Assessment Report

Sault Ste. Marie Region

Source Protection Area

APPENDIX 3 -
CHAPTER 4
GROS CAP INTAKE PROTECTION ZONE
STUDY NUMERICAL MODELING – IPZ-3
DELINEATION

February 5, 2015

The Assessment Report was initially approved on November 25, 2011.
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Gros Cap Intake Source Water Protection Studies

Spill Modelling in Support of IPZ-3 Delineation and Designation of Significant Threats

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Gros Cap Intake Source Water Protection Studies

Spill Modeling in Support of IPZ-3 Delineation and Designation of Significant Threats

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. The *Gros Cap Intake Protection Zone Study* (Baird, 2008) included data collection, intake characterization, ADCP current data collection and analysis, water and sediment sampling and analysis, and preliminary IPZ delineation. Based on recommendations in that report, additional work was undertaken to develop a three dimensional (3D) hydrodynamic model that was used to better define the local currents and to complete the IPZ-2 delineation. That work is described in Baird (2010).

In 2010 Baird was retained to undertake additional work in support of IPZ-3 delineation and identification of significant threats for the Gros Cap intake. This report describes that work. It is strongly recommended that this report be read with the earlier reports.

1.2 Scope of Work

The objective of this work was to determine if a contaminant released from a spill in the shipping channel could be transported to the intake and result in the deterioration of the water for use as a source of drinking water. A simplified numerical approach was used to assess the potential impact of two spills selected by SSMRCA for modeling. Both the MIKE3 and CORMIX models were used in the analysis.

The work presented in this report is based on the Technical Rules: Assessment Report dated November 16, 2009. The rules that are relevant to this study are outlined in Section 2.

The model setup, model runs undertaken and results of the modeling are described in Section 3.

Summary and conclusions are provided in Section 4.

2.0 TECHNICAL RULES

This section provides a summary of the rules that are relevant to IPZ-3 delineation at Gros Cap as described in (MOE, 2009a). The text has been shortened and only relevant parts of the rules are listed. The reader is referred to the original document (MOE, 2009a) for a complete set of rules.

Classification of Intakes

Rule 55 Subject to rule 55.1, a surface water intake associated with a type I, II or II system shall be classified as a type A intake if the intake is located in a Great Lake.

Delineation of IPZ-3

Rule 68 If modelling or other methods demonstrate that contaminants released during an extreme event may be transported to a type A intake, an area known as IPZ-3 shall be delineated and shall be composed of the following areas:

(1) The area within each surface water body through which contaminants released during an extreme event may be transported to the intake.

(2) A setback on the land that abuts the portion of the surface water body that is the greater of 120 m measured from the high water mark; and the Conservation Authority Regulation Limit if in effect.

Rule 69 The area delineated in accordance with rule 68(1) shall not exceed the area within the surface water body that may contribute water to the intake during or as the result of an extreme event.

Identifying Areas for Significant, Moderate and Low Drinking Water Threats

Rule 130 An activity listed as a drinking water threat in accordance with Rule 118 or 119 is or would be a significant drinking water threat in a surface water intake protection zone associated with a intake to which rule 68 applies if modelling or another method demonstrates that a release of a chemical parameter or pathogen from the activity or proposed activity would be transported through the IPZ to the intake and result in the deterioration of the water for use as a source of drinking water.

Rules 72, 73 and 75 describe transport pathways delineation for IPZ-3s, however this is not relevant to the work described herein, as the IPZ-3 delineation is based on a spill in the shipping channel and it therefore does not extend onland.

On Nov. 15, 2010, MOE issued a memorandum which provides further direction (MOE, 2010). The memorandum states that Rule 68 prescribes an IPZ-3 is to be delineated if a spill can be shown to result in deterioration of the water supply. It further explains that the intent of Rules 68 and 130 was that the location and type of activity of concern would be identified and based on an understanding of that type of activity, contaminants of concern, potential spill volume, the Event Based Approach would be used to determine whether or not an IPZ-3 should be delineated. Future activities may be considered where it is known that an activity will be taking place or is expected to take place in the future.

Rule 130 is not only applicable to threats within the IPZ-3. It may be used to designate significant threats within the IPZ-1 and IPZ-2.

3.0 NUMERICAL MODELLING IN SUPPORT OF IPZ-3 DELINEATION

A simplified numerical approach was conducted to assess the potential impact of spills from the nearby shipping channel, on intake water quality. The investigation was carried out in accordance with MOE (2009b), which outlines three options to delineate the IPZ-3 using the event based approach: Contaminant Transport Approach; Boundary Approach; and Combined Approach. For this study, the Contaminant Transport Approach was used. The Contaminant Transport Approach is used when the Source Protection Committee (SPC) is concerned about specific activities that may compromise the water supply at the intake. Modelling is used to determine if the contaminant could be transported to the intake and result in the deterioration of the water for use as a source of drinking water. The IPZ-3 is then delineated as described in Section 2. This section describes contaminant transport modelling undertaken in support of IPZ-3 delineation.

