ROUND TWO INFORMATION REQUEST (IR) RESPONSE

EA No: 0809-001 **Information Request No: Alternatives North IR #10**

Date Received

November 30, 2011

Linkage to Other IRs (Round II)

Yellowknives Dene First Nation IR #04

Date of this Response

February 17, 2012

Request

Preamble

The effects of the diffuser on ice thickness and water quality in Yellowknife Bay are concerns that have been expressed many times as part of the Environmental Assessment. In committing to provide the Review Board and parties with the major design changes to the development as part of Undertakings 3 and 9, a summary of the diffuser design study was to be provided and is not in the materials filed by the Developer.

Question

Please provide a summary of the diffuser design study promised during the Technical Sessions Day Two as recorded on pages 259-260 of the transcripts.

Reference to DAR (relevant DAR Sections)

s. 6.8.6 Outfall and Diffuser

Reference to the EA Terms of Reference

s.3.2.4.9 Development Description

Response

The attached document prepared by Golder Associates (Doc 139) summarizes the work completed to date for the Preliminary Design of the diffuser system. The document sets out the water quality standards in Yellowknife Bay based on current information and available background data. The design work sets out the proposed water quality targets in the mixing zone in the bay, and the design criteria which were used for determining the configuration (length of diffuser, number of port, port diameter) of the diffuser.

TECHNICAL MEMORANDUM

DATE November 12, 2011

PROJECT No. 11-1427-0030/3000

TO Lisa Dyer
PWGSC

AECOM DOC. No. 318-WTP-10-MEM-0001-Rev3_20111112

GAL DOC. No. 139

FROM Nicolas Lauzon and John Hull

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SUMMARY OF GIANT DIFFUSER PRELIMINARY DESIGN

1.0 INTRODUCTION

The proposed new water treatment plant at Giant Mine is a facility that is intended to operate year-round. Treated effluent from the facility would be discharged to the environment through a diffuser located in Yellowknife Bay (Figure 1). An effluent diffuser is a hydraulic structure intended to promote rapid mixing of an effluent in close proximity to the structure using high discharge velocities. A diffuser may include several discharge ports on a main pipeline to achieve the required effluent dilution. Diffusers are often used for the discharge of mine effluents into local aquatic environments.

This document summarizes a preliminary design for the proposed diffuser in Yellowknife Bay and is subdivided into the following components:

- Description of regulatory requirements defining the effluent quality criteria and the ambient receiving environment water quality standards, in order to establish the dilution ratio required from the diffuser (Section 2);
- Listing of design criteria guiding the determination of the diffuser ports configuration and characteristics of the diffuser pipeline (Section 3);
- Characterization of effluent mixing within the ambient environment (i.e., Yellowknife Bay) and determination of a preliminary diffuser port configuration (Section 4); and
- Conclusion and recommendations of tasks to advance the diffuser to its detailed design phase (Section 5).

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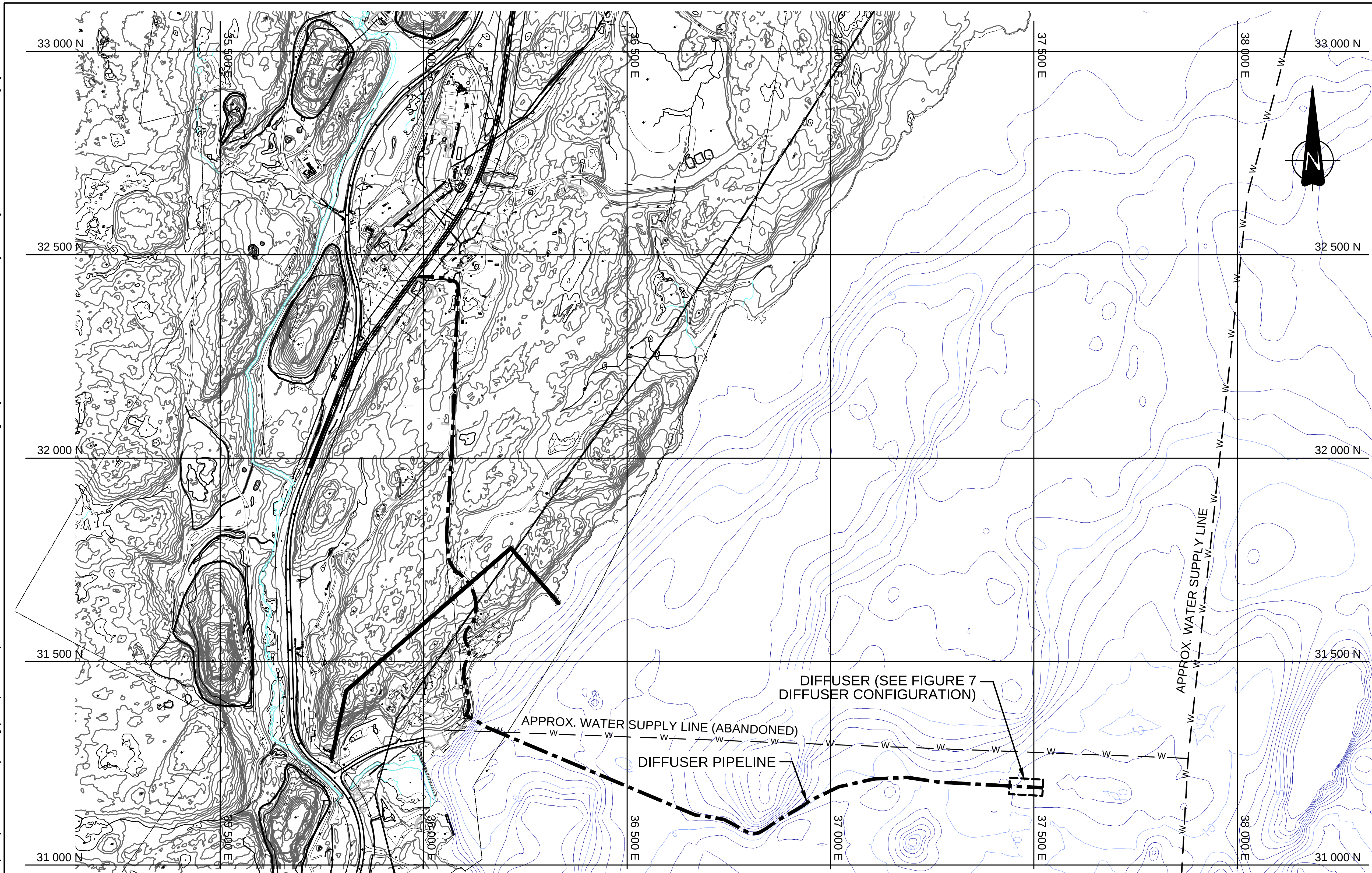
This preliminary design is a progression and advancement of the initial design proposed in the Developer's Assessment Report (INAC and GNWT 2010) and developed by Hay (2005). This progression, which satisfies the objectives of the DAR, includes the considerations of the following:

- A more comprehensive assessment of effluent quality criteria and water quality standards (Section 2), for a larger array of water quality constituents instead of only arsenic;
- Updated effluent discharge rates (Section 3), based on the preliminary design of the water treatment plant;
- An updated bathymetry for refining the selection of the location of the diffuser within Yellowknife Bay (Section 4); and
- Assessment of effluent mixing in the Bay under an ice cover (Section 4).



LEGEND

- TOPOGRAPHIC 2.5m INTERVAL CONTOUR
- EXISTING WATER COURSE
- BATHYTMETRIC 1m INTERVAL CONTOUR
- BATHYTMETRIC 5m INTERVAL CONTOUR

REFERENCES

1. PWGSC, CAD FILE: GIANT MINE - CONTOURS (0.5M) - 2009 - GMRP.DWG, DATE RECEIVED: JANUARY 10, 2011.

NOTES

1. EXISTING TOPOGRAPHY, CADASTRAL AND MINE LAYOUT PROVIDED BY PWGSC.
2. ALL COORDINATES SHOWN REFER TO THE GMRP COORDINATE SYSTEM.
4. TOPOGRAPHIC CONTOURS SHOWN AT 2.5m INTERVALS.
5. BATHYMETRY CONTOURS SHOWN AT 1m INTERVALS.

