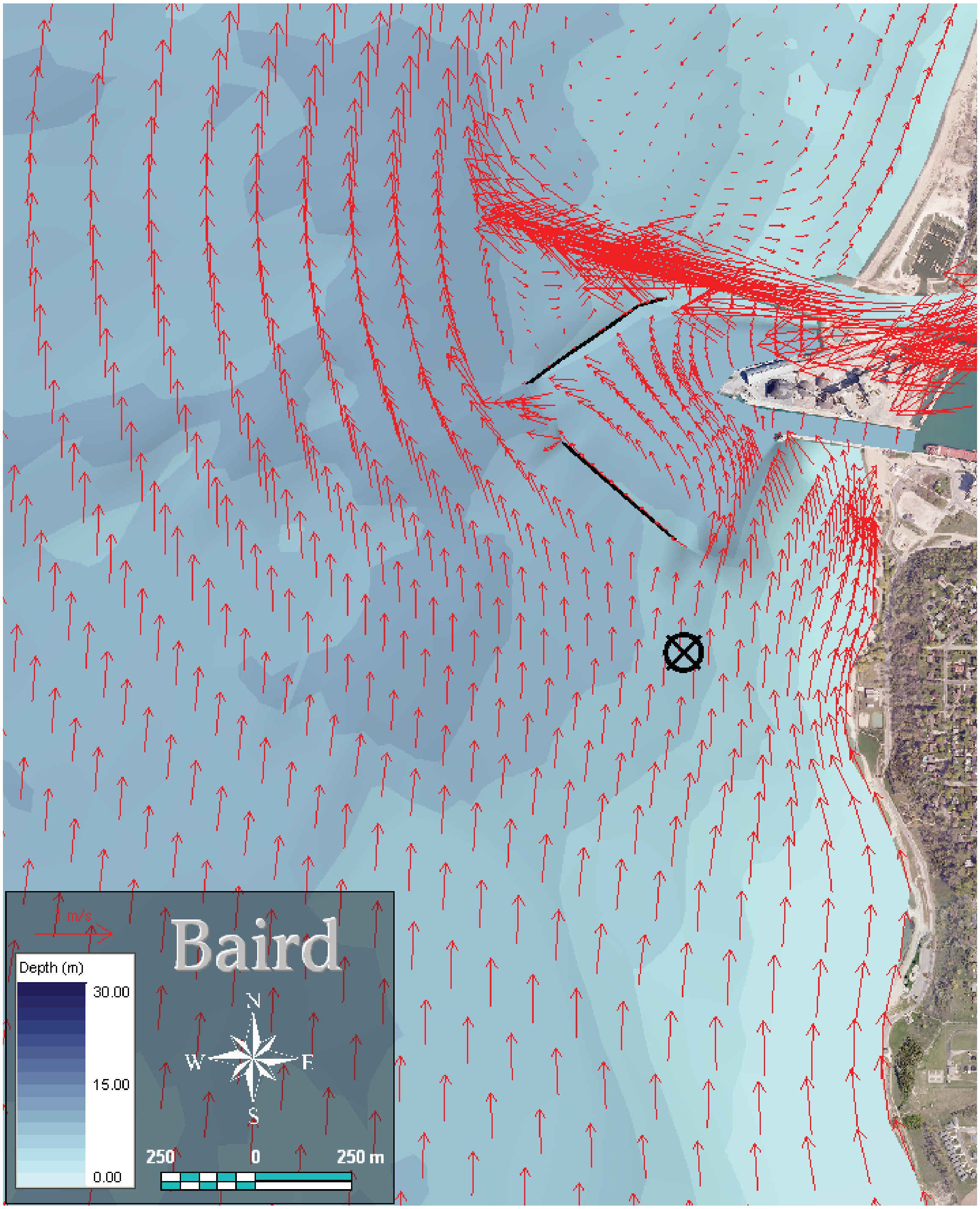

Figure B.6 Surface Currents for 10-Year Return Period Wind from Southwest and 2-Year Return Period Flow in Maitland River