3.1 Identification of Activities for Modelling Scenarios

The Clean Water Act requires that SPCs list activities that are or would be drinking water threats. Although transportation corridors are not included in the list of activities (see Ontario Regulation 287/07), the regulations and Technical Rules (MOE, 2009a) provide a mechanism through which SPCs can identify specific activities (transportation of specific substances) taking place within a transportation corridor as a threat. Transportation threats can be considered by adding a new drinking water threat as per Rule 119 of the Technical Rules. This requires that an application be made to the Director.

The SSMRCA SPC identified the international shipping channel located offshore of Gros Cap as a potential threat under Rule 119. Potential drinking water threats were identified by SSMRCA, based on a review of shipping data and two spills were provided to Baird for modelling (see Table 3.1).

Table 3.1 Potential Drinking Water Threats used in the Spills Analysis

Water Quality Parameter	Density (kg/m^3)	Volume (m^3)
Fuel Oils	850	11,519
Potassic Fertilizer	1281	22,644

It is important to note that both materials were assumed to be liquid, as the numerical models are capable of simulating dissolved substances only.

It was assumed for purposes of the numerical modelling that the spill event would occur rapidly; that is, in less than an hour. Given the size of Lake Superior and the dilution potential, it was assumed that only a catastrophic large-volume chemical release would have a potential impact at the intake. The analysis was carried out at a location in the shipping channel close to the intake, but outside the IPZ-2.

3.2 Model Description

An assessment of the impact of spills from ships on the water quality at the intake was conducted using two modelling systems; MIKE3 and CORMIX. The MIKE3 hydrodynamic model was originally developed to support the delineation of IPZ-2, this model was further developed (as part of this study) to simulate the fate and transport of contaminant plumes. Both models are capable of simulating the transport of contaminants within water bodies, and each exhibits certain strengths and weaknesses with respect to simulating specific phenomena of the mixing process. For example, CORMIX is capable of simulating the mixing process in detail at the point of discharge, but cannot account for spatially varying current fields in the receiving waters. Conversely, MIKE3 can capture the spatial variability of lake currents but cannot properly resolve the mixing process at the point of discharge. As such, the analysis was conducted using both models.

MIKE3

Developed by the Danish Hydraulic Institute (DHI), MIKE3 is a comprehensive software system designed for the simulation of three-dimensional flows and environmental processes including effluent discharged from point sources. The strength of far-field models such as MIKE3, is in evaluating the fate and transport of effluent plumes in the far-field region, which is a zone where ambient current conditions dominate the mixing process. MIKE3 is computationally intensive, as such, limited model simulations were carried out.

CORMIX

The U.S. EPA approved Cornell Mixing Zone Expert System (CORMIX) model is a software system for the analysis, prediction and design of aqueous, toxic or conventional pollutant discharges into diverse water bodies. The strength of CORMIX is in evaluating the centerline dilution of a discharged substance in the near-field region, which can be described as the zone where momentum and buoyancy characteristics of the effluent jet dominate the mixing process.

3.3 MIKE3 Model Setup

This study utilized the existing MIKE3 hydrodynamic model that was previously developed as part of the Gros Point Intake Protection Zone Study (Baird, 2010). The model was further developed, through the integration of the transport module, in order to assess the impact of potential spill events on the drinking water intake. It should be noted that the transport module has not been calibrated.

The three-dimensional model MIKE3 was set up to simulate spill scenarios from commercial shipping operations under a west wind condition with a return period of approximately 100 years. A westerly wind condition was chosen in order to drive the contaminant plume towards the intake. Using recorded wind data from the Sault Ste Marie Airport (ID: 6057592), a wind event from November 10, 1975 was identified and used to drive the model simulations. Figure 3.1 graphically shows the wind event. Note that wind speeds peaked at 23 m/s, which is the 100 year event for west wind conditions (Baird, 2010).

The hypothetical spill event was simulated from one location as shown in Figure 3.2. The site is 3 km west-southwest of the intake in approximately 15 m water depth. Figure 3.3 shows a 2D map of surface currents at the peak of the wind event, travel time to the intake is approximately 3 hours.