0 100 200 300 400 500

SCALE IN METRES

Public Works and Government Services Canada — Travaux publics et Services gouvernementaux Canada

REAL PROPERTY SERVICES
Western Region
SERVICES IMMOBILIERS
Région de l'ouest

PRELIMINARY
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DO NOT SCALE DRAWINGS

Revision/Revision	Description/Description	Date/Date
0	ISSUED WITH MEM-0001-R3	20111112
0	ISSUED WITH MEM-0001-R2	20111110
A	ISSUED WITH MEM-0001-R1	20111110
A	ISSUED WITH MEM-0001-R0	20111107

Client/client

PUBLIC WORKS GOVERNMENT SERVICES CANADA

Project title/Titre du projet

GIANT MINE REMEDIATION PROJECT
GIANT MINE REMEDIATION PROJECT, NWT

WETER TREATMENT PLANT TASK NO. 10

Approved by/Approuve par: JAH

Designed by/Concept par: NL

Drawn by/Dessine par: JK

PWGSC Project Manager/Administrateur de Projets TPSGC: HENRY WESTERMANN

PWGSC, Architectural and Engineering Resources Manager/ Ressources Architectural et de Directeur d'ingénierie, TPSGC

Client/client: PWGSC

Drawing title/Titre du dessin

PLAN VIEW OF DIFFUSER LOCATION

Project No./No. du projet	Sheet/Feuille	Revision no./La Révision no.
R.014204.318	FIGURE 1 OF 7	0

Drawing File: N:\Bur-Graphics\Projects\2009\1427\09-1427-0006\Drafting\4000\Task 4100\60162479_R014204-318-MEM-0001-CF01-R0.dwg Layout:DIFFUSER LOCATION Thursday, February 09, 2012 11:07:18 AM By: jkowacki

A0 - PWGSC - ANSI B-L1 - 11X17

60162479_R014204-318-MEM-0001-CF01-R0

2.0 REGULATORY RE□UIREMENTS

The water and effluent quality management policy of the Mackenzie Valley Land and Water Board (MVLWB 2011) requires the determination of:

- Water quality standards applied to the aquatic environment beyond a mixing zone of the discharged effluent; and
- Effluent quality criteria for end-of-pipe discharges of effluent into an aquatic environment (i.e., ambient waters).

A mixing zone is an area of the aquatic environment where the effluent is mixed with ambient water and outside of which must meet the water quality standards. The water quality standards for the project were determined from the following regulatory guidelines:

- Federal and territorial drinking water guidelines (RRNWT 1990 and HC 2010); and
- Environmental guidelines for the protection of aquatic life (CCME 2007).

These guidelines were compared to background concentrations observed in Yellowknife Bay (i.e., ambient waters). Table 1 summarizes the comparison of the water quality constituents together with existing guidelines. For any given constituent, the water quality standard for ambient water was considered as follows:

- If the median of observed concentrations in the bay were lower than that guideline then the most stringent regulatory guideline applies;
- If the median is higher than one or more regulatory guidelines then the standard becomes a threshold 10% higher than the median of observed concentrations in the bay; or
- If there is no regulatory guideline then the standard becomes a threshold 10% higher than the median of observed concentrations in the bay.

The water quality standards considered for the project are highlighted in bold in Table 1.

Effluent quality criteria for selected water quality constituents were defined as part of the design of the proposed new water treatment plant. These criteria are summarized in Table 2, along with regulatory guidelines that include the metal mining effluent regulation (MMER 2002) and the expired water license N1L2-0043 for Giant Mine (MVLWB 1998). Effluent quality criteria for constituents targeted for water quality standards in Table 1, but not part of the selection identified in the design of the water treatment plant were determined from the observed concentrations at the existing water treatment plant at Giant. The maximum observed concentrations at the existing water treatment plant (see Table 2), were selected as effluent quality criteria, since they would impose more stringent design considerations for the diffuser. The effluent quality criteria considered for the project are highlighted in bold in Table 2.

The effluent quality criteria, water quality standards and ambient water median concentrations were used to calculate the dilution ratio to be achieved by the diffuser (see Table 2). This ratio was determined for each constituent with an effluent quality criterion that is higher than the water quality standard (i.e., for constituents that require dilution). The highest calculated dilution ratio was then retained as a design criterion for the diffuser, since it represents the critical dilution requirement. This highest dilution ratio is that calculated for arsenic (100 to 1) and is based on the calculations summarized below:

- Arsenic is a target constituent for the design of the proposed new water treatment plant, and the intention is to never exceed the effluent water quality (0.5 mg/l), which has been exceeded by the existing water treatment plant in the past (maximum observed concentration of 0.61 mg/l).
- As many as 43 of the 51 observations of arsenic in the bay (Table 1) were obtained from analytical methods with detection limits that are close or significantly higher than the water quality standard of that constituent (i.e., detection limits of 0.002, 0.02 and 0.3 mg/l, compared to a guideline for the protection of aquatic life of 0.005 mg/l).
- Many cases with these high detection limits reported observable concentrations, however these observations were near these limits, and they should be assigned a high uncertainty level.
- A total of 8 of 51 observations were obtained from analytical methods with a low detection limit, and provided arsenic concentrations between less than 0.0002 and 0.0075 mg/l (median of 0.00056), with 7 observations appreciably below the guideline for the protection of aquatic life (0.005 mg/l).
- To ensure a conservative assessment, the arsenic dilution ratio was therefore approximated at 100 to 1, based on the effluent quality criterion and water quality standard of that constituent, and assuming an ambient concentration in the bay that would be to the level of these 8 low observations.

T□□□□ 1 □W□□□r □ □□□□□ S□□□d□rd□ □□r Y□□□□ □□□□□ B□□

P□r□□ □□□r	U□□□	R□□□□□□□r□ G□d□□□□□ □□ □□□ A□ □□□□□ E□□r□□□ □□□			A□ □□□□□(Y□□□□ □□□□□ B□□) W□□□r □ □□□□□ (□)				
		Dr□□□□□□ W□□□r (RRNWT 1□□0)	Dr□□□□□□ W□□□r (HC 2010)	Pr□□□□□□□□ □□ A□□□□□□ L□□□ (CCME 2007)	M□□□□ □□	M□d□□□	M□□□□ □□	T□□□□ N□□ □□r □□ S□□ □□□□	S□□ □□□□ B□□□□ D□□□□□□□□ L□□ □□□
P□□□□□□□									
Total Suspended Solids	mg/L	-	-	-	1	**2.4**	39	13	3
Total Dissolved Solids	mg/L	500	**□00**	-	<10	37	43	7	1
M□□□r I□□□									
Chloride	mg/L	250	**2□0**	-	0.9	1.9	6.4	36	0
Sodium	mg/L	-	**200**	-	1	2	5.5	29	6
Sulphate	mg/L	250	**□00**	-	<5	<5	5	36	25
N□□r□□□□									
Ammonia	mg/L	-	-	**1.□1 (□)**	0.003	0.01	0.043	32	7
C□□□□d□									
Total Cyanide	mg/L	0.01	0.2	**0.00□**	<0.001	<0.004	0.05	9	5
T□□□□ M□□□□□									
Aluminium	mg/L	-	0.1	**0.1 (□)**	0.017	0.06	0.15	8	0
Arsenic	mg/L	0.05	0.01	0.005	<0.0002	**0.03**	0.4	51	26
Cadmium	mg/L	0.01	0.005	**0.00□ (d)**	<0.00005	<0.002	0.2	48	41
Copper	mg/L	1	1	0.002 (d)	0.00084	**0.31**	2	48	24
Iron	mg/L	0.3	0.3	**0.3**	<0.02	<3	187	47	2
Lead	mg/L	0.05	0.01	0.001 (d)	<0.00005	**□0.2**	1.7	47	25
Manganese	mg/L	0.05	**0.0□**	-	<0.005	<0.02	1.7	26	19
Mercury (Inorganic)	mg/L	-	0.001	0.000026	<0.00001	**□0.02**	0.1	48	36
Molybdenum	mg/L	-	-	**0.073**	0.000115	<0.01	<0.01	8	7
Nickel	mg/L	-	-	0.025	0.00052	**0.2□**	1	48	27
Selenium	mg/L	0.01	0.01	**0.001**	<0.0005	<0.0005	<0.2	8	8
Uranium	mg/L	-	0.02	-	0.000246	**□0.□**	<0.5	3	2
Zinc	mg/L	5	5	0.03	0.004	**0.28**	<5	48	33

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Parameter	Units	Regulatory Guidelines for the Aquatic Environment			Ambient (Yellowknife Bay) Water Quality (a)				
		Drinking Water (RRNWT 1[illegible]0)	Drinking Water (HC 2010)	Protection of Aquatic Life (CCME 2007)	Minimum	Median	Maximum	Total Number of Samples	Samples Below Detection Limits
Organics									
Oil and Grease	mg/L	-	-	-	-	-	-	0	0
Radionuclides									
Radium-226	Bq/L	-	**0.[illegible]**	-	<0.005	0.005	0.006	8	0

(a) The sources of data are Moore et al. (1978), Jackson et al. (1996), Jackson (1998) and Golder (2008).