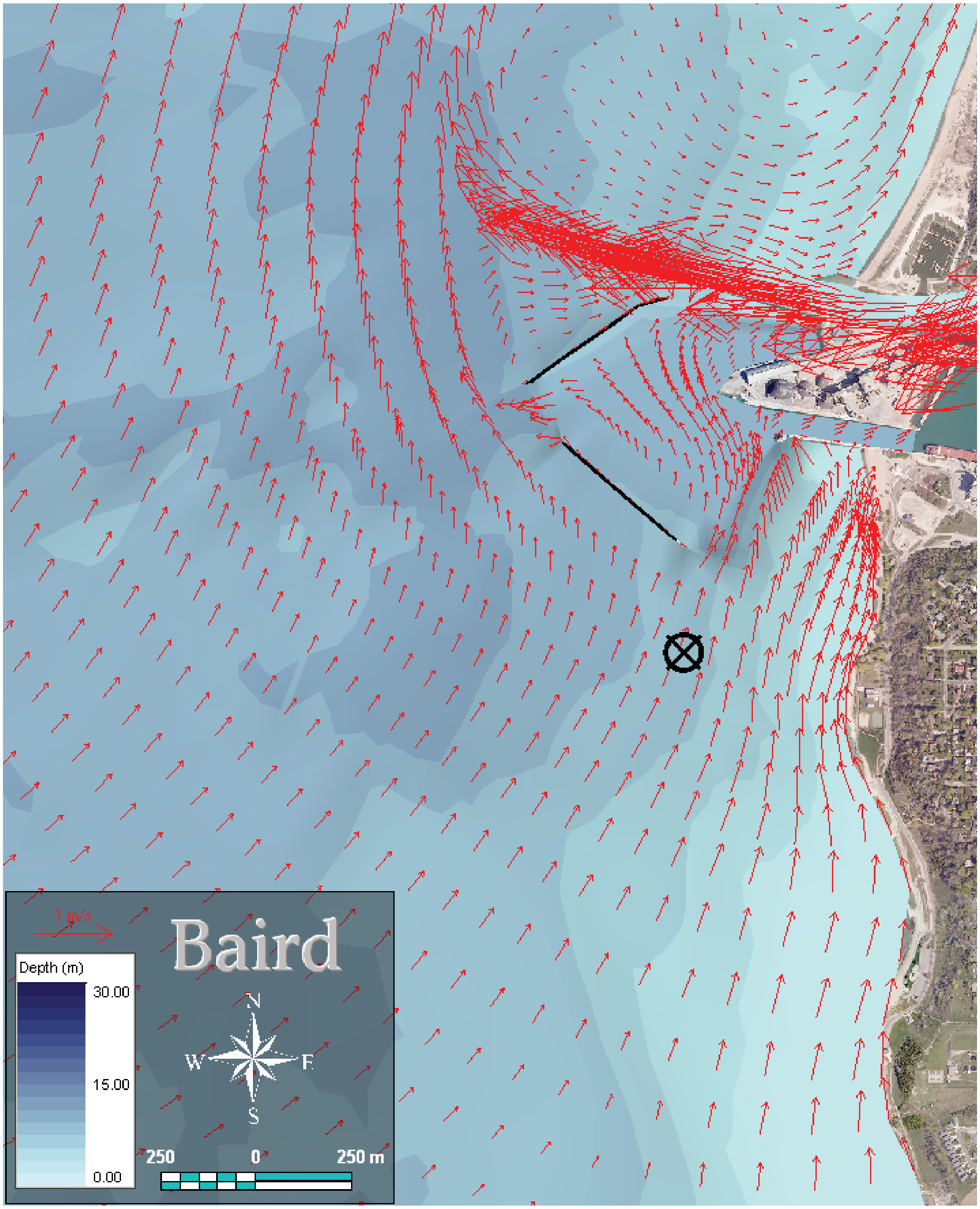

Figure B.7 Surface Currents for 10-Year Return Period Wind from West and 2-Year Return Period Flow in Maitland River