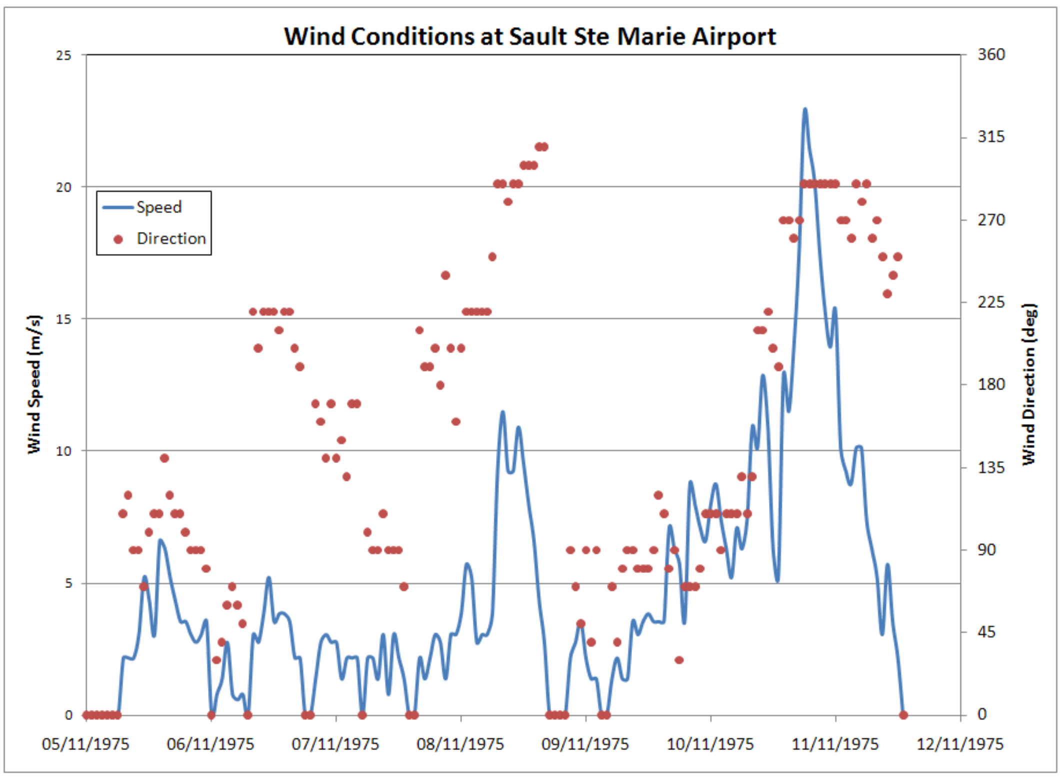

Figure 3.1 Wind Condition used in MIKE3 Model Simulations

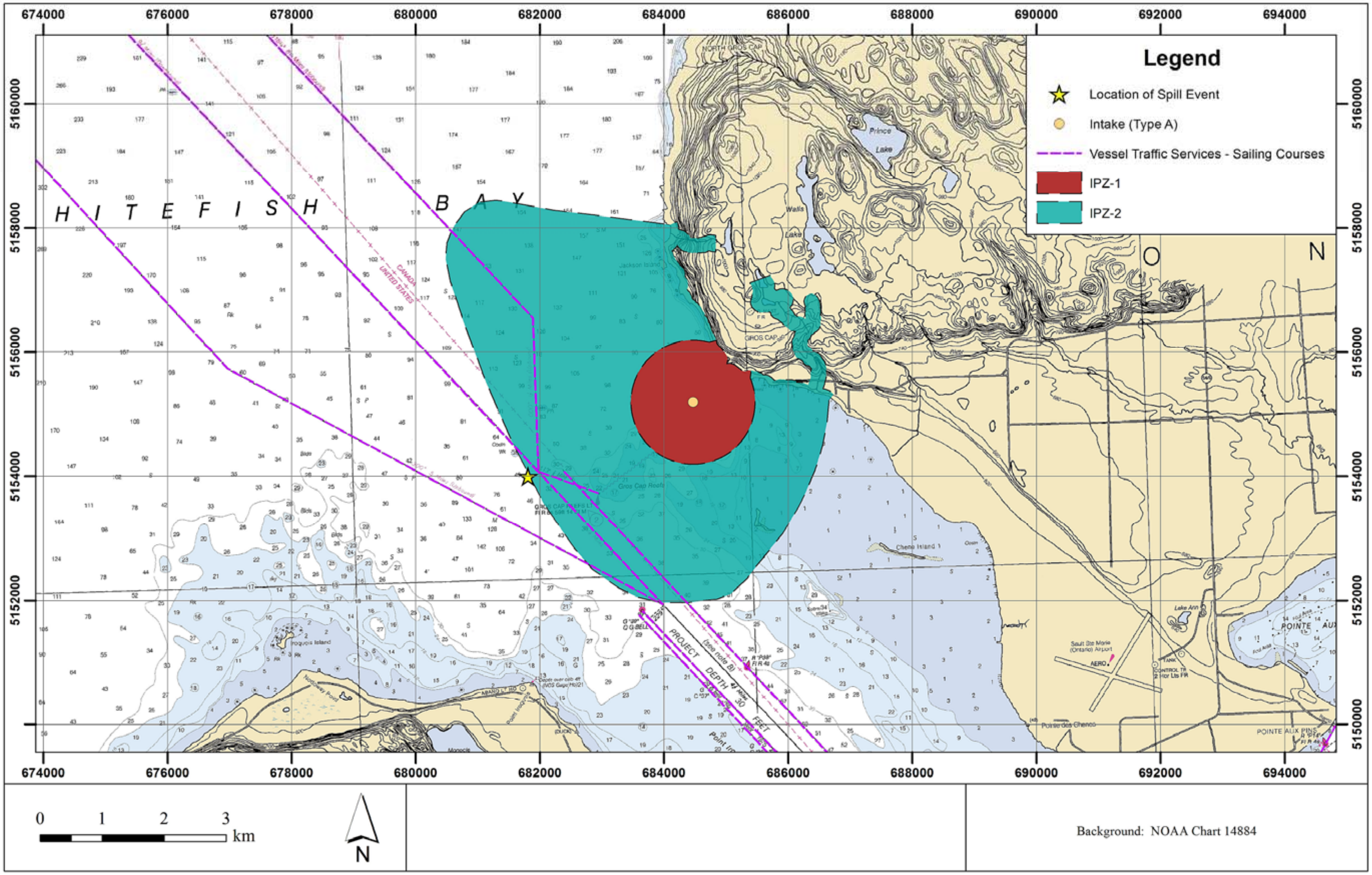

Figure 3.2 Location of Spill Event and Intake

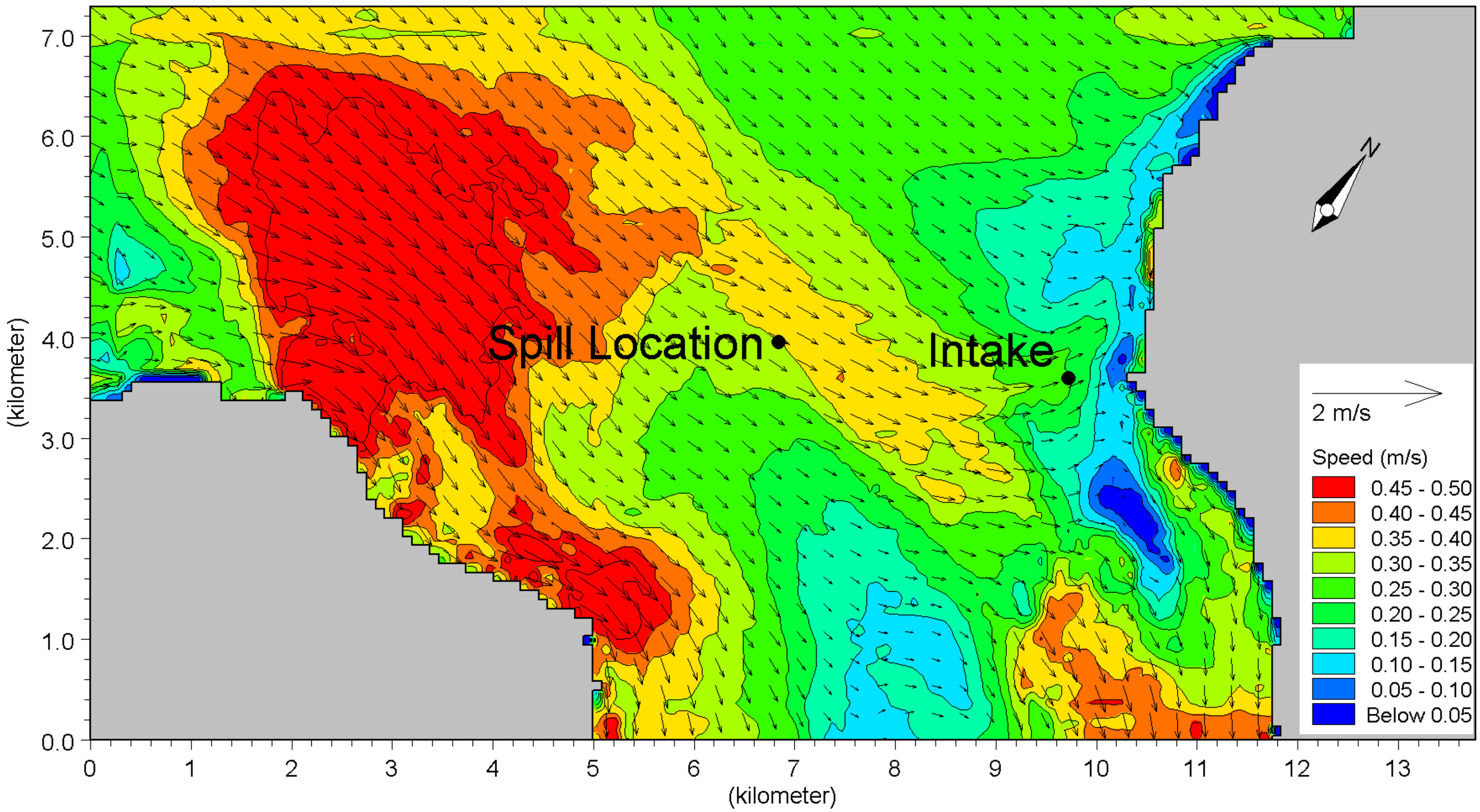

Figure 3.3 Modelled Surface Currents at the Peak Wind Condition (23 m/s)

3.4 CORMIX Model Setup

Given that the MIKE3 transport module was un-calibrated and recognizing that far-field models like MIKE3 can overestimate dilution due to factors such as model grid resolution and numerical dispersion, the CORMIX model was utilized to help bracket the potential range in dilution estimates. This is a useful step in the absence of a calibrated model as it provides insight into the uncertainty of the analysis. Both models are widely used to assess contaminant transport, and as discussed in Section 3.2, the models are able to resolve different aspects of the mixing process; that is, CORMIX is much better at resolving near-field mixing process and MIKE3 can account for spatial variability in the far-field.

The CORMIX model was setup to represent conditions that are similar to those defined in the MIKE3 model. Setup of the CORMIX model involves simplification of bathymetric features and current conditions in the lake. Unlike the MIKE3 model, the geometric configuration of the point of discharge is required. It was assumed for this study that the rupture in the hull of the ship was 2m in diameter.