(b) Guideline calculated based on ambient water pH and temperature.

(c) Guideline calculated based on ambient water pH.

(d) Guidelines calculated based on ambient water hardness.

Table 2: Effluent Quality Criteria and Required Dilution Ratios for the Effluent

Parameter	Units	Regulatory Guidelines (Maximum Authorized Concentrations) [illegible] End of Pipe: Metal Mining Effluent Regulations (MMER 2002)	Regulatory Guidelines (Maximum Authorized Concentrations) [illegible] End of Pipe: Giant Water Licence N1L2-0043 (MVLWB 1[illegible]8)	Proposed Water Treatment Plant Objectives	Existing Water Treatment Plant Discharge Water Quality ([illegible]): Minimum	Existing Water Treatment Plant Discharge Water Quality ([illegible]): Median	Existing Water Treatment Plant Discharge Water Quality ([illegible]): Maximum	Existing Water Treatment Plant Discharge Water Quality ([illegible]): Total Number of Samples	Existing Water Treatment Plant Discharge Water Quality ([illegible]): Samples Below Detection Limit	Water Quality Standard ([illegible])	Required Dilution ([illegible])
Physical											
Total Suspended Solids	mg/L	15	15	**1[illegible]**	<1	<1	27	50	35	2.4	53
Total Dissolved Solids	mg/L	-	-	-	1770	2230	**2410**	23	0	500	5
Major Ions											
Chloride	mg/L	-	-	-	156	221	**341**	10	0	250	1.4
Sodium	mg/L	-	-	-	89.4	107	**14[illegible]**	36	0	200	Not required
Sulphate	mg/L	-	-	-	928	1160	**12[illegible]0**	6	0	500	3
Nutrients											
Ammonia	mg/L	-	12	**12**	<0.005	0.024	0.059	14	6	1.51	8
Cyanide											
Total Cyanide	mg/L	1	0.8	1	<0.005	<0.005	**0.012**	38	25	0.005	3
Total Metals											
Aluminium	mg/L	-	-	-	0.0045	0.01	**0.31**	61	3	0.1	6
Arsenic	mg/L	0.5	0.5	**0.[illegible]**	0.21	0.32	0.61	112	0	0.03	100
Cadmium	mg/L	-	-	-	0.00005	<0.00025	**0.000[illegible]**	59	34	0.009	Not required
Copper	mg/L	0.3	0.3	**0.3**	0.0054	0.0093	0.042	69	2	0.31	Not required
Iron	mg/L	-	-	-	<0.01	0.019	**0.1[illegible]**	61	12	0.3	Not required

Parameter	Units	Regulatory Guidelines (Monthly Average Concentrations) at the End of Pipe		Proposed Water Treatment Plant Objectives	Existing Water Treatment Plant Discharge Water Quality (b)					Water Quality Standard (a)	Required Dilution (c)
		Metal Mining Effluent (MMER 2002)	Giant Water Licence N1L2-0043 (MVLWB 1998)		Minimum	Median	Maximum	Total Number of Samples	Samples Below Detection Limit		
Lead	mg/L	0.2	0.2	**0.2**	0.0001	<0.00025	0.007	59	29	<0.2	10
Manganese	mg/L	-	-	-	<0.005	0.0171	**0.[illegible]**	61	6	0.05	12
Mercury (Inorganic)	mg/L	-	-	-	<0.00001	<0.0002	**[illegible]0.0002**	34	34	<0.02	Not required
Molybdenum	mg/L	-	-	-	0.012	0.02	**0.031**	61	2	0.073	Not required
Nickel	mg/L	0.5	0.5	**0.[illegible]**	<0.01	0.047	0.1	69	2	0.25	10
Selenium	mg/L	-	-	-	0.0006	<0.005	**0.017**	59	23	0.001	22
Uranium	mg/L	-	-	-	0.0003	0.00085	**0.00[illegible]1**	59	0	<0.5	Not required
Zinc	mg/L	0.5	0.2	**0.[illegible]**	<0.004	0.0065	0.071	69	1	0.28	8
Organics											
Oil and Grease	mg/L	-	-	[illegible]	<1	<1	<1	5	5	-	Not required
Radionuclides											
Radium-226	Bq/L	0.37	-	**0.37**	0.02	0.02	0.02	1	0	0.5	Not required

(a) The source of data is INAC (2011)

(b) Effluent water quality from Table 1.

(c) The required dilution is the greater of regulatory guidelines or 10% above measured background concentrations in Yellowknife Bay, whichever is more stringent.

3.0 DESIGN CRITERIA

Design of an effluent diffuser requires testing of several port configurations (i.e., number of ports, port diameter, port angle, space between ports, port geometry), and selecting a configuration that meet the required dilution ratio (i.e., 100 to 1, Section 2). The main design basis is then to achieve that dilution ratio so that constituent concentrations in the effluent plume, beyond the regulatory mixing zone, meet the water quality standards. The main design criterion for the diffuser ports is therefore the definition of the mixing zone and the dilution factor required.

The Northwest Territories provide guidance for the definition of mixing zones that is focused on wastewater effluent (NWTWB 1992). The water and effluent quality management policy of the Mackenzie Valley Land and Water Board (MVLWB 2011) further indicates that guidance on mixing zones are under development (i.e., not yet available). Size and shape of the mixing zone is established on a case by case basis and maximum limits vary among regions (provinces and states). The objective of this task in this project was to select a diffuser port configuration that minimizes the size of the mixing zone, while being bounded by the following limits:

- The mixing zone from one port must not exceed a radius of 66 m (200 feet), a general guideline set by EPA (1995);
- The mixing zone from one port must not exceed the radius of the near field area of the mixing model used (CORMIX in Section 4), since this radius is considered to correspond to the limit of application of that model (the near field area is where mixing is primarily influenced by the momentum of the effluent jet rather than ambient conditions and its outer boundary is located where the plume touches the water surface); and
- The region of the effluent plume from one port with a dilution ratio of 100 to 1 or less must not overlap with that same region from any other port.

The establishment of the characteristics of the diffuser ports and pipeline was guided by the design criteria summarized in Table 3.

Table 3 Diffuser Port and Pipeline Design Criteria

Parameter	Criterion	Comment
Dilution required at boundary of mixing zone	100	As calculated for the parameters at this site (Table 2).
Mixing zone radius form one port	66 m or near field area (whichever is smaller)	Respectively a general guideline by EPA (1995) and the domain of application for the mixing model used for the project.
Overlapping of port effluent plume	No overlapping of effluent plume	Minimize dilution inefficiency resulting from overlapping plumes from the diffuser ports.
Average effluent discharge flow	26 and 17 l/s	Respectively, the short and long term average discharge flow from the water treatment plant.
Maximum effluent discharge flow	34 and 21 l/s	Respectively, the short and long term maximum discharge flow from the water treatment plant.
Diffuser port exit velocity	Between 6 to 10 m/s	Range of velocities to apply to the average and maximum effluent discharge flows to promote mixing with ambient waters.
Port height above bay bottom	1 m	Minimize entrainment of bottom sediment from the port jets.
Inland Pipeline Alignment	Shortest possible alignment	Limit material used for constructing the pipe and minimize maintenance.
	Near existing access road	Facilitate maintenance.
Submerged Pipeline Alignment	Following a down gradient route to the extent possible	Facilitate installation of the pipeline and minimizing formation of air pocket in the submerged portion of the pipeline.
Water velocity in the pipeline	Between 0.3 and 1.2 m/s	Provide sufficient velocity to minimize the occurrence of clogging while being sufficiently low to minimize internal wear and tear in the pipeline and minimize friction losses.
Air volume in the pipe for sizing ballast weight	50% of pipeline internal volume	A conservative assumption to calculate ballast weight that will be sufficiently high to maintain the submerged portion of the pipeline at the bottom of the bay.