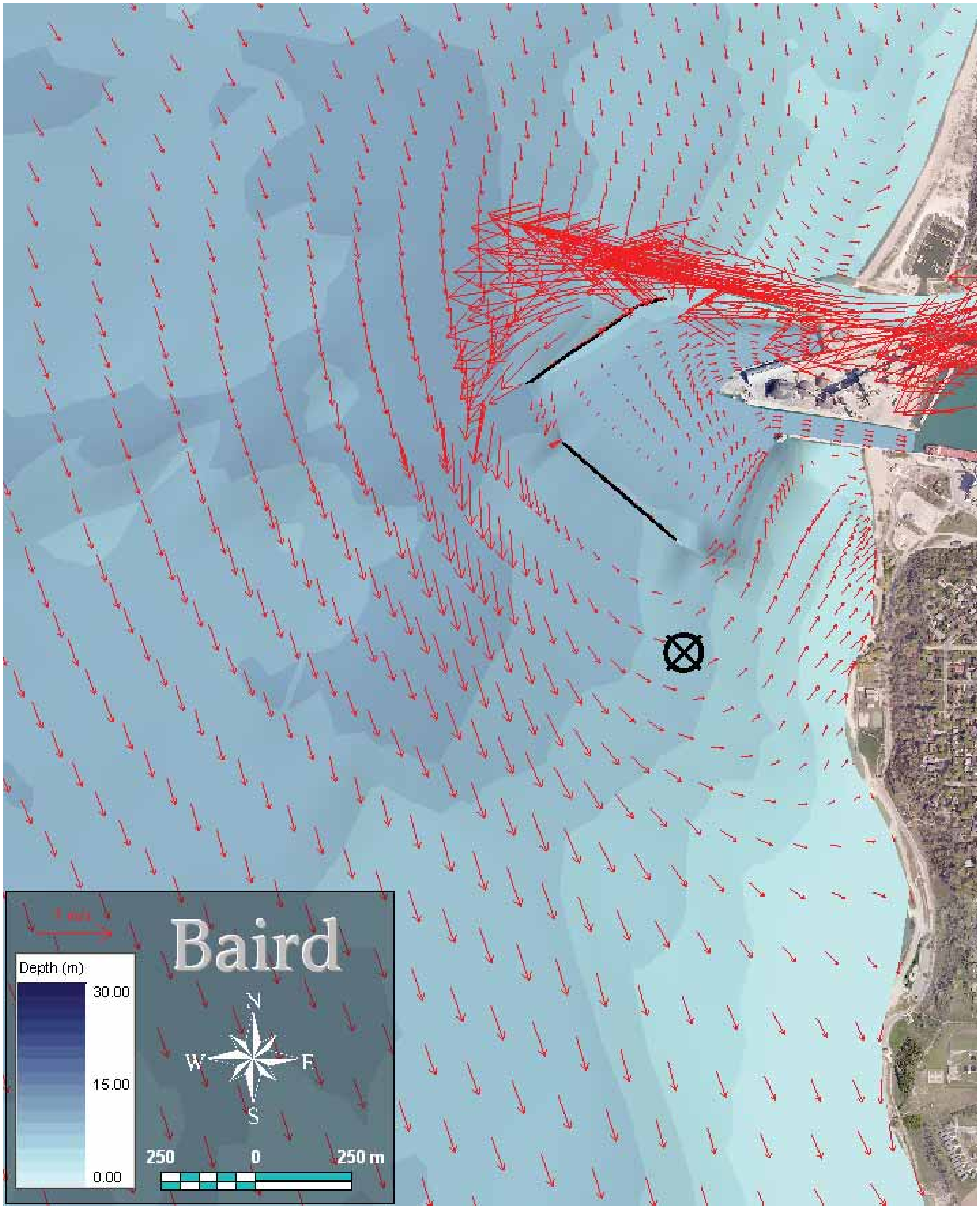

Figure B.8 Surface Currents for 10-Year Return Period Wind from Northwest and 2-Year Return Period Flow in Maitland River