3.5 Model Runs in Support of IPZ-3 Delineation

The MIKE3 model was setup to simulate a spill event for three potential scenarios:

1. Fuel oil spill at the surface (Positively Buoyant);
2. Potassic fertilizer spill at the lake bed (Negatively Buoyant);
3. Hypothetical spill, fully mixed through water column (Neutrally Buoyant)

As previously stated, the two spills selected for modelling included a positively buoyant substance (fuel oil) and a negatively buoyant substance (potassic fertilizer). Fuel oil is less dense than water, therefore, the plume would tend to remain at the surface. Potassic fertilizer is heavier than water and would tend to sink and mix through the water column.

Preliminary analysis showed that discharging a positively buoyant plume at the bottom would result in higher dilutions at the intake as compared with releasing at the surface. A similar result would occur if the negatively buoyant plume was released at the surface; therefore, the spill events presented above represent a cross-section of worst case conditions.

The spill volumes that are presented in Table 3.1 were released at a constant rate over a period of one hour. Constant concentrations of 1000 mg/L were assumed for all runs and the impact at the intake was documented in the form of dilution estimates as shown in Table 3.2. The concentration represents an arbitrary value used to determine dilution estimates for each scenario.

Table 3.2 Dilution Estimates at the Intake

Simulation	Spill	Spill Volume (m^3)	Discharge (m^3/s)	Average Current Speed (m/s)	Dilution Estimates at Intake Location: At Intake MIKE3	At Intake CORMIX	Minimum Dilution in Water Column MIKE3	Minimum Dilution in Water Column CORMIX
Surface Discharge	Fuel Oil	11,519	3.9	0.35	>5000:1	>5000:1	128:1	26:1
Bottom Discharge	Potassic Fertilizer	22,644	6.3	0.07	100:1	24:1	100:1	24:1
Fully Mixed Water Column	Neutrally Bouyant Material	22,644	6.3	0.2	205:1	208:1	205:1	208:1

The following observations were made based on the findings from the modelling.

- Fuel oil released at the surface remains largely as a surface plume at the intake location; as a result, the estimated dilution at the intake (situated 15m deep) is very large (>5,000:1); at the water surface, dilution estimates ranged from 128:1 to 26:1 for the MIKE3 and CORMIX model respectively.

