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REPORT ON

CONCEPTUAL DESIGN OF THE EFFLUENT OUTFALL DIFFUSER FOR WALLY LAKE

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EXECUTIVE SUMMARY

This report presents the conceptual design of an effluent outfall diffuser in Wally Lake to address NIRB commitment No. 11 for a Type-A Water License for the Meadowbank Gold Project. The commitment states that Meadowbank Mining Corporation shall provide details regarding the effluent outfall configuration, including discharge characteristics, the likely behaviour of the plume(s), and bathymetric information for Wally Lake in the water license application to the Nunavut Water Board. Discharge into Wally Lake will occur during the open water conditions from June to September for a period of five years.

The mine effluent would achieve the water quality guidelines from the Metal Mining Effluent Regulation at the point of discharge of the diffuser. A water quality assessment determined that a 14 to 1 dilution of the mine effluent was needed to achieve the aquatic life guidelines or background concentrations at the boundary of a 30-m radius mixing zone from the center of the diffuser.

The Cornell Mixing Model (CORMIX) was used for near-field mixing and dilution analysis of the mine effluent plume in Wally Lake. Results of the analysis and the mine effluent dilution requirements were used to identify a conceptual design of a diffuser. The diffuser will provide the desired dilution factor for a range of effluent discharge rates between 3,500 and 8,000 m^3/day. The table below presents the characteristics of the diffuser.

Description	Value Used
Port diameter (mm)	75
Number of ports	5
Port exit velocity (m/s)	3 to 4
Length of diffuser line (m)	40
Port spacing (m)	10
Port height (m)	1
Vertical angle of port	90º
Minimum dilution factor	24 to 1

The diffuser will be located within the near field monitoring area of the aquatic effects monitoring program (AEMP) planned for Wally Lake as part of the MMER requirements.

Detailed design for the diffuser is not possible at this time due to insufficient site-specific data (e.g., geotechnical foundation conditions). Detailed design will be required prior to Year 4 of the mine operation for Vault Lake area. Delaying the detailed design until Year 2 or 3 of the mine plan will allow for the collection of additional background data to aid in the design process. The framework for the implementation of a final decision on the diffuser design will include:

- Completing a geotechnical survey of the corridor for the diffuser line from Vault Lake to Wally Lake;

- Producing drawings and assessing materials, quantities and specific structural components (e.g., pump, control valves, pipes and structural supports) for building and operating the diffuser; and

- Producing an operation and maintenance program to ensure the optimal performance of the diffuser.

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by Meadowbank Mining Corporation (MMC), formerly known as Cumberland Resources Ltd. (Cumberland), to address NIRB commitment No. 11 for a Type-A Water License for the Meadowbank Gold Project. The commitment states that MMC shall provide details regarding the effluent outfall configuration, including discharge characteristics, the likely behaviour of the plume(s), and bathymetric information for Wally Lake in the water license application to the Nunavut Water Board (NWB).

MMC development plans include mining within Vault Lake and constructing a dike (see Figure 1) to contain mine effluent within the lake. Currently, Vault Lake flows into Wally Lake. After constructing the dike, Vault Lake will be drained and used as an attenuation pond for mine effluent collected from rock storage piles, open pits, dike areas and dike seepages, as well as Vault area contact water (Golder 2005). MMC plans to install a diffuser outfall in Wally Lake for mine effluent outflows from Vault Lake during the open water period (Golder 2005). This report assesses a conceptual design of the proposed diffuser outfall.

The scope of work involved determining design information for the outfall, including discharge characteristics and physical diffuser configuration, and predicting the corresponding plume(s). The objective of the work was to identify a diffuser that would maximize dilution of mine effluent near the outfall, and consequently minimize the effect on lake water quality and aquatic life.

The limits from the Metal Mining Effluent Regulation (MMER 2002) must be met by the effluent at the point of discharge of the diffuser. In addition to the MMER requirements, it is desirable for parameter concentrations outside the mixing zone to be lower than drinking water and aquatic life guideline values (R.R.N.W.T 1990 and CCME 2006) or changes in water quality from background levels should be negligible. A mixing zone with a 30 m radius from the center of the diffuser was assumed for water quality assessment. This mixing zone is consistent with US EPA (1995) recommendations. The proposed location for diffuser is within low value fish habitat areas (Cumberland 2005b).

Section 2 identifies key water quality parameters that could have effects on water uses in Wally Lake due to releases from Vault Lake. Section 3 of this report describes the mixing model used to predict effluent plume and dilution within Wally Lake. Section 4 describes hydrodynamic and water quality conditions in Wally Lake and mine effluent characteristics of outflows from Vault Lake. Section 5 determines the conceptual diffuser configuration based on results of the mixing model. Section 6 presents conclusions and recommendations for final detailed design of the diffuser.

2.0 KEY WATER QUALITY PARAMETERS

This section identifies parameters in the mine effluent discharges from Vault Lake to Wally Lake (Golder 2005) that could potentially affect water chemistry in Wally Lake. Table 1 compares measured values of the potentially affected parameters in Wally Lake (Azimuth 2003 and Cumberland 2005a), predicted mine effluent concentrations for these parameters, effluent criteria (MMER 2002), and drinking water and aquatic life guidelines (R.R.N.W.T 1990 and CCME 2006). The following observations were made from Table 1:

- None of the parameter concentrations observed in Wally Lake or predicted in the mine effluent exceeds Nunavut's drinking water quality guidelines or the Canadian MMER guidelines.

- Maximum concentrations of cadmium and copper observed in Wally Lake exceed aquatic life guidelines. The predicted mine effluent concentration for cadmium is lower than that observed in Wally Lake. The predicted mine effluent concentration for copper is 50% higher than the maximum concentration observed in Wally Lake.

It is also desirable that effluent concentrations outside the mixing zone of the diffuser be lower than drinking water and aquatic life guideline values to minimize the effect on aquatic life. Ammonia and mercury require the highest dilution of 13 to 1 and 14 to 1, respectively, to reduce the corresponding concentration to guideline values for the protection of aquatic life

TABLE 1: Summary of Predicted Effluent and Observed Wally Lake Water Quality

Parameter	Unit	Predicted Effluent Discharge Concentration (Golder 2005)	MMER Effluent Limits (MMER 2002)	Drinking Water Guidelines (R.R.N.W.T 1990)	Aquatic Life Guidelines (CCME 2006)	Measured Water Quality in Wally Lake (Azimuth 2003 and Cumberland 2005a)			Effluent Dilution Needed	Dilution Factor Sought
						Min.	Median	Max.		
pH	N/A	6.5	6.0 – 9.5	-	6.5-9.0	6.9	7.35	7.54	No	
TDS	mg/L	153	-	500	-	17	28.5	34	No	
Ag	mg/L	0.0000093	-	0.05	0.0001	<0.00002	<0.00002	<0.00002	No	
Al	mg/L	**0.21**	-	-	0.1	<0.005	0.005	0.01	**Yes**	**2.2**
As	mg/L	**0.010**	0.5	0.05	0.005	<0.0005	<0.0005	<0.0005	**Yes**	**2.1**
Ba	mg/L	0.013	-	1	-	<0.02	<0.02	<0.02	No	
Ca	mg/L	7.7	-	-	-	3.4	3.9	6.1	No	
Cd	mg/L	0.000020	-	0.01	0.000017	<0.00005	<0.00005	0.00124	No	
Cl	mg/L	2.3	-	250	-	0.6	0.8	1.3	No	
Cr	mg/L	0.00075	-	0.05	0.001	<0.001	<0.001	<0.001	No	
Cu	mg/L	**0.0045**	0.3	1.0	0.002	<0.001	<0.001	0.003	**Yes**	**3.5**
F	mg/L	0.20	-	1.7	-	0.04	0.06	0.09	No	
Fe	mg/L	0.037	-	0.3	0.3	<0.03	<0.03	0.04	No	
Hg	mg/L	**0.00037**	-	-	0.000026	<0.00005	<0.00005	<0.00005	**Yes**	**14**
Mn	mg/L	0.0055	-	0.05	-	0.0007	0.001	0.0018	No	
Mo	mg/L	0.0059	-	-	0.073	<0.001	<0.001	<0.001	No	
NH4_N	mg/L	**25.9**	-	-	2.04	<0.02	0.01	0.036	**Yes**	**13**
Ni	mg/L	0.0028	0.5	-	0.025	<0.001	<0.001	0.003	No	
NO3_N	mg/L	**29.1**	-	45	13	<0.005	0.014	0.095	**Yes**	**2.2**
Pb	mg/L	0.00037	0.2	0.05	0.001	<0.0005	<0.0005	0.0014	No	
Se	mg/L	0.00044	-	0.01	0.001	<0.001	<0.001	<0.001	No	
SO4	mg/L	11.5	-	250	-	3	4	7	No	
Tl	mg/L	0.00004	-	-	0.0008	<0.0002	<0.0002	<0.0002	No	
Zn	mg/L	0.0075	0.5	5	0.03	<0.005	0.005	0.02	No	

Note: The parameters in bold were assessed for effluent dilution

3.0 NEAR-FIELD MIXING MODEL

3.1 General

Near-field mixing and dilution near the proposed outfall would be influenced by the buoyancy and momentum of the discharge, while the transport and shape of the resulting plume would be determined mainly by the ambient currents within the lake. Near field mixing includes a recirculation zone where the effects of discharge buoyancy, momentum and ambient currents would create turbulence, which would be responsible for initial mixing within the lake. Further near field mixing occurs from radial spreading of the effluent plume outside the recirculation zone. The major challenge in modelling near-field mixing and dilution in the Wally Lake would involve representing turbulence near the discharge point and downstream of the outfall in the mixing model.

Existing numerical turbulence models often have empirical coefficients that are not universal and have restricted ranges of applicability for different combinations of discharge and ambient conditions. Semi-empirical formulas with applicable ranges, based on simplified governing equations for conservation of mass and momentum and on physical laboratory and field modelling data, are generally more reliable than numerical turbulence models. The Cornell Mixing Model (CORMIX) (Jirka *et al*. 1996), which was used for near-field mixing and dilution analysis, considers all available physically-based and semi-empirical turbulence formulas and selects the appropriate formula for the discharge and ambient conditions.

This CORMIX model was used for conceptual design and analysis of effluent diffusers in northern Canadian lakes, such as Snap Lake (DeBeers 2002) and Lac de Gras for Diavik Diamond Mine Project.

3.2 Model Description

CORMIX was used to simulate the near-field mixing and dilution behaviour of mine effluent water discharges from Vault Lake. The model is one of the most extensively used models for predicting near-field mixing and dilution of both conservative and non-conservative substances in surface waterbodies. The model has specific sub-systems for analyzing submerged multi-port diffusers (CORMIX2). The CORMIX model system assumes steady-state and generally uniform ambient conditions and effluent discharges. The model predicts the jet or plume geometry and the dilution characteristics required for assessment of near-field mixing. The predictions of the model are typically based on determination of an appropriate hydrodynamic flow pattern using an expert system and the solution of the corresponding simple flow patterns to obtain complete analysis from the discharge point to the far-field.

3.3 Model Inputs

Input data to the CORMIX model are grouped into four categories: namely, site/case identifier, ambient conditions, discharge characteristics, and mixing zone data. The site/case identifier is the name given to model simulation scenario. The ambient conditions include stratification information and/or water density, water current, water depth and width, wind speed, and lake bottom roughness coefficient. The required discharge data include the characteristics of the effluent at the point of discharge, location and orientation of the discharge ports within the surface waterbody, effluent flow rate, density, and parameter concentration. The mixing zone data consist of definition of the spatial region where mixing and plume characteristics are required and optional information on ambient water quality standard, toxic dilution zone and regulatory mixing zone.

3.4 Model Outputs

The output from the CORMIX model is presented by qualitative descriptions, detailed quantitative numerical predictions, and 2-dimensional or 3-dimensional graphical output using the CorVue graphic package to show predicted effluent jets and plumes. Qualitative descriptions provided by the output file include descriptive messages addressing the simulated scenario and the logic reasoning employed by the model system. Detailed quantitative predictions of the jet or plume geometry and dilution characteristics are provided in the output file, including the coordinates of the jet or plume centerline, the bulk or centerline dilution and concentration, and the jet or plume width. In addition, information is provided on the different types of simulation modules used and the reasons for using them, the cumulative travel time at the end of each simulation module, and, if applicable, the location of plume attachment to the bed or bank and possible model limitations.

4.0 WALLY LAKE AMBIENT CONDITIONS AND MINE EFFLUENT CHARACTERISTICS

Conservative assumptions were used within the CORMIX model to define the ambient conditions in Wally Lake and characteristics of mine effluent discharged from Vault Lake. The conservative assumptions include:

- potential worst case combination of ambient conditions in Wally Lake for estimation of low lake current velocity based on the following information:
  - the shortest fetch length (600 m) estimated for the Wally Lake (Golder 2006). A shorter fetch would induce lower lake currents and smaller mine effluent dilution; and
  - the smallest 4-day average wind speed observed (6 km/h) at the Meadowbank meteorological station (South Camp, AMEC 2003 and 2005). The 4-day averaging period was based on US EPA (1991) recommendation for assessing chronic water quality effects on aquatic health;
- maximum difference between the densities of mine effluent and Wally Lake water to represent the negative buoyant plume; and
- maximum predicted mine effluent concentrations to characterize worst water quality effects.

Assumptions for selecting the design lake current velocity were based on the information presented in the following sections.

4.1 Wally Lake

Golder (2006) conducted a survey in 2006 to define the bathymetry of Wally Lake. The volume and average depth of the lake were 27.9 Mm^3 and 3.64 m, respectively, based on the results of bathymetric survey. The lake is composed of a relatively flat bottom with isolated bowls that can reach depths up to 22 m. The proposed location of the diffuser is within the deepest region of Wally Lake in the vicinity of Vault Lake (see Figure 1).

Water temperature of the lake is relatively constant for water depths between 0 and 5 m (Cumberland 2005). From June to September, water temperature typically varies between 5 and 12 ˚C. Total dissolved solids (TDS) concentrations in the lake range from 17 to 34 milligrams per litre (mg/L), with a median value of 27 mg/L (Azimuth 2003).

No measurements of current velocities within Wally Lake are available. Due to the size of the lake, wave motions from winds will control current velocities and direction during the open water period from June to September.

4.2 Effluent from Vault Lake

The mine effluent temperature in Vault Lake will be similar to observed water temperature in Wally Lake (Cumberland 2005). Water chemistry for the mine effluent was presented in Golder (2005). Mine effluent TDS concentrations were estimated to range from 9 to 153 mg/L.

Discharges of the effluent into Wally Lake are planned to occur between June and September for a period of 5 years (Golder 2005), from Year 4 to 8 of the mine operation for Vault Lake area. Therefore the diffuser would not operate under ice cover conditions. The average daily rates are predicted to be below 8000 m^3/day.

The diffuser design assumes continuous supply of fresh ambient water from other parts of the lake to the mine effluent discharge area within Wally Lake. A water balance based on lake runoff yield for the project basins (AMEC 2003 and 2005) indicated that average outflow rates from Wally Lake would range from 31000 to 133000 m^3/day on average between June and September.

4.3 Model Inputs

4.3.1 Ambient Information

Ambient information used to characterize the local area surrounding the proposed diffuser location in the CORMIX model is summarized in Table 3.

TABLE 2: Summary of Wally Lake Characteristics Used for Analysis

Parameters	Value
Water depth (m)	7.4
Lake currents (m/s)	0.003
Temperature (˚C)	5
TDS (mg/L)	17
Water density (kg/m^3)	999.983
Manning's coefficient	0.015

The proposed location of the diffuser is shown in Figure 1. This location is estimated to be 80 m from shore with water depth of 7.4 m based on bathymetric survey of Wally Lake (Golder 2006). The diffuser location was selected to obtain a deep water column for effective dilution of the effluent, locate the mixing zone within a zone of low habitat value for fish (Cumberland 2005b), and minimize the length of the outfall pipe. The diffuser is intended to operate only during the planned mine effluent discharge period from June to September.

Calculation of density is based on temperature and TDS concentration, as proposed by Ford and Johnson (1983) and Gill (1982). Generally, mixing simulations within the near-field depend primarily on the momentum and buoyancy of the discharge. Predictions of plume characteristics are not sensitive to Manning's resistance coefficient. Therefore typical values of Manning's coefficient for lakes were used for modelling.

4.3.2 Effluent Information

Proposed mine effluent discharge information used for near-field mixing and dilution analysis is summarized in Table 4.

TABLE 3: Summary of Effluent Characteristics Used for Analysis

Parameter	Value
Discharge rate (m^3/day)	7610 (a)
Concentration (%)	100
Temperature (°C)	5
TDS (mg/L)	153
Density (kg/m^3)	1000.090
Length of pipe from shore to diffuser (m)	80

(a) This value represents the maximum average daily rate predicted for the mine effluent (Golder 2005).

The maximum water quality parameter concentrations in effluent are assumed to be 100%. The water temperature and TDS concentrations shown in Tables 2 and 3 were selected to maximize the difference in densities between the mine effluent and Wally Lake water. The total suspended solids (TSS) contribution to the density of the lake water was assumed to be negligible due to the low ambient TSS concentration (equal or smaller than the detectable value of 3 mg/L).

5.0 DIFFUSER CONFIGURATION

5.1 General

The potential dilution that can be achieved by a selected diffuser configuration depends on diffuser port diameter, port exit velocity, port height, and port spacing. For a given port, dilution decreases with increasing port diameter. Therefore, it is desired to use the smallest possible port diameter. However, a minimum threshold for port diameter is necessary to minimize costs and operational difficulties associated with small diameter discharge ports. For practical considerations, it was necessary to use a diffuser with port diameters larger than 37.5 mm to reduce the risk of clogging within the ports and to minimize head losses. A maximum port diameter was selected to optimize the number of ports required to enhance dilution over a range of flow rates.

The port exit velocity affects the distance travelled by the jet and the momentum and local turbulence, which determine the initial mixing and dilution near the ports. Higher exit velocities produce longer mixing lengths of the jet and higher local turbulence and, consequently, greater initial mixing. However, an exit velocity much higher than 10 m/s could produce problems such as cavitation, which can lead to foaming and also result in high head (energy) losses in the diffuser pipes. Exit velocities between 3 and 8 m/s are recommended for diffuser design in CORMIX model.

The height of the diffuser ports above the lake bottom affects the maximum depth of water available for mixing, as well as the potential for entrainment of fine particles at the bed of the lake in the discharge jet. If the port exit is close to the bottom of the lake, the water depth available for mixing is maximized; however, there would be a higher potential for sediment scouring, and for sediment entrainment in the water column.

The spacing of the diffuser ports is constrained by a minimum distance to reduce the potential for overlap of plumes from different ports and a maximum spacing determined by the length of diffuser line and the number of ports. Larger spacing enhances dilution by facilitating greater entrainment of fresh ambient water into the plume.

5.2 Diffuser Selection

Preliminary analysis of several scenarios of port diameter and exit velocity combinations was undertaken using the CORMIX model. The analysis was aimed at selecting a practical diffuser configuration that achieves effective dilution. Minimum bulk dilution factors and the recirculation region predicted by the CORMIX model for several combinations of port diameter and exit velocity are summarized in Table 4. The ports for each diffuser scenario in Table 4 are equally spaced along a 40-m diffuser line.

TABLE 4: Minimum Bulk Dilution Factors at the Point of Discharge for a 7610 m^3/day Discharge Rate

Exit Velocity (m/s)	Diameter of Ports (mm)				
	Variable[a]	100 [b, c]	75 [c]	50	37.5
3.0 - 3.7	11 (114) [1][d]	24 (136) [3]	24 (125) [6]	24 (121) [14]	24 (118) [26]
3.7 - 4.1	11 (147) [1]	24 (136) [3]	24 (143) [5]	24 (146) [11]	24 (143) [20]
6.1 - 6.6	11 (198) [1]	- (-)	24 (210) [3]	24 (204) [7]	24 (198) [13]
7.5 - 8.0	11 (236) [1]	- (-)	- (-)	24 (229) [6]	24 (240) [10]

(a) Diameter of single port (between 125 and 200 mm) that results in a discharge rate of 7610 m^3/day.
(b) Since two ports are required, no CORMIX model simulations produced for exit velocities between 4.1 and 7.5 m/s for 100 mm diameter ports.
(c) No combinations of 100 or 75 mm diameter ports can produce exit velocities between 6.6 and 8.0 m/s.
(d) The number in the round brackets represents the radius around the diffuser where dilution occurs from the recirculation of the effluent within ambient water, while the number in the square brackets provides the number of ports.

For the diffuser results shown in Table 4, hydrodynamic instability and complete mixing over the entire water depth occurred in the recirculation region due to high discharge momentum in a relatively shallow lake. The results shown in the column labelled "Variable" represent single port discharge cases. The remaining columns that have simulation results are for multi-port discharges with more than two ports. The CORMIX model also provides the bulk dilution factor with respect to the horizontal distance from the center of the diffuser (see Figure 2).

Dilution at the end of the recirculation region generally increases when smaller diameter multiple ports are used instead of a larger diameter single discharge port. A fairly constant bulk dilution factor of about 24 at the boundary of the recirculation region is predicted when more than two ports are used. Table 4 also indicates that the spatial extent of the recirculation region depends on port exit velocity. The spatial extent of the region typically decreases with a decrease in port exit velocity. At the same bulk dilution factor, a smaller recirculation region suggests that the area surrounding the diffuser is more effectively utilized for dilution.

A sensitivity analysis predicted a range of bulk dilution factor between 21 and 32 when the water depth in Wally Lake varies between 7.4 and 8.4 m or when lake currents are less than 0.007 m/s. The smallest dilution factor predicted in the sensitivity analysis achieves the desired dilution for all water quality parameters. Table 5 summarizes predicted parameter concentrations based on bulk dilution at the mixing zone boundary.

TABLE 5: Mine Effluent Plume Characteristics for Key Parameters

Parameter	Units	Maximum Predicted Effluent Concentration at Discharge	Background Concentration in Wally Lake	Parameter Concentration at Mixing Zone Boundary (Bulk Dilution of 24 to 1)	Aquatic Life Guidelines
Al	mg/L	0.21	0.005	0.014	0.1
As	mg/L	0.010	0.0 (a)	0.00042	0.005
Cu	mg/L	0.0045	0.0005 (b)	0.00067	0.002
Hg	mg/L	0.00037	0.0 (a)	0.000015	0.000026
NH4_N	mg/L	25.9	0.01	1.09	2.04
NO3_N	mg/L	29.1	0.014	1.2	13

Notes:

(a) No detectable values were observed in the Vault and Wally Lake system for arsenic and mercury. It is assumed that background concentration for these parameters in Wally Lake is equal to zero for the calculation of dilution.

(b) Observations of copper concentration in the Vault and Wally Lake system are composed of detectable and non-detectable values. It is assumed that the background concentration for this parameter in Wally Lake is equal to half the detection limit (US EPA 1991) for the calculation of dilution.

On the basis of results of the preliminary CORMIX model simulations summarized in Table 4, a diffuser configuration was selected. The diffuser has five 75 mm diameter ports. The configuration of the selected diffuser is summarized in Table 6 and shown in Figure 3. This configuration will undergo further analysis during detailed design and construction.

TABLE 6: Summary of Diffuser Configuration

Description	Value Used
Port diameter (mm)	75
Number of ports	5
Port exit velocity (m/s)	3 to 4
Length of diffuser line (m)	40
Port spacing (m)	10
Port height (m)	1
Vertical angle of port	90º

The multiple ports will include flow control arrangements such as valves to allow adjustment of the number of active ports required to achieve good mixing and dilution for a range of flow rates. Therefore, the performance of the diffuser presented in Table 6 covers a range of effluent discharge from 3,500 to 8,000 m^3/day. Mine effluent discharge through the diffuser will occur at fairly constant rate only during the open water period from June to September. The exact period and rate of mine effluent discharge for a given year will depend on water management requirements to maintain Vault Lake at desired levels.

For the selected diffuser configuration (see Table 6), exit velocities were limited to 3 to 4 m/s. For the available water depth, simulations of mixing at the selected diffuser location for port exit velocities higher than 4 m/s did not produce further improvements in bulk dilutions (see Table 4). As discussed earlier in Section 5.1, port exit velocities below 3 m/s are not recommended for diffusers.

The diffuser ports will rise 1 m vertically above the lake bottom to minimize the risk of scouring and bottom sediment entrainment in the jet plume. Also, the ports will be sufficiently far below the water surface to minimize the likelihood of damage to the diffuser from ice during the ice-covered period.

The direction of the local ambient lake currents near the diffuser location will be variable during the open water period. If the ports are oriented towards one particular direction away from the vertical plane, the discharge jet may encounter lake currents flowing in the opposite direction and reduce the associated mixing and dilution outside of the near-field zone. Consequently, a vertical port orientation was selected to avoid situations in which lake currents and discharge jet from the ports would be in opposite directions.

5.3 Mixing and Dilution Performance of Diffuser

For the proposed diffuser configuration, the description of the flow classification by the CORMIX system indicates that the local effect of the discharge momentum flux will be strong in relation to the water depth and in relation to the stabilizing effect of the discharge buoyancy. The vertical jet from the diffuser ports will result in near-vertical surface impingement, upstream spreading, vertical mixing, and buoyant restratification in the vicinity of the ports.

For the weak lake currents, a vertical recirculation zone will be produced leading to mixing over the full water depth in the near-field region in which strong initial mixing will occur. However, the flow will tend to re-stratify outside this zone that would extend a few layer depths around the diffuser line. In particular, upstream spreading will occur due to the strong buoyancy of the discharge.

The plume will spread laterally along the bottom layer while being advected by the ambient current. The mixing rate will be relatively small. The plume may interact with a nearby bank or shoreline. After some distance the background turbulence in the ambient shear flow will become the dominating mixing mechanism.

Steady-state conditions were assumed for both ambient and discharge conditions. Table 7 summarizes the diffuser performance for different discharge rates.

Delineating a defined plume is not possible due to the continuously changing directions of the currents in Wally Lake. However, a continuous supply of fresh ambient water from other parts of the lake and the prevailing north-west wind in the region (AMEC 2003 and 2005) would induce lake currents at the diffuser site that would carry the effluent toward the outlet of Wally Lake.

TABLE 7: Diffuser Performance at Different Mine Water Discharge Rates

Discharge (m^3/day)	Number of ports	Bulk Dilution Factor at Various Horizontal Distances from Centre of Diffuser			
		30 m [(a)]	100 m	150 m	250 m
3500	3	55	66	72	72
4000	3	48	60	65	65
4500	3	42	55	59	61
5000	4	39	51	55	56
5500	4	34	46	51	53
6000	4	31	42	48	51
6500	5	29	38	45	49
7000	5	28	36	42	46
7500	5	27	35	40	44
8000	5	25	33	38	42

(a) The 30-m distance represents the mixing zone boundary where parameter concentrations are predicted to be below aquatic life guideline values or within the median background concentrations in Wally Lake. A minimum dilution factor of 14 to 1 is required from the selected diffuser.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The predicted mine effluent concentrations from the outflows of Vault Lake to Wally Lake meet the Metal Mining Effluent Regulation. In addition, the predicted effluent concentrations meet the drinking water standards without dilution. Even with the regulatory standards met, it was decided that the installation of a diffuser for effluent discharge would be desirable to increase the level of protection to aquatic life. Generic concentrations for aquatic life protection (CCME 2006) were used as target at the mixing zone boundary for the design of the diffuser. Predicted dilution factors are based on steady-state conditions in the lake and at the mine effluent discharge point. They also assume a continuous supply of fresh ambient water from other parts of the lake to the mine effluent discharge area within Wally Lake. The conceptual design was based on mine effluent discharge during the open water period from June to September. The diffuser is predicted to achieve a minimum bulk mine water effluent dilution of 24 at the point of discharge. This dilution factor will reduce concentrations of effluent parameters at the boundary of the mixing zone to the generic levels established in the CCME guidelines for the protection of aquatic life or to the existing background concentration in the lake.

These conclusions are based on the following conceptual multi-port diffuser design:

- five 75 mm ports equally spaced along a 40 m long diffuser line;
- the diffuser ports rise vertically 1.0 m above the lake bottom to maximize mixing in water column and to minimize the risk of bottom sediment entrainment;
- valves or other flow control devices will be installed between each set of consecutive ports;
- the diffuser is located in a 7.4 m average depth of water during the open water period at a location shown in Figure 1; and
- the 40 m long diffuser is connected to an 80 m outfall pipe that conveys the effluent discharge to the diffuser line.

The diffuser will be located within the near field monitoring area of the aquatic effects monitoring program (AEMP) planned for Wally Lake as part of the MMER requirements.

Detailed design for the diffuser is not possible at this time due to insufficient site-specific data (e.g., geotechnical foundation conditions). Detailed design will be required prior to Year 4 of the mine operation for Vault Lake area. Delaying the detailed design until Year 2 or 3 of the mine plan will allow for the collection of additional background data to aid in the design process. The framework for the implementation of a final decision on the diffuser design will include:

- Completing a geotechnical survey of the corridor for the diffuser line from Vault Lake to Wally Lake;

- Producing drawings and assessing materials, quantities and specific structural components (e.g. pump, control valves, pipes and structural supports) for building and operating the diffuser; and

- Producing an operation and maintenance program to ensure the optimal performance of the diffuser.

The reader is referred to the "Important Information and Limitations of This Report" which follows the text but forms an integral part of this document.

GOLDER ASSOCIATES LTD.

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NL/GS/cm/lw
Attachments
O:\Final\2006\1413\06-1413-089\412 25Jul_07 RPT-Ver 0 - Conceptual Design Of The Effluent Outfall Diffuser For Wally Lake.Doc

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IMPORTANT INFORMATION AND LIMITATIONS OF THIS REPORT

Standard of Care: Golder Associates Ltd. (Golder) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practising under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty, expressed or implied is made.

Basis and Use of the Report: This report has been prepared for the specific site, design objective, development and purpose described to Golder by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this report and are not applicable to any other project or site location. Any change of site conditions, purpose, development plans or if the project is not initiated within eighteen months of the date of the report may alter the validity of the report. Golder can not be responsible for use of this report, or portions thereof, unless Golder is requested to review and, if necessary, revise the report.

The information, recommendations and opinions expressed in this report are for the sole benefit of the Client. No other party may use or rely on this report or any portion thereof without Golder's express written consent. If the report was prepared to be included for a specific permit application process, then upon the reasonable request of the client, Golder may authorize in writing the use of this report by the regulatory agency as an Approved User for the specific and identified purpose of the applicable permit review process. Any other use of this report by others is prohibited and is without responsibility to Golder. The report, all plans, data, drawings and other documents as well as all electronic media prepared by Golder are considered its professional work product and shall remain the copyright property of Golder, who authorizes only the Client and Approved Users to make copies of the report, but only in such quantities as are reasonably necessary for the use of the report by those parties. The Client and Approved Users may not give, lend, sell, or otherwise make available the report or any portion thereof to any other party without the express written permission of Golder. The Client acknowledges that electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore the Client can not rely upon the electronic media versions of Golder's report or other work products.

The report is of a summary nature and is not intended to stand alone without reference to the instructions given to Golder by the Client, communications between Golder and the Client, and to any other reports prepared by Golder for the Client relative to the specific site described in the report. In order to properly understand the suggestions, recommendations and opinions expressed in this report, reference must be made to the whole of the report. Golder can not be responsible for use of portions of the report without reference to the entire report.

Unless otherwise stated, the suggestions, recommendations and opinions given in this report are intended only for the guidance of the Client in the design of the specific project. The extent and detail of investigations, including the number of test holes, necessary to determine all of the relevant conditions which may affect construction costs would normally be greater than has been carried out for design purposes. Contractors bidding on, or undertaking the work, should rely on their own investigations, as well as their own interpretations of the factual data presented in the report, as to how subsurface conditions may affect their work, including but not limited to proposed construction techniques, schedule, and safety and equipment capabilities.

Soil, Rock and Groundwater Conditions: Classification and identification of soils, rocks, and geologic units have been based on commonly accepted methods employed in the practice of geotechnical engineering and related disciplines. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Golder does not warrant or guarantee the exactness of the descriptions.

Special risks occur whenever engineering or related disciplines are applied to identify subsurface conditions and even a comprehensive investigation, sampling and testing program may fail to detect all or certain subsurface conditions. The environmental, geologic, geotechnical, geochemical and hydrogeologic conditions that Golder interprets to exist between and beyond sampling points may differ from those that actually exist. In addition to soil variability, fill of variable physical and chemical composition can be present over portions of the site or on adjacent properties. **The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report.** The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities (traffic, excavation, groundwater level lowering, pile driving, blasting, etc.) on the site or on adjacent sites. Excavation may expose the soils to changes due to wetting, drying or frost. Unless otherwise indicated the soil must be protected from these changes during construction.

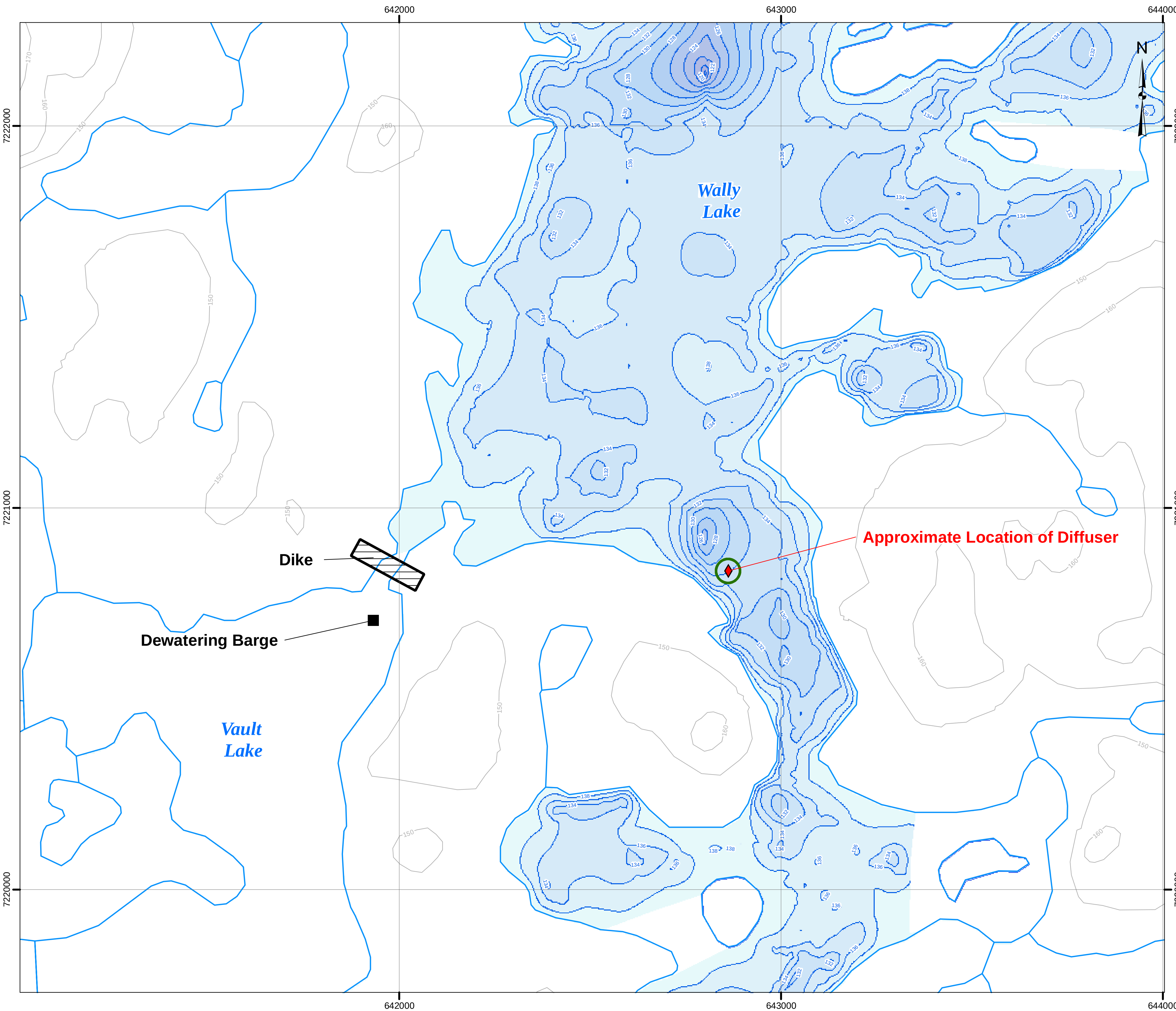
Sample Disposal: Golder will dispose of all uncontaminated soil and/or rock samples 90 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client's expense. In the event that actual contaminated soils, fills or groundwater are encountered or are inferred to be present, all contaminated samples shall remain the property and responsibility of the Client for proper disposal.

Follow-Up and Construction Services: All details of the design were not known at the time of submission of Golder's report. Golder should be retained to review the final design, project plans and documents prior to construction, to confirm that they are consistent with the intent of Golder's report.

During construction, Golder should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Golder's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Golder's report. Adequate field review, observation and testing during construction are necessary for Golder to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Golder's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

Changed Conditions and Drainage: Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Golder be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Golder be employed to visit the site with sufficient frequency to detect if conditions have changed significantly.

Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Golder takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.



N:/Bur-Graphics/Projects/2007/1413/07-1413-0039/GIS/projects/figure-1_bathymetry_vault_lake_outlet_wally_lake_diffuser.mxd

LEGEND

- Approximate Location of Diffuser
- Mixing Zone
- Dike
- Waterbody/Watercourse
- Topographic Contour (10 m interval)
- Bathymetric Contour (2 m interval)

NOTES

1. All contours are expressed as elevations.
2. Surveyed lake elevation at time of survey = 139.40 m.
3. Bathymetry gridding performed using natural neighbours interpolation in ArcGIS 9.1 with the Spatial Analyst extension.

REFERENCE

1. Topographic data: Cumberland Resources Ltd.
2. Datum: NAD 83 Projection: UTM Zