Supporting Document L2

Giant Mine Effluent Dilution Study
(Hay & Co., 2005)

HAYCO

HAY & COMPANY
CONSULTANTS A DIVISION OF EBA

Suite 900 – 1066 West Hastings Street
Vancouver BC Canada V6E 3X2
Tel: 604-875-6391 ■ Fax: 604-875-8363
Email: hayco@hayco.com ■ Website: www.hayco.com

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Giant Mine Remediation Project
P.O. Box 1500
Suite 500, 4920 52nd St.
Yellowknife NT X1A 2R3

Attention: Mr. Bill Mitchell, Project Manager

Dear Mr. Mitchell:

Re: Giant Mine Effluent Dilution Study

1 INTRODUCTION

We are pleased to provide the following report outlining our assessment of a proposed outfall diffuser in Yellowknife Bay. The performance of the diffuser at two alternative locations is evaluated.

2 BACKGROUND

An outfall diffuser is being considered for the discharge of treated water from Giant Mine into Yellowknife Bay, just north of the city of Yellowknife, Northwest Territories. The goal is to reduce arsenic concentration in the receiving water, outside of an initial mixing zone, to the CCME FWAL guideline of 0.005 mg/L. For the maximum arsenic concentration of 0.4 mg/L in the discharge, this would require the dilution to be 80:1. Two candidate locations are considered for the placement of the diffuser: location 1 is 8.5 m deep and 508 m offshore and location 2 is 10 m deep and 1502 m offshore (Figure 1).

Figure 2 provides a schematic of a multi-port diffuser, as proposed herein for the Giant Mine outfall. The diffuser consists of a straight pipe section, or manifold, at the end of the outfall line, to which are attached several smaller diameter pipe sections, consisting of a riser and a port, through which the effluent is discharged. These ports can be configured in a number of different ways. The outflow nozzles are shown as horizontally-oriented in Figure 2, but could also consist merely of holes drilled into the outfall diffuse manifold. Furthermore, the nozzles could be directed at a partially upward angle, as used in one of the configurations studied in this report.

The diffuser is constructed so that mixing with the receiving waters, and hence dilution, is maximized, based on two principles:

1. flow speeds are increased as the effluent passes through the small-diameter output nozzles, and hence entrainment of ambient water is increased, entrainment being proportional to the velocity difference between the exiting liquid and the ambient;
2. because of the spread of the plumes or jets that issue from each diffuser nozzle, the surface area for mixing with the ambient is increased, which increases the ultimate dilution.

The fate and transport of an outfall discharge is usually described in terms of near and far field processes, as shown schematically in Figure 3, for the case of significant currents in the receiving water (top), and for the case of negligible currents in the receiving waters. The distinction between near and far fields is made because the length and time scales of the dominant mixing processes vary considerably in the receiving environment, but can be schematized reasonably well into these two regions. The near field is also sometimes referred to as the initial dilution zone or the initial mixing zone. In the near field, intense mixing quickly results in dilutions on the order of hundreds or more. This mixing is caused by turbulence generated by the discharge itself. The near field ends when the turbulence dissipates to levels similar to those in the ambient, marking the beginning of the far field. The wastefield at this point is said to be established. It may either be submerged or on the surface, depending on the strength of the ambient density stratification and ambient currents. The trapping depth is the depth of the plume centreline at the point that the waste field is established, i.e., when the effluent makes the transition from the near-field dynamics to the far-field dynamics.

In the top panel of Fig. 3, corresponding to significant ambient currents, the trapping depth is considerably below the surface whereas in the bottom panel, with negligible currents, the trapping depth is essentially zero, and the plume has surfaced. The near field processes are dominant only within a short distance from the diffuser, and only for the first few minutes after the effluent is discharged. Beyond the near field, the established wastefield is advected by ambient currents and diffused by turbulence in the ambient waters, in the region known as the far field. The far field processes occur over time scales of hours and distances of kilometres.