- Predicted dilution estimates at the intake for the bottom release scenario were determined to be 24:1 based on the CORMIX model; the MIKE3 model predicted a dilution of approximately 100:1. It should be noted that for the bottom release scenario in MIKE3, the plume did not directly impact the intake due to the spatial variability of the current conditions. As such, the results were estimated by assessing the plume concentration as it passed just north of the intake.

- The fully mixed (neutrally buoyant) scenario assumed that the contaminant was mixed through the water column. For this analysis the larger spill volume (i.e. 22,644 m^3) was used as this would generate lower dilution estimates. At the intake location, dilution estimates generated by CORMIX and MIKE3 were similar as the results ranged from 208:1 to 205:1, respectively. A review of the MIKE3 model output showed that the plume path crosses the intake location at the surface, however, it passes just north of the intake at depth. This is illustrated in Figure 3.4, which compares the plume location at the surface and at a water depth of 15m for the same time period under the fully mixed scenario.

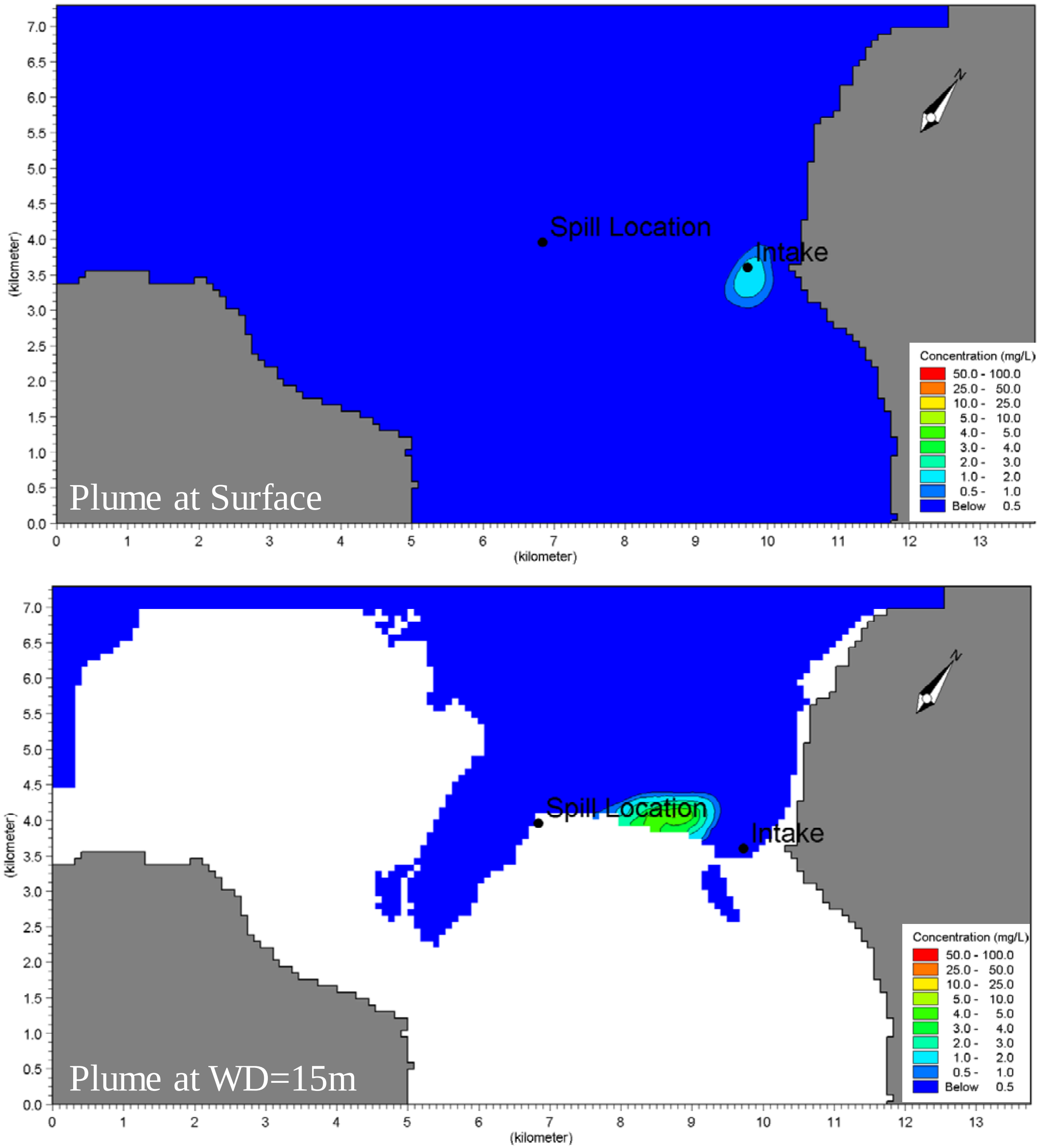

Figure 3.4 Comparison of Plume Location at Surface and in a Water Depth of 15m (Neutrally Buoyant Scenario)

3.6 Limitations of Numerical Modelling Approach

The following summarizes key assumptions that were made and limitations of the numerical modelling approach:

- The purpose of this study was to conduct a preliminary analysis to determine if a spill event from a ship, in close proximity to the intake, could affect the quality of the source water. Limited model simulations were undertaken to examine the potential impacts of the spill scenarios on the drinking water intake. The analysis was limited to one location at the boundary of the IPZ-2.

- The spill event was assumed to occur over a period of one hour. This is a conservative assumption as slower leaks would result in higher dilution estimates.

- The numerical models do not account for chemical processes and interactions such as weathering, emulsification, or volatilization of the spill material.

- The MIKE3 advection-dispersion model was employed to support the spills analysis. The hydrodynamic model was initially developed and compared against measured ADCP data in the first phase of the study. The model was further developed to include the advection-dispersion model. Note that the transport module was not calibrated.

- It was assumed that both materials considered in the spills analysis are liquids. This assumption is necessary as the advection-dispersion model can only simulate the fate and transport of dissolved substances.

- The CORMIX model required assumptions regarding the diameter of the rupture (or point of discharge). For this study, it was assumed that the spill occurred through a rupture in the hull that is 2m in diameter. The sensitivity of this assumption on dilution estimates was not considered in this study.

3.7 Impact of Spill at Intake Location

Water quality constituents for potassic fertilizer and fuel oils, and the Ontario Drinking Water Standards (ODWS) for these constituents were provided to SSMRCA by Connestoga-Rovers and Associates (CRA). Using the dilution estimates presented in Table 3.2, concentrations at the intake were determined for those constituents that had a drinking water standard. The findings from the analyses are presented in Appendix A. Dilutions were tabulated for the intake location (near the lakebed). The minimum dilution in the water column is also provided. The predicted concentrations are presented for both CORMIX and MIKE3 model results. This provides some indication of the level of uncertainty in the modeling.

The results showed that a large volume spill of either Potassic Fertilizer or Fuel Oil from a commercial ship in relatively close proximity to the intake (approximately 3.2 km) exceeded the drinking water standards at the intake under the westerly wind event simulated in this study.

Note that the results are based on dilution estimates from advection dispersion models and do not consider chemical reactions such as weathering, emulsification, or decay to name a few.

4.0 SUMMARY AND CONCLUSIONS

1. Numerical modeling has been undertaken to assess the potential impact of spills from the shipping channel, on water quality at the Gros Cap intake. Two models were used in the analysis: the CORMIX model and the MIKE3 model.

2. The investigation was carried out in accordance with MOE (2009b) using the Contaminant Transport Approach.

3. Two spills were selected by the SSMRCA for modeling: a fuel oil spill of 11,519 m^3 and a potassic fertilizer spill of 22,644 m^3. These represent positively and negatively buoyant materials respectively. In addition, model runs were undertaken using a neutrally buoyant material for comparison.

4. The model results provided in Table 3.2, summarize dilutions at the intake for the spills modeled. Results are presented for the intake location, as well as the minimum dilution through the water column. There were some differences in the dilutions predicted by the two models and this provides a measure of the level of uncertainty in the analysis.

5. Water quality constituents for potassic fertilizer and fuel oils were provided to SSMRCA by Conestoga-Rovers and Associates, along with the associated Ontario Drinking Water Standards (ODWS). Using the dilution estimates determined from the numerical models, concentrations at the intake were calculated for those constituents that had a drinking water standard. The results showed that a large volume spill of either Potassic Fertilizer or Fuel Oil from a commercial ship in relatively close proximity to the intake (approximately 3.2 km) exceeded the drinking water standards at the intake under the westerly wind event simulated in this study. Exceedances occurred using the dilutions predicted by both the CORMIX and MIKE3 models.

6. The spill simulated in the modeling exercise was located at the edge of the IPZ-2, in the shipping channel as shown in Figure 3.2. The models predicted exceedances of the ODWS for a number of constituents as listed in Appendix A. This activity may therefore be designated as a significant threat under Rule 130 and delineation of an IPZ-3 was not necessary because the activity is located within the IPZ-2. Further analysis could be undertaken to determine whether a spill from further away in the shipping channel could compromise the drinking water at the intake.

7. The purpose of this study was to conduct a preliminary analysis to determine if a spill event from a ship, in close proximity to the intake, could affect the quality of the source water. Limited model simulations were undertaken to examine the potential impacts of the spill scenarios on the drinking water intake. The analysis was limited to one location.

8. Dilution estimates were determined using advection-dispersion models. It is important to recognize that the numerical models do not account for chemical processes and interactions such as weathering, emulsification, or volatilization of the spill material.

5.0 REFERENCES

Baird, 2008. Gros Cap Intake Protection Zone Study. Final Phase 1 Report dated January 22, 2008. A report prepared for Sault Ste. Marie Region Conservation Authority.

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APPENDIX A: SPILL SCENARIO DILUTIONS AT INTAKE

Table A1. Estimated Concentration Levels at the Intake Location

WQ Parameter	Density (kg/m^3)	Constituents	ODWS (mg/L)	% By Weight	Concentration (mg/L)	Dilution in Water Column		Dilution at Intake		Concentration in Water Column (mg/L)		Concentration at Intake (mg/L)	
						MIKE3	CORMIX	MIKE3	CORMIX	MIKE3	CORMIX	MIKE3	CORMIX
Potassic Fertilizer	1281	Potassium Chloride	250	99.8	1278438	100	24	100	24	12784	53268	12784	53268
		Sodium Chloride	250	4	51240	100	24	100	24	512	2135	512	2135
Gasoline	850	Benzene	0.00500	1.9	16150	128	26	5000	5000	126	621	3	3
		Toluene	0.02400	8.1	68850	128	26	5000	5000	538	2648	14	14
		Ethylbenzene	0.00240	1.7	14450	128	26	5000	5000	113	556	3	3
		m-Xylene	0.30000	4.6	39100	128	26	5000	5000	305	1504	8	8
		o-Xylene	0.30000	2.5	21250	128	26	5000	5000	166	817	4	4
		p-Xylene	0.30000	1.9	16150	128	26	5000	5000	126	621	3	3
Diesel	850	Benzene	0.00500	0.029	247	128	26	5000	5000	2	9	0.05	0.05
		Toluene	0.02400	0.18	1530	128	26	5000	5000	12	59	0.31	0.31
		Ethylbenzene	0.00240	0.068	578	128	26	5000	5000	5	22	0.12	0.12
		m+p-Xylenes	0.30000	0.22	1870	128	26	5000	5000	15	72	0.37	0.37
		Xylene	0.30000	0.043	366	128	26	5000	5000	3	14	0.07	0.07
		Total Xylenes	0.30000	0.5	4250	128	26	5000	5000	33	163	1	1
		Arsenic	0.02500	7.1E-06	0.1	128	26	5000	5000	0.00047	0.00232	0.00001	0.00001
		Cadmium	0.00500	4.9E-05	0.4	128	26	5000	5000	0.0033	0.0160	0.0001	0.0001
		Chromium	0.05000	0.00017	1	128	26	5000	5000	0.0113	0.0556	0.0003	0.0003
		Iron	0.30000	0.0037	31	128	26	5000	5000	0.2457	1	0.0063	0.0063
		Manganese	0.05000	0.00032	3	128	26	5000	5000	0.0213	0.1046	0.0005	0.0005
		Zinc	5.00000	0.00031	3	128	26	5000	5000	0.0206	0.1013	0.0005	0.0005
		Benzo(a)pyrene	0.00001	0.00022	2	128	26	5000	5000	0.0146	0.0719	0.0004	0.0004
Crude Oil	850	Benzene	0.00500	0.16	1360	128	26	5000	5000	11	52	0.2720	0.2720
		Toluene	0.02400	0.67	5695	128	26	5000	5000	44	219	1	1
		Ethylbenzene	0.00240	0.17	1445	128	26	5000	5000	11	56	0.2890	0.2890
		m+p-Xylenes	0.30000	0.5	4250	128	26	5000	5000	33	163	1	1
		m-Xylene	0.30000	0.66	5610	128	26	5000	5000	44	216	1	1
		o-Xylene	0.30000	0.26	2210	128	26	5000	5000	17	85	0.4420	0.4420
		p-Xylene	0.30000	0.26	2210	128	26	5000	5000	17	85	0.4420	0.4420
		Benzo(a)pyrene	0.00001	0.00024	2	128	26	5000	5000	0.0159	0.0785	0.0004	0.0004
No. 6 Fuel	850	Benzo(a)pyrene	0.00001	0.0044	37	128	26	5000	5000	0.2922	1	0.0075	0.0075

Exceeds ODWS