4.0 EFFLUENT MIXING

4.1 Mixing Model

The CORMIX model system (Doneker and Jirka 2007) was used to provide numerical simulations of the mixing and dilution behaviour of the mine effluent in the near-field in Yellowknife Bay. CORMIX is one of the most extensively used models for predicting plume mixing and dilution of substances in surface waterbodies. This model has been used for conceptual design and analysis of effluent diffusers in other northern Canadian waterbodies. Ambient and effluent water characteristics required to implement the mixing model are presented in Sections 4.2 and 4.3, respectively. A multiport diffuser is recommended as the endpoint of the effluent outfall. Dilution results from the mixing model and the characteristics of the recommended diffuser configuration are respectively presented in Sections 4.4 and 4.5.

4.2 Characteristics of Ambient Conditions

Ambient conditions (i.e., for Yellowknife Bay) are summarized in Table 4. Typically, for a given characteristic, a range of values is provided representing the possible conditions in the bay. Details on the information referenced to establish these characteristics are provided in Table 4 and discussed below.

Table 4: Summary of Yellowknife Bay Ambient Conditions

Characteristic	Adopted Values	Comments
Average Ambient Depth (m)	9.0 and 7.0	Respectively for the open water and ice cover periods. Derived from the bathymetry of the Bay (Figure 1), the observed water levels in the bay (Figure 2), and observed ice thickness in the bay. Average ambient depths are for the lowest water level observed in the bay (156.1 m), and the depth during the ice cover period account for a 2 m thick ice cover.
Wind Speed (km/h)	No wind, 16, 72	Represent cases of no wind, and observed average and maximum hourly wind at Yellowknife Airport meteorological station.
Average Ambient Velocity (m/s)	0.005, 0.07, 0.6	A range of velocities representing near stagnant conditions, an assumed average condition based on the hourly average wind speed, and an extreme case based on the observed hourly maximum wind speed.
Ambient Temperature (˚C)	Un-stratified: 4, 19 Stratified: 16, 19	Un-stratified: assigned temperatures during the ice cover and open water periods, respectively to provide the highest density differential between ambient and effluent waters. Stratified (at 5 m depth): assigned temperature in the lower and upper water layers in the bay to provide a high density differential between ambient and effluent waters and the highest observed temperature differential between water layers.
Ambient total Dissolved Solids (mg/L)	37	Median of observations in Yellowknife Bay (Table 1)
Ambient Total Suspended Solids (mg/L)	2.4	Median of observations in Yellowknife Bay (Table 1)
Water Density (kg/m^3)	Un-stratified: 1000.0, 998.4 Stratified: 999.0, 998.4	Calculated from water temperature, total dissolved solids and total suspended solids (Coles and Wells 2003), respectively for un-stratified ice cover and open water periods and for the stratified case during the open water period.
Manning's Coefficient	0.015	Assumed; typical value for waterbodies for lakes and bays.

The bathymetry of Yellowknife Bay in the region of the diffuser location is illustrated in Figure 1. The bathymetry contours in Figure 1 were derived from depth surveys undertaken in September 9, 10, 14, 15, 17, 19, 27 and 29, 2010. Surface water levels observed during the survey, (at Water Survey Canada station 07SB001. WSC 2011), varied between 156.26 and 156.33 m, with an average of 156. 3 m. Long term surface water level characteristics (i.e., from 1934 to 2009) in the bay are presented in Figure 2, and indicate that the minimum water level observed over this period was 156.1 m. Ambient depth at the proposed diffuser location may then be lower than 10 m, and an average ambient depth of 9 m (Table 4) was therefore considered in the model during the open water period (i.e., May to October). Under winter conditions, the ambient depth must be reduced to account for the presence of an ice cover on the bay. Ice thickness measurements in the bay, taken for this project on March 29 and 30, 2010, and obtained from the Canadian Ice Database (Lenormand et al. 2002) vary between 97 and 183 cm, for an average of 134 cm. A thickness of 200 cm was considered for this analysis, yielding an average ambient depth of 7 m (Table 4) during the ice cover period (i.e., November to April).

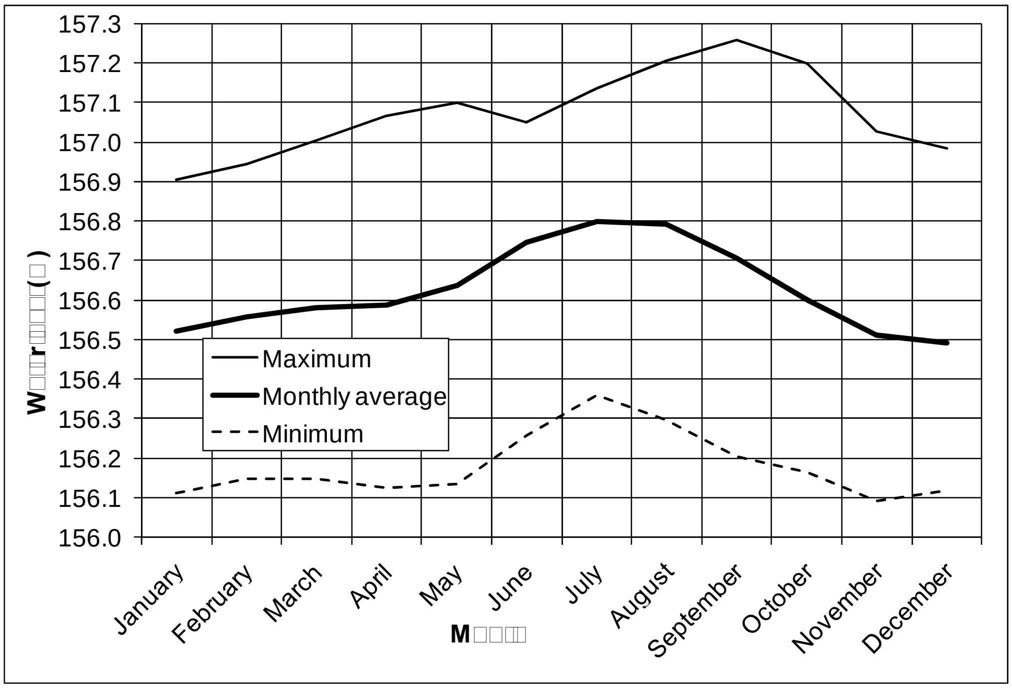

Figure 2: Surface Water Levels in Yellowknife Bay

Effluent mixing is dependent on ambient currents in Yellowknife Bay, which are expected to be driven mainly by wind conditions during the open water period. Hourly wind observations from 1953 to 2010, from Environment Canada meteorological station at Yellowknife Airport (EC 2011) were compiled to establish average and maximum speed (Table 5) as well as occurrences (Figure 3) according to major directions, during the open water period. Winds occur most often from the east (41% from NE, E and SE combined), with notable occurrences from the south (18%) and the north (15%). The average hourly wind speed of all directions combined is 16 km/h, while the maximum hourly wind speed was observed from the west at 72 km/h).

Table [illegible] Wind Speed Characteristics at Yellowknife Airport, from May to October

Direction	Average Hourly Wind Speed (km/h)	Maximum Observed Hourly Wind Speed (km/h)
North (N)	17.3	68
North East (NE)	15.2	64
East (E)	15.6	52
South East (SE)	14.9	56
South (S)	16.1	56
South West (SW)	12.0	51
West (W)	14.7	72
North West (NW)	17.4	64

Shear stress at the air-water interface theoretically leads to near water surface lake currents equal to approximately 3% of wind speed (Cole and Wells 2003). However, current velocities in the bay were estimated from 1) drogue tracking simulation studies (Hamilton et al. 1989); and 2) a rhodamine dye tracer study (Grainge 1963). Current velocities were estimated to be 0.6 to 0.7% of wind speed during the period of the dye tracer study, while velocities were calculated to vary between 0.35 to 2.6% of wind speed on the days the drogue tracking simulation studies was undertaken. During both studies, wind speeds were near the long term hourly average of 16 km/h at Yellowknife Airport. For the purpose of this study, the following range of current velocities was considered for the open water period:

- A near stagnant condition (i.e., velocity of 0.005 m/s) to represent a case of no wind (or under ice condition);
- An average velocity assumed as 1.5% (i.e., a mid percentage from the drogue tracking study) of the average hourly wind (i.e., velocity of 0.07 m/s); and
- A extreme velocity corresponding to 3% of the maximum hourly wind (0.6 m/s).