In this study, the UMERGE component of the Visual Plumes Model, published in 2002 by the Environmental Research Division of the US Environmental Protection Agency (Frick et al., 2001), will be used to quantify the diffuser performance under the expected range of operating conditions. The model predicts centerline dilution, plume rise and plume diameter as the plume evolves from the end of the diffuser port until it is trapped or surfaces. The US-EPA Visual Plumes model is the commonly accepted standard for near-field modelling of outfall diffusers, and is capable of simulating both single- and multi-port diffusers. The model simulates single and merging submerged plumes in stratified ambient flow and buoyant surface discharges. For the far field, one can either make use of simple analytical dispersion models, or use a three-dimensional circulation model to simulate the far-field and long-term, cumulative effects of effluent discharge. For this study, the goals of 80:1 dilution could be met by the diffuser alone, so there was no need to consider more complicated processes in the far-field.

Two seasons, winter and summer, were considered for this study. For each season, the characteristics of the effluent discharge and the receiving water body, (Tables 1 and 2), were used as inputs to the Visual Plumes Model. The information regarding the temperature and salinity stratification in Yellowknife Bay is extracted from Hamilton et al. (1989). Two water treatment scenarios were evaluated, involving different rates of effluent discharge to the bay. The 'short-term' scenario includes the treatment of runoff from the tailing containment areas, as well as water that accumulates in the underground mine. Under the 'long-term' scenario, only the mine water would be treated, and the rate of effluent discharge would be lower. However, the arsenic concentration in the discharge will remain the same and the objective is to achieve the 80:1 dilution for both the short and long terms at the trapping depth. To ensure that the goal will be achieved at all times, the worst-case scenario was assessed using an assumption that the current of the receiving water body at the diffuser is minimal (0.01 m/s).

Table 1

Characteristics of The Effluent Discharge

	Summer		Winter	
	Wet Year	Average Year	Wet Year	Average Year
Flow rate - short term (m^3/s)	0.0247	0.0190	0.0247	0.0190
Flow rate - long term (m^3/s)	0.0155	0.0122	0.0155	0.0122
Equivalent effluent salinity (PSU)	2.2	2.2	2.2	2.2
Effluent temperature (^oC)	15	15	1	1
TDS (mg/L)	2200	2200	2200	2200
Maximum annual average total arsenic (mg/L)	0.2	0.2	0.2	0.2
Maximum monthly average total arsenic (mg/L)	0.4	0.4	0.4	0.4
Outfall depth at location 1 (m)	8.5	8.5	8.5	8.5
Outfall depth at location 2 (m)	10	10	10	10
Assumed current at diffuser (m/s)	0.01	0.01	0.01	0.01

Table 2

Stratification Characteristics of The Receiving Waters in Yellowknife Bay

Depth (m)	Summer		Winter	
	Temperature (^oC)	Salinity (PSU)	Temperature (^oC)	Salinity (PSU)
0	13.0	0.11	0.0	0.04
1	13.0	0.111	0.0	0.04
2	13.0	0.112	0.0	0.045
3	12.9	0.113	0.0	0.051
4	12.3	0.114	0.0	0.056
5	10.2	0.115	0.5	0.061
6	10.0	0.116	0.6	0.066
7	9.8	0.117	0.7	0.072
8	9.3	0.118	0.8	0.077
9	9.2	0.120	-	

3 MODEL RESULTS

Three configurations were tested in this study and are detailed in Table 3 below. The vertical angle refers to the discharge angle for the nozzles relative to the horizontal, with 0^o being horizontal, 90^o being vertically upward, while the horizontal angle is the discharge angle relative to the x-coordinate. In this case, the x-coordinate aligns with the prevalent current direction, assumed to be pointing to the south, and the diffuser is aligned with the y-coordinate, pointing to the east. It was found that diffuser performance could be substantially improved first by orienting the outfall ports to a 50° angle in the vertical (Configuration 2 versus Configuration 1), and second, by decreasing the port diameter (Configuration 3 versus Configuration 2).

Table 3

Configurations of The Outfall Diffuser

	Configuration 1	Configuration 2	Configuration 3
Port diameter (m)	0.035	0.035	0.031
Port elevation (m)	0.5	0.5	0.5
Port vertical angle (deg)	90	50	50
Port horizontal angle (deg)	0	0	0
Number of Ports	12	12	12
Port spacing (m)	8	8	4
Diffuser length (m)	96	96	48

The head losses for the different configurations and flow rates are listed in Table 4. The head loss assumes a 0.4 m diameter diffuser section, to minimize flow variability across the ports.

Table 4
Head Losses of The Outfall Diffuser

	Short-term flow rate		Long-term flow rate	
Configuration	Wet Year	Average Year	Wet Year	Average Year
1	0.31 m	0.18 m	0.12 m	0.08 m
2	0.31 m	0.18 m	0.12 m	0.08 m
3	0.42 m	0.24 m	0.17 m	0.10 m

The diffuser performance, for the various configurations, receiving water conditions and flow rates, is presented in Tables 5-12, respectively. Note that the trapping depth is where the plume ceases to rise and become neutrally buoyant with respect to the ambient water and the horizontal distance to reach trapping depth refers to the initial mixing region (see Figure 3). Also note that for location 2, only the performance of the diffuser configuration 3 is shown, since that configuration dilutes the discharge water most effectively.

Table 5
Diffuser Performance with Configuration 1 at Location 1 (short-term flow rate)

	Summer		Winter	
	Wet	Average	Wet	Average
Trapping depth (m)	7.2	7.4	8.1	8.5
Dilution at Trapping depth	91	82	119	106
Horizontal distance to reach Trapping depth (m)	1.7	1.8	2.4	2.2
Effluent velocity (m/s)	2.1	1.6	2.1	1.6

Table 6
Diffuser Performance with Configuration 1 at Location 1 (long-term flow rate)

	Summer		Winter	
	Wet	Average	Wet	Average
Trapping depth (m)	7.5	7.8	8.5	8.5
Dilution at Trapping depth	72	63	93	78
Horizontal distance to reach Trapping depth (m)	1.6	1.4	2.5	3.1
Effluent velocity (m/s)	1.3	1.1	1.3	1.1

Table 7
Diffuser Performance with Configuration 2 at Location 1 (short-term flow rate)

	Summer		Winter	
	Wet	Average	Wet	Average
Trapping depth (m)	7.4	7.6	8.5	8.5
Dilution at Trapping depth	104	88	120	100
Horizontal distance to reach Trapping depth (m)	7.0	5.8	7.8	6.4
Effluent velocity (m/s)	2.1	1.6	2.1	1.6

Table 8
Diffuser Performance with Configuration 2 at Location 1 (long-term flow rate)

	Summer		Winter	
	Wet	Average	Wet	Average
Trapping depth (m)	7.8	8.0	8.5	8.5
Dilution at Trapping depth	77	68	85	72
Horizontal distance to reach Trapping depth (m)	5.0	4.3	5.3	4.4
Effluent velocity (m/s)	1.3	1.1	1.3	1.1

Table 9
Diffuser Performance with Configuration 3 at Location 1 (short-term flow rate)

	Summer		Winter	
	Wet	Average	Wet	Average
Trapping depth (m)	7.3	7.4	7.8	8.5
Dilution at Trapping depth	132	109	162	130
Horizontal distance to reach Trapping depth (m)	7.8	6.4	9.1	7.3
Effluent velocity (m/s)	2.7	2.1	2.7	2.1

Table 10
Diffuser Performance with Configuration 3 at Location 1 (long-term flow rate)

	Summer		Winter	
	Wet	Average	Wet	Average
Trapping depth (m)	7.6	7.8	8.5	8.5
Dilution at Trapping depth	95	83	112	94
Horizontal distance to reach Trapping depth (m)	5.5	7.8	6.3	5.2
Effluent velocity (m/s)	1.7	1.3	1.7	1.3

Table 11

Diffuser Performance with Configuration 3 at Location 2 (short-term flow rate)

	Summer		Winter	
	Wet	Average	Wet	Average
Trapping depth (m)	7.8	8.0	8.8	10.0
Dilution at Trapping depth	117	100	163	131
Horizontal distance to reach Trapping depth (m)	7.1	6.0	9.2	8.8
Effluent velocity (m/s)	2.7	2.1	2.7	2.1

Table 12

Diffuser Performance with Configuration 3 at Location 2 (long-term flow rate)

	Summer		Winter	
	Wet	Average	Wet	Average
Trapping depth (m)	8.5	10.0	10.0	10.0
Dilution at Trapping depth	103	107	113	94
Horizontal distance to reach Trapping depth (m)	5.9	8.3	6.0	7.0
Effluent velocity (m/s)	1.7	1.3	1.3	1.7

For all of the cases being evaluated, the Visual Plumes Model shows that the effluent plume will not reach the water surface but will be trapped under water at depths between 7.2 m to 10 m. The trapping depth depends on the location of the discharge and the seasonality as well as the configuration of the diffuser. The horizontal distance to reach the trapping depth varies from 2 to 10 metres in the cases evaluated.

At location 1, with the short-term, higher flow rate, the dilution ratio always reaches at least 80:1 at the trapping depth. With the longer-term, lower flow rate, dilution does not always reach the target value for either configuration 1 or configuration 2. At location 2, configuration 1 fails to attain the target value for summer (with and without treatment in average year) and for winter (without treatment in average year). However, at location 2, both configurations 2 and 3 always reach the required dilution with configuration 3 achieving 10-15% higher dilution than configuration 2. Table 13 summarizes the performance of the various configurations in terms of whether or not they always achieve a dilution greater than or equal to 80:1.

Table 13

Truth Table for The Performance of The Three Diffuser Configurations

Configuration	Location 1	Location 2
1	N	N
2	N	Y
3	Y	Y
Y: always achieve 80:1 dilution ratio N: does not always achieve 80:1 dilution ratio		

Generally speaking, configuration 2 has a higher dilution ratio than configuration 1, and configuration 3 has the highest dilution ratio among the three arrangements. Configuration 3 is acceptable at both locations, and configuration 2 is acceptable at location 2 only.

At any instant of time, as shown in Figure 3, the region in which dilutions are less than the 80:1 target value is contained within a quasi-conically shaped volume of water, emanating from the diffuser port and terminating at the trapping depth. Table 14 shows the plan area and volume of water that would be below the target 80:1 dilution ratio for configuration 3. The location of this lower dilution water will shift in response to changing current, sometimes lying north of the diffuser, say, and sometimes south.

Table 14
Plan Area and Plume Volume of Water below The Target 80:1 Dilution Ratio for Configuration 3

				Plan Area (m^2)	Plume Volume of Under-diluted Water (m^3)
Summer	Location 1	Short-term	Wet	245	100
			Average	245	76
		Long-term	Wet	241	70
			Average	216	58
	Location 2	Short-term	Wet	241	102
			Average	241	83
		Long-term	Wet	235	74
			Average	216	60
Winter	Location 1	Short-term	Wet	235	100
			Average	245	85
		Long-term	Wet	238	70
			Average	218	53
	Location 2	Short-term	Wet	235	100
			Average	245	85
		Long-term	Wet	241	71
			Average	216	54

3 SUMMARY

The three diffuser configurations that were evaluated achieved different dilution ratios upon reaching their respective trapping depths after near field mixing. At location 1, only configuration 3 achieved the required dilution for both the short-term and long-term flow rates. At location 2, configuration 1 fails to attain the required dilution in some instances, and configurations 2 and 3 always produced sufficient dilution, with configuration 3 achieving a 10-15% higher dilution ratio than configuration 2. For configuration 3, the target dilution of 80:1 is mostly achieved before reaching the trapping depth and it occurs mostly within 5 m of the outfall diffuser. For configuration 3, at either location, and for all flow rates, the volume of water within which the dilution is less than 80:1 will be approximately 100 m^3 or less.

4 REFERENCES

Frick, W.E., P.J.W. Roberts, L.R. Davis, J.Keyes, D.J. Baumgartner and K.P. George. 2001. *Dilution Model for Effluent Discharge, 4th Edition (Visual Plumes).* Environmental Research Division, NERL, ORD, U.S. Environmental Protection Agency.

Hamilton, H., L. Linton, S. Goudey, R. Dewey and M. Palmer. 1989. *Water Quality Study of Yellowknife Bay: 1987-1988:* Prepared for water Resources Division, Department of Indian & Northern Affairs, Yellowknife, NWT.

We trust the above results are adequate for the immediate purposes of Indian and Northern Affairs Canada. Should you have any questions regarding the content of this report, please do not hesitate to contact Dr. Stronach.

Yours Very Truly,
HAY & COMPANY CONSULTANTS

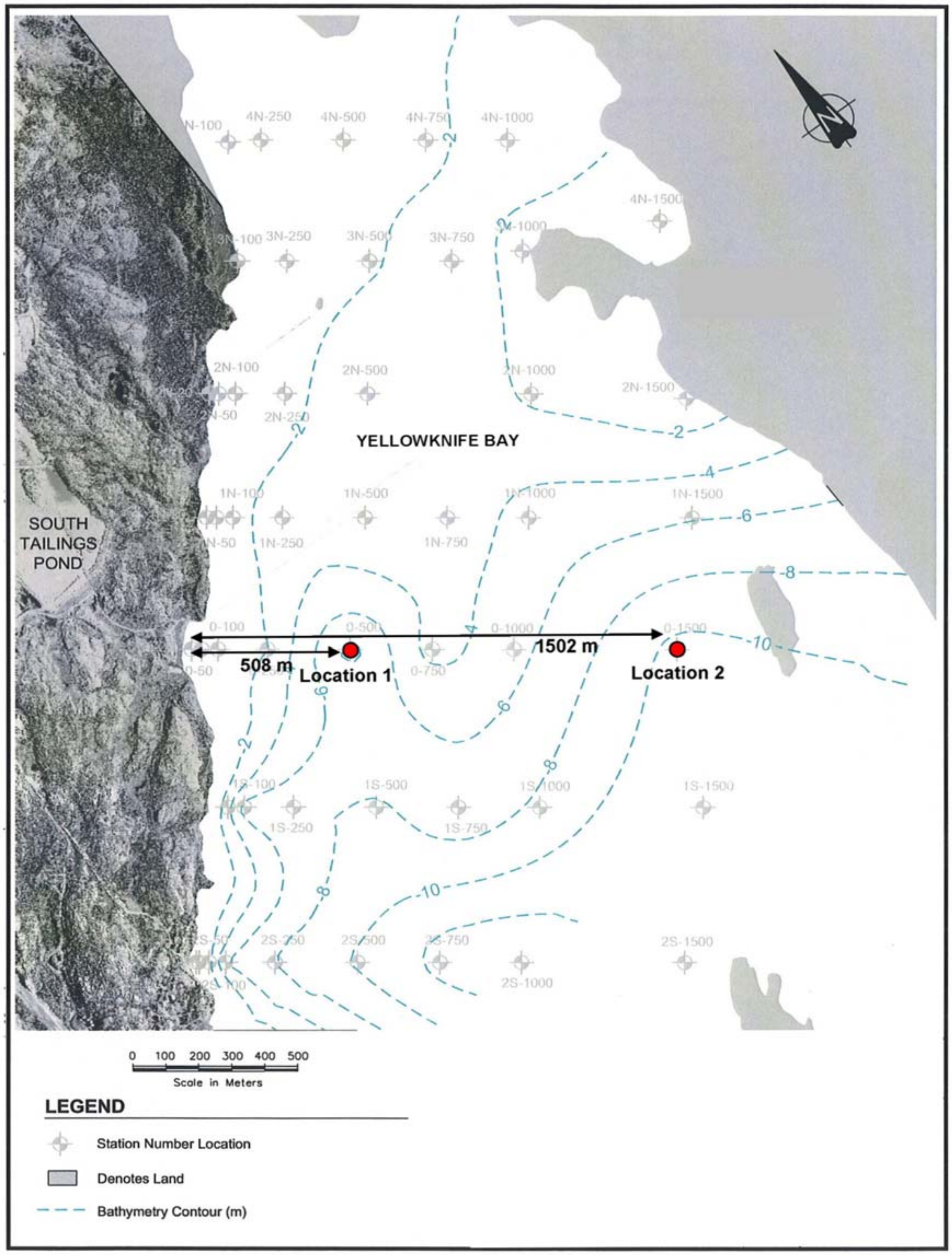
Albert Leung, M.A.Sc., E.I.T.
Hydrotechnical Engineer
Reviewed by:

James Stronach

Jim Stronach, Ph.D., P.Eng.
Senior Physical Oceanographer

AL/jk

FIGURES



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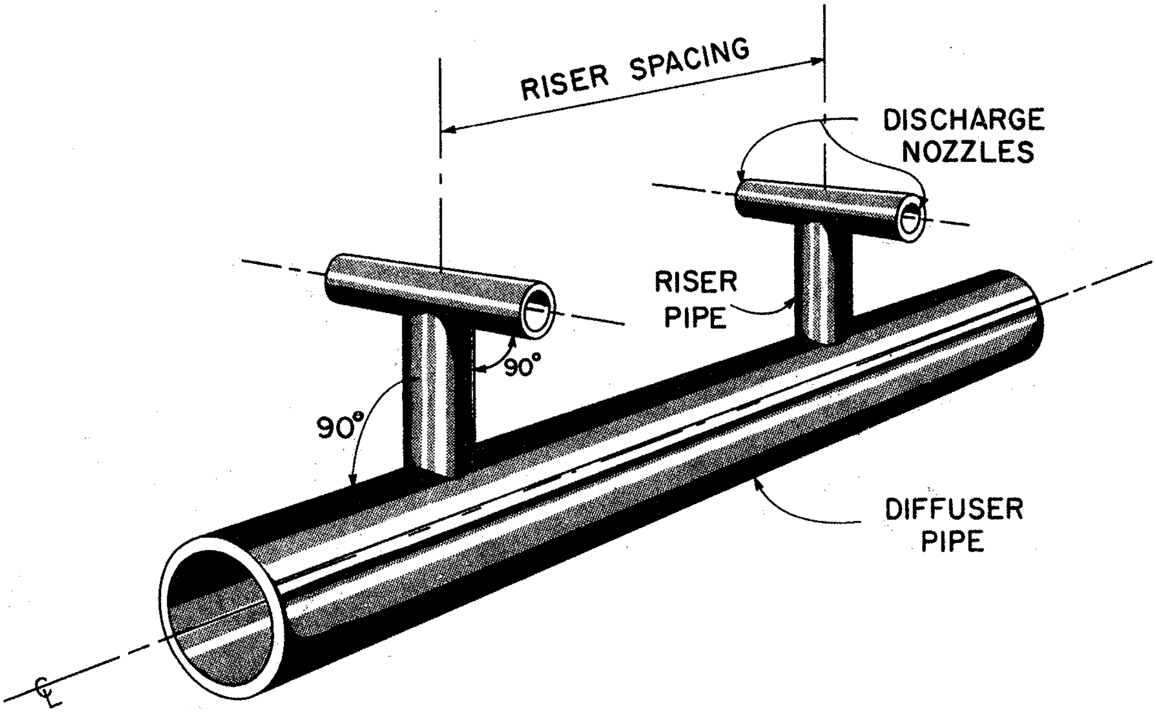
GIANT MINE EFFLUENT DILUTION

DIFFUSER LOCATIONS

FIG

1



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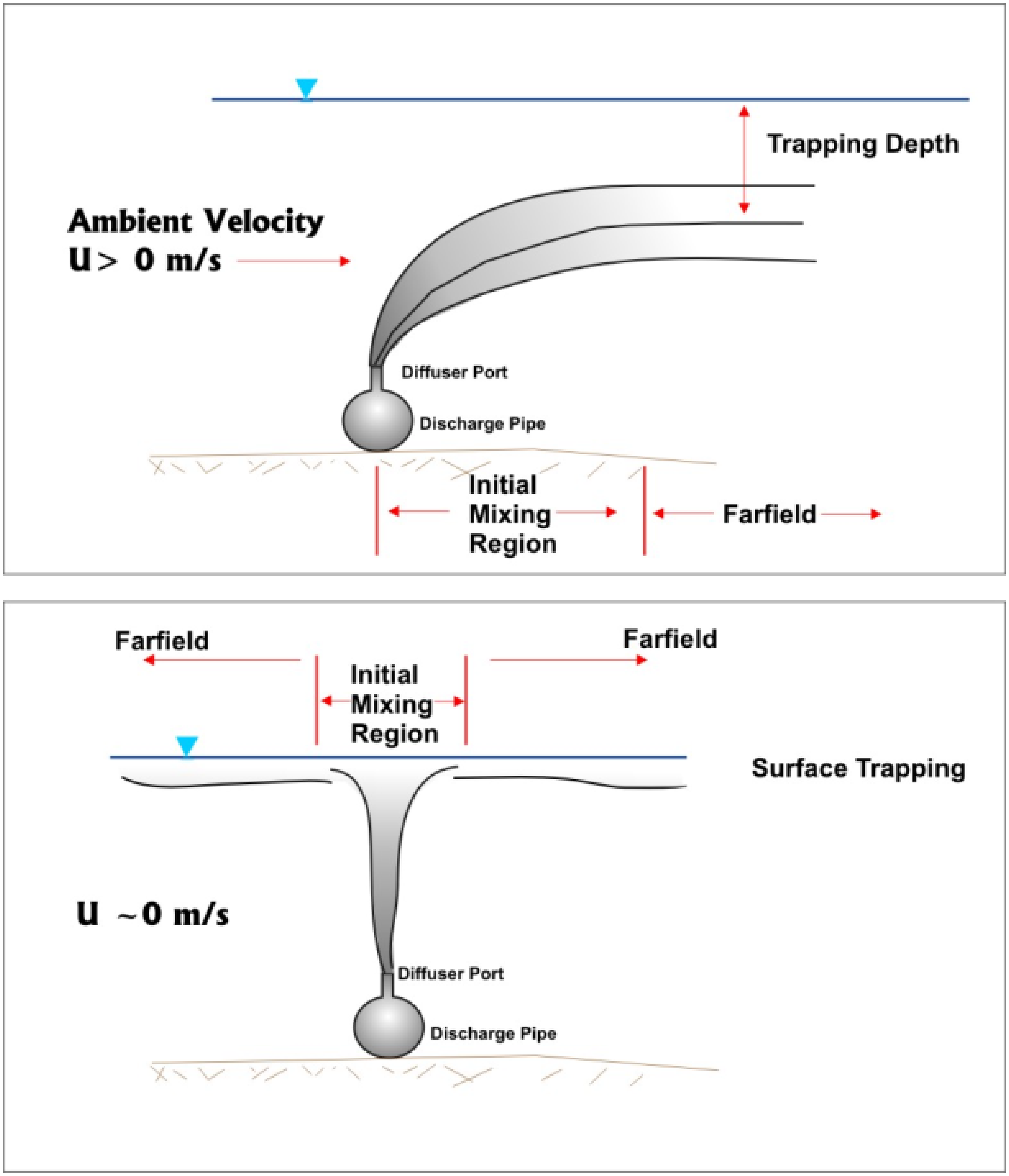
GIANT MINE EFFLUENT DILUTION

DIFFUERS PORTS SCHEMATIC DIAGRAM

FIG 2



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GIANT MINE EFFLUENT DILUTION
DIFFUSER PERFORMANCE STUDY

SCHEMATIC DIAGRAM
SUBMERGED OUTFALL

FIG.
3

EXCEL FILE: filename here