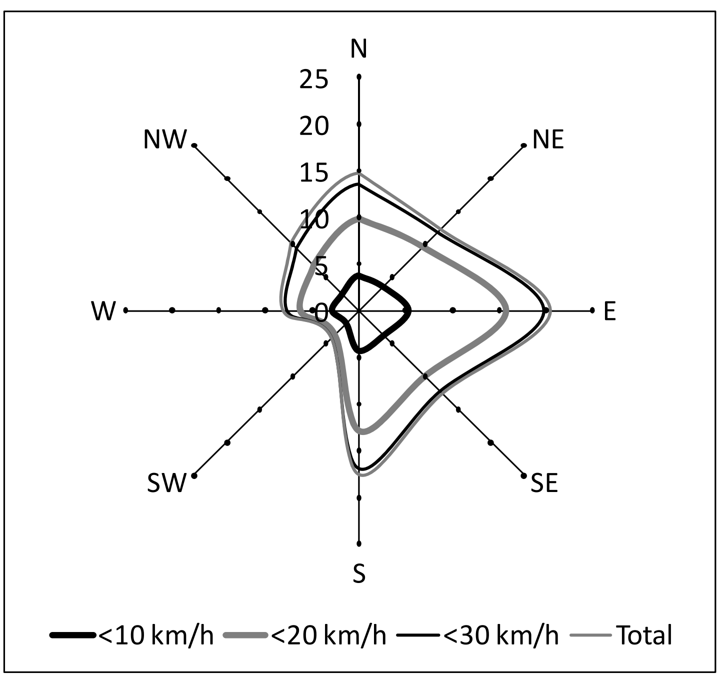

Figure 3: Wind Occurrence (in percent) in the major Directions, from May to October

During the ice cover period, winds are not expected to impact current velocities in the bay. Flows from the Yellowknife River are anticipated to provide a source of freshwater into the bay year round, and to ultimately convey the effluent toward Great Slave Lake. Flow characteristics compiled from observations taken at Water Survey Canada station 07SB002 (WSC 2011) on the Yellowknife River from 1939 to 2009 are illustrated in Figure 4. Flows typically initiate a rise in May at the start of the freshet until they reach their peak in June and July, then gradually decrease from August to April. Flows during the winter are relatively low and therefore the current velocity in the bay used in the mixing model for the ice cover period was the case of near stagnant conditions (i.e., 0.005 m/s).

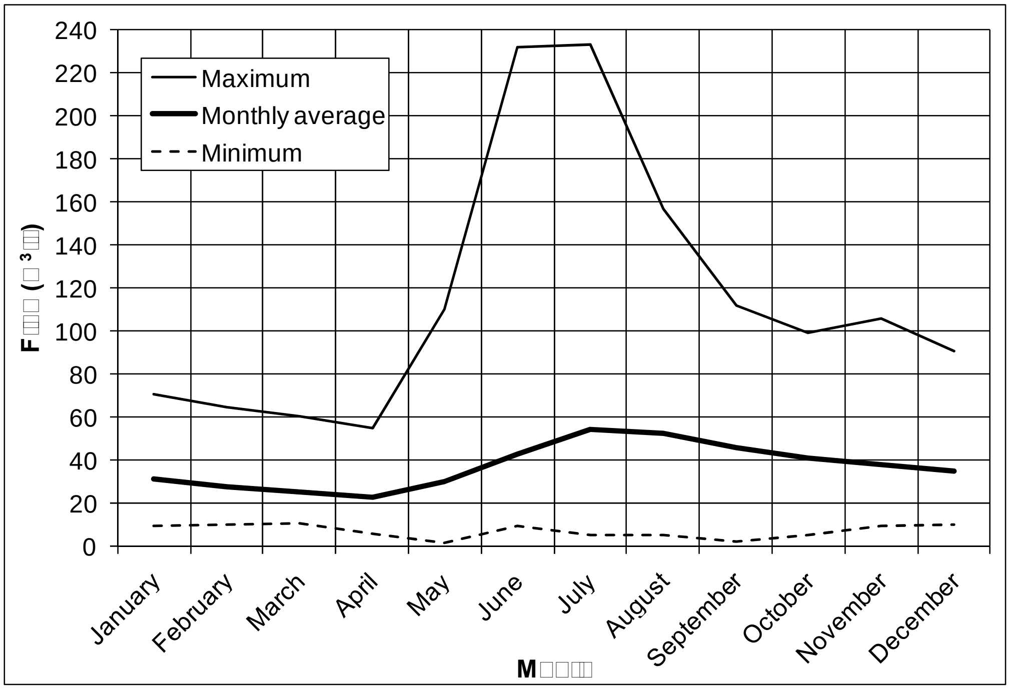

Figure 4: Flows from Yellowknife River

Water density affects mixing and is dependent on water temperature and concentration of total dissolved and suspended solids. Water temperature observations in Yellowknife Bay reported by Moore et al. (1978), Hamilton et al. (1989) and Golder (2009) vary between approximately 4 and 19°C during the open water period and 0 and 4°C during the ice cover period. Furthermore, observations in Hamilton et al. (1989) and Golder (2009) indicate a gradually decreasing temperature as a function of depth between July and August. The decrease was notably pronounced at depths between 4 and 6 m, indicating a thermocline at this depth, with a difference in temperature between 2 and 3°C. As part of this study, the following ambient water temperature cases were considered:

- Un-stratified water column during the ice cover period: a temperature of 4°C to provide the highest density differential between ambient and effluent waters;
- Un-stratified water column during the open water period: a temperature of 19°C to provide the highest density differential between ambient and effluent waters; and
- Stratified water column at a depth of 5 m during open water period: temperature of 16 and 19°C, respectively for the lower and upper water layers in the bay, providing a high density differential between ambient and effluent waters and the highest observed temperature difference between the upper and lower water layer.

Observed total dissolved and suspended solids in Yellowknife Bay were relatively low and would have little impact on water density. The median values for these two water quality parameters (i.e., 37 and 2 mg/l, respectively for total dissolved and suspended solids, Table 1) were considered to calculate ambient water density.

4.3 Characteristics of Effluent

Effluent characteristics are summarized in Table 6. Discharge rates were estimated from the expected treated water volumes, based on the expected volumes from all water sources directed to the water treatment plant. Short and long term discharge rates are respectively for the underground freezing and post underground freezing periods (Section 2.2.3). Observed water temperature of the influent to the existing water treatment plant varies between 2 and 11°C, with winter temperature not exceeding 8°C (B. Williamson, AECOM, pers. Comm., 2011). It is considered that a temperature of 9°C would represent the effluent water temperature providing the highest density differential between effluent and ambient conditions. The total dissolved and suspended solids levels presented in Table 6 respectively represent the maximum observed concentration from the existing water treatment plant and the maximum allowable effluent concentration from the proposed water treatment plant.

Table 6: Summary of Effluent Characteristics

Characteristic	Adopted Value	Comment
Discharge Rate (l/s)	34, 26, 21, 17	Respectively the short term maximum and average discharge rates and long term maximum and average discharge rates from the proposed water treatment plant (Table 3).
Discharge Temperature (˚C)	9	Within the range of temperature observed at the existing water treatment plant, and providing the highest density differential between ambient and effluent water for both the open water and ice cover periods.
Discharge Total Dissolved Solids (mg/L)	2400	Maximum observed concentration from the existing water treatment plant (Table 2).
Discharge Total Suspended Solids (mg/L)	15	Effluent quality criterion for the water quality parameters (Table 2).
Density (kg/m^3)	1001.7	Calculated from water temperature, total dissolved solids and total suspended solids (Coles and Wells 2003); (negatively buoyant plume in all cases).

4.4 Modelling Results

The design process for the diffuser consisted of the following:

1) Identifying the geometry of a port (diameter and angle) that would provide the required 100 to 1 dilution based on the characteristics of the effluent listed in Table 6, for all the combinations of ambient characteristics (i.e., depths, current velocities and temperatures) that can be realized from the values listed in Table 5. This step determined the fraction of the discharge that can pass through one port while achieving the required dilution.

2) Identifying the number of ports, with the geometry identified in the first step, required to pass the total effluent discharge and the distance between ports to prevent overlapping of plume jets from the ports.

The following diffuser port configurations were tested:

- Port diameters of 13, 19, 25 and 31 mm;
- Port angles of 90 (vertical), 45 and 30 degrees;
- Port exit velocities of 6 and 10 m/s (Table 3); and
- Co-flowing (effluent and current velocities in the same direction) and cross-flowing (effluent and current velocities at a 90-degree angle) scenarios.

The combination of the range of ambient characteristics and diffuser port configurations resulted in the analysis of over 336 test runs with the mixing models. Conclusions from this analysis are as follows:

- The ports were sized to meet the required dilution of 100 plus an accuracy allowance of 50% (dilution of 150) as stated in the Doneker and Jirka (2007).
- A vertical port (90˚ angle from the reservoir bottom) does not provide the required dilution ratio under near stagnant conditions (current velocity of 0.005 m/s), and therefore should be discarded as a configuration option for the diffuser.
- The 30˚ and 45˚ angled ports provide similar dilution ratios; however a 30˚ angle is preferred to minimize the interaction of the plume jet with ice at the bay surface during the ice cover period.
- Using larger port diameters yields larger discharge flow volumes from a single port, and larger flow volumes resulted in longer distance required to achieve the 150 to 1 dilution ratio. It is recommended to use a small diameter (i.e., 13 mm) to achieve the required dilution while minimizing contact with either the ice or thermocline interface.
- When no temperature stratification is present in the bay, the plume jet from a port is predicted to make contact with the water surface or the ice cover. Model predictions nevertheless indicate that mixing of the effluent with ambient water would achieve the 150 to 1 dilution before the plume makes contact with the water surface during the open water period (Figure 5a). During the ice cover period, it is predicted that the plume would make contact with the ice cover bottom (Figure 5b).
- The tested temperature stratification in the bay is predicted to constitute the equivalent of a barrier that would deflect the effluent plume from the diffuser port (Figure 6a). This deflection is however predicted to induce a lateral spreading of the plume (Figure 6b), allowing further dilution. The 150 to 1 effluent dilution isocontour would be in contact with the thermocline interface.
- Uncertainty should be considered on dilution predictions after a plume makes contact with a barrier or interface (i.e., ice cover in Figure 5a or thermocline in Figure 6). The near field region, which is the domain of validity of CORMIX, ends when the plume reaches an interface. The length of the contact is however relatively short. As a result it is proposed that the mixing zone be slightly higher than the near field area, consisting of an area with a radius of 15 m around each port. During the detail design phase, adjustment should be made to the port angle to minimize the length of contact with any interface.

- Prediction of effluent dispersion beyond the near-field is not possible with CORMIX. However some qualitative assessment is provided as follows: Outside the near-field mixing zone, mixing in the lake would be dependent on current velocity (driven by wind and waves) in the bay and the difference between ambient and effluent water densities. The negatively buoyant effluent (i.e., high effluent density compared to ambient water density) may create a zone of effluent along the bottom of the lake, where mixing would then occur gradually from lateral dispersion and vertical distribution.
- The maximum velocity of the effluent plume in contact with the ice cover bottom is predicted to be approximately 0.15 m/s. Thinning of the ice cover might occur, and should be confirmed during the diffuser detailed design phase. The thinning, if any, would be local and may be further minimized by adjusting the port angle (i.e., lower than 30°).

As a summary, a port with a diameter of 13 mm and angle from the bay bottom of 30° is predicted to achieve the required 100 to 1 effluent dilution, within a mixing zone with a 15 m radius, for the combinations of ambient characteristics tested. The largest width of the effluent plume area with a dilution ratio of 150 to 1 or less is approximately 0.75 m, which was considered in the determination of the distance between ports in Section 4.5.

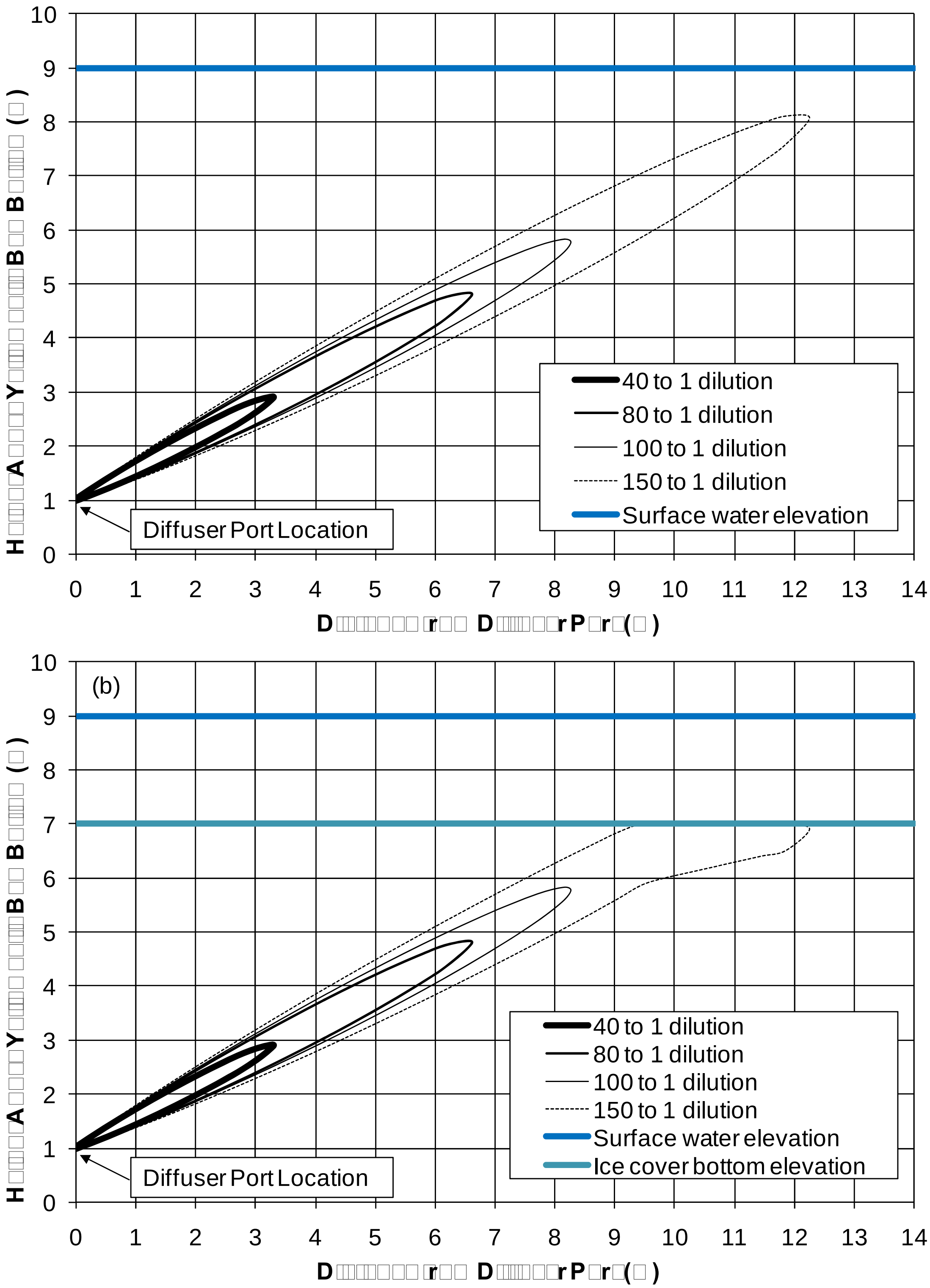

Figure 5: Effluent Dilution from a Single Port for an Un-Stratified Ambient Water Column: (a) Open Water and (b) Ice Cover Periods (worst ambient conditions, with near stagnant current)

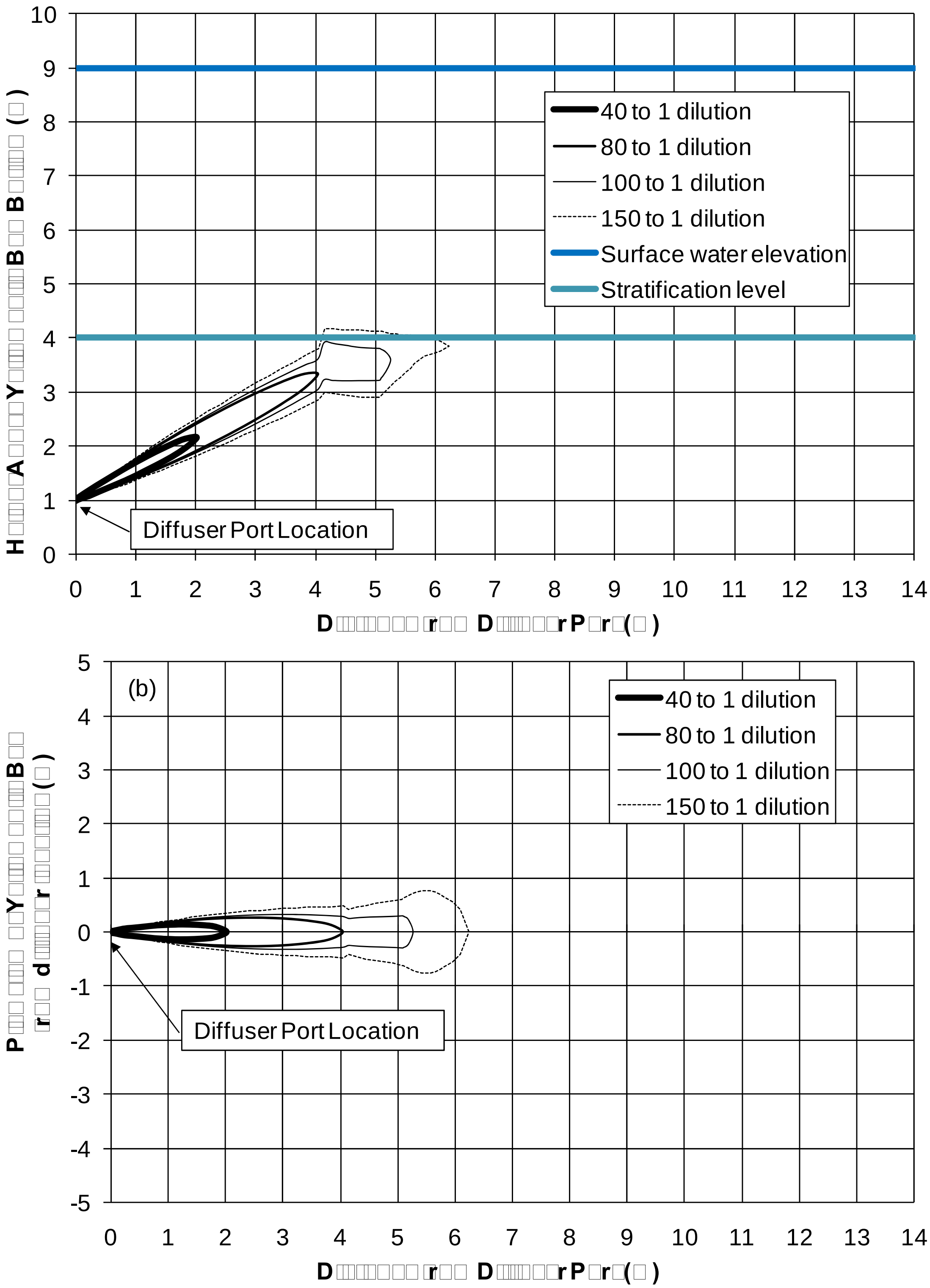

Figure 6: Effluent Dilution from a Single Port for a Stratified Ambient Water Column: (a) Profile and (b) Plan Views (worst ambient conditions, with near stagnant current)

4. Diffuser Port Configuration

Flow through a single 13 mm diameter port must range between 0.8 and 1.3 l/s in order to meet the design requirement of port exit velocity between 6 and 10 m/s (Table 4). A diffuser with 28 ports is recommended to discharge the short term effluent flows (i.e., average and maximum flow of 26 and 34 l/s, resulting in a flow per port of 0.9 and 1.2 l/s, respectively). Before the onset of long term conditions, several ports will have to be sealed during a maintenance operation with divers, in order to meet the design requirement on port exit velocity with the reduced flow of that operation period (i.e., average and maximum flow of 17 and 21 l/s). For long term conditions, the number of active ports should be reduced to 18 (i.e., flow per port of 0.8 and 1.2 l/s, respectively for average and maximum flow conditions).

The space between ports was established to minimize overlap of the effluent plume from each port, while minimizing the total length of the diffuser in order to minimize the total area of the mixing zone (i.e., the combined area of the mixing zone of each port). For preliminary design the distance between ports is proposed to be 3 m, equalling twice the largest width of the effluent plume area with a dilution ratio of 150 to 1 or less. The total length of the diffuser, from the first to the last port would therefore be 81 m, yielding a rectangular shaped mixing zone around the diffuser with a width of 30 m (i.e., the diameter of the mixing zone for one port) and a length of 111 m (i.e., the length of the diffuser plus the diameter of the mixing zone for one port on either end of the diffuser). In addition, it is recommended that ports discharge in alternate directions, as shown in Figure 7, to further minimize the occurrence of effluent plume overlaps.

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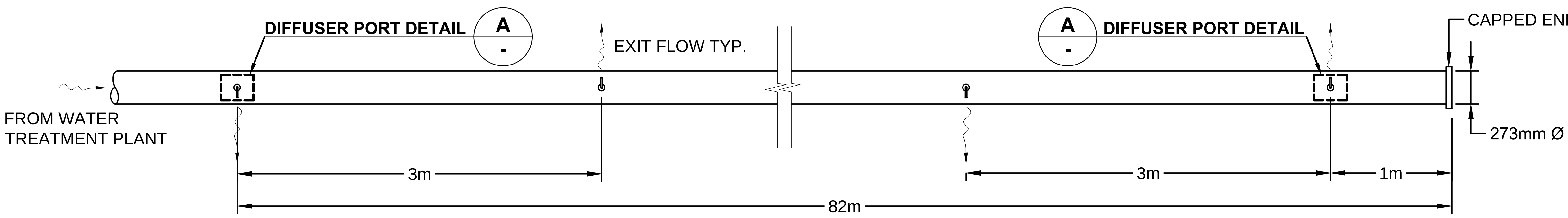
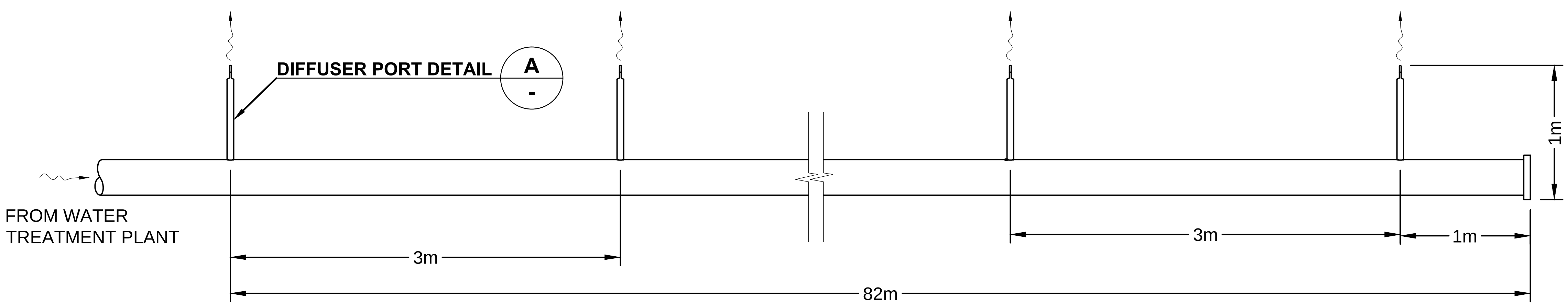
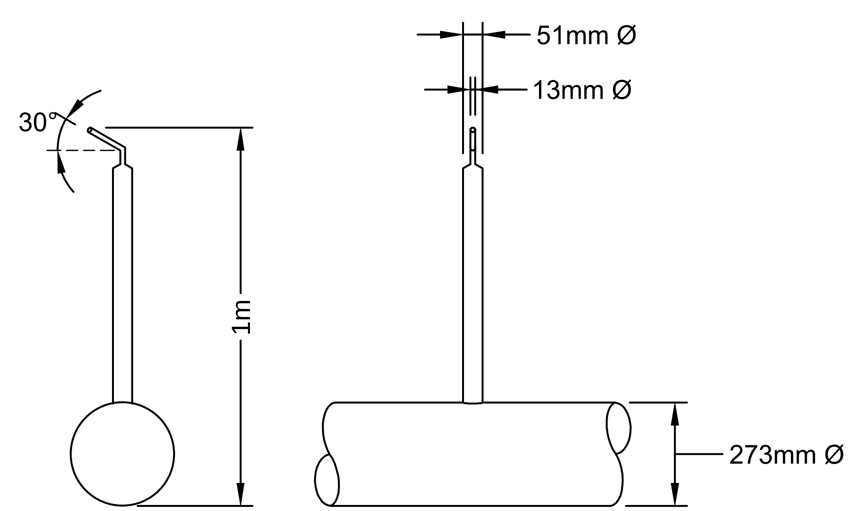


1 - **PLAN VIEW**
SEE SCALEBAR A



2 - **PROFILE VIEW**
SEE SCALEBAR A



NOTE:
A TOTAL OF 28 PORTS ARE INCLUDED, SPACED 3 m APART.

A - **DIFFUSER PORT DETAIL (28 PORTS TOTAL)**
SEE SCALEBAR B

0 0.4 0.8 1.2 1.6 2
SCALEBAR A (m)

0 0.25 0.5 0.75 1 1.25
SCALEBAR B (m)

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Revision/Revision	Description/Description	Date/Date
0	ISSUED WITH MEM-0001-R3	20111112
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A	ISSUED WITH MEM-0001-R1	20111107
A	ISSUED WITH MEM-0001-R0	20111107

Client/client
PUBLIC WORKS GOVERNMENT SERVICES CANADA

Project title/Titre du projet
GIANT MINE REMEDIATION PROJECT
GIANT MINE REMEDIATION PROJECT, NWT

WATER TREATMENT PLANT TASK NO. 10

Approved by/Approuve par
JAH

Designed by/Concept par
NL

Drawn by/Dessine par
JK

PWGSC Project Manager/Administrateur de Projets TPSGC
HENRY WESTERMANN

PWGSC, Architectural and Engineering Resources Manager/ Ressources Architectural et de Directeur d'ingénierie, TPSGC

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Drawing title/Titre du dessin
DIFFUSER CONFIGURATION

Project No./No. du projet	Sheet/Feuille	Revision no./La Révision no.
R.014204.318	FIGURE 7 OF 7	0

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Runs with CORMIX were undertaken to test the proposed diffuser configurations, for spaces between ports of 1.5, 3 and 6 m, and for ports discharging in the same direction or in alternate directions. Considering all combinations of ambient characteristics, a total of 42 model runs of multiport diffuser configuration were undertaken. Test runs with multiport diffusers indicated that CORMIX may overestimate dilution by 22% on average (Etemad-Shahidi and Azimi 2007). Dilution prediction made in this project for multiport diffuser configurations were therefore reduced by 22%. The required dilution is consistently predicted to occur within a shorter distance for configurations with ports discharging in alternate opposing direction than those discharging in the same direction. The dilution of 150 to 1 would not be achieved within a distance of 15 m from the port, with some of the combinations of ambient characteristics and with 1.5 m space between ports (i.e., cross flowing effluent with average to high current velocities). The dilution of 150 to 1 is predicted to be met within a distance of 15 m at all time for all combinations, with 3 and 6 m space between ports. The effluent dilution predicted for configurations with 3 m space between ports is relatively similar to that of configurations with 6 m space between ports.

The diffuser configuration consisting of 28 ports spaced 4 m apart and discharging in alternate directions is therefore considered reasonable for preliminary design and achieves the required dilution of 100 to 1. The summary of the diffuser port configuration is provided in Table 7. It is proposed that the diffuser be aligned in the east-west direction at the location shown in Figure 1; however this alignment and location must be confirmed during the detailed design phase, using the results of far field effluent dilution from a two- or three-dimensional hydrodynamic model. To maintain proper dilution, flow rate from the water treatment plant should be equal or more than 20 and 15 l/s, respectively for short and long term operation.

Table 7: Proposed Preliminary Diffuser Port Configuration

Parameter	Value
Length of Diffuser (m)	81
Number of Ports	28 (short term) and 18 (long term)
Discharge Pattern	Alternate opposing direction
Distance between pairs of ports (m)	3
Port Diameter (m)	0.013 (or 0.5 inch)
Angle of ports from the reservoir bottom (˚)	30
Height of ports from the reservoir bottom (m)	1
Minimum Discharge Flow (l/s)	20 (short term) and 15 (long term)

□.0 CONCLUSIONS

The diffuser proposed for the discharge of effluent from the Giant Mine new water treatment plant would have the following characteristics: 28 ports, spaced 3 m apart, raised 1 m above the Yellowknife Bay bottom, in series on a single pipeline and discharging in alternate opposing directions, with a diameter of 13 mm at the port exit. The diffuser ports would be connected to the water treatment plant using an HDPE pipeline. The effluent quality criteria and water quality standard of the ambient environment (i.e., Yellowknife Bay) were assessed to determine the effluent dilution ratio to be achieved by the diffuser. The most stringent ratio calculated was that for arsenic, at 100 to 1. Model predictions of effluent mixing characteristics in the bay indicate that the proposed diffuser configuration can achieve the required dilution ratio within a mixing zone set at a 15 m radius centered at each port. The configuration with 28 ports is valid for effluent flow expected in the short term operation of the water treatment plant. Effluent flow will be reduced for long term operation, and the number of active ports during that phase should be limited to 18, with all other ports being sealed.

Modelling predictions of effluent mixing characteristics was performed in the near field area of the diffuser. The fate of the effluent in the far field is dependent on the geometry of Yellowknife Bay and the flow and climate conditions affecting that body of water. The proposed diffuser location is assumed to be within the main channel of Yellowknife River within the bay, with the expectation that the flow momentum from the river, which discharges year-round, will convey the mixed effluent toward Great Slave Lake. As part of the detailed design phase for the diffuser, the location of the diffuser will be confirmed through the modelling of far field conditions in the bay, using a two- or three-dimensional hydrodynamic model. From that modelling effort, the diffuser location may be adjusted to minimize recirculation of the effluent within the bay.

As part of and as support to the detailed design phase of the diffuser, the following tasks are required:

- A geotechnical investigation of the inland pipeline alignment, to determine soil characteristics and presence of permafrost, in order to establish construction methods for a buried pipe;
- A geotechnical investigation of the submerged pipeline alignment to identify bedding characteristics, presence of fine sediment pocket and other obstacle to the placement of the pipe;
- A detailed hydraulic analysis of the pipeline to confirm pumping requirements and pipe sizes;
- Sampling of bay bottom sediment at the general location of the diffuser for an analysis of granular distribution and settling properties, in order to evaluate possible mobilization of particles from the diffuser jets;
- An inspection of shoreline conditions (topography, soil characteristics, and benthic and fish habitat) to confirm the location of the point of entry of the pipeline from the land to the bay;
- A survey of ice thickness in several areas of the Yellowknife Bay in the next winter to consolidate the current database of ice observations;
- Implementation of a hydrodynamic model of the bay, including the diffuser as a water source and all water supply intake (present or planned), to assess the fate of the Giant mine effluent in that waterbody;
- Monitoring of wind speed and direction near Yellowknife Bay, as a support to the hydrodynamic modelling effort, to confirm validity of wind measurements at Environment Canada Yellowknife Airport station;
- Monitoring of water quality in the bay on a seasonal basis for at least one year at several location in the bay, using analytical method with sufficiently low detection limits, to consolidate the database of ambient water quality;
- Limnological surveys on a seasonal basis for at least one year at several locations in the bay, for an assessment of the temperature, dissolved oxygen and conductivity profile as a function of depth (these data would serve in the calibration of the hydrodynamic model);
- At least two survey campaigns (i.e., during the open and ice cover periods) for the assessment of water current at several locations in the bay (this data would serve in the calibration of the hydrodynamic model); and

- A refined bathymetric survey in the general location of the diffuser and along the alignment of the diffuser pipeline, as a support for the design and hydrodynamic modelling effort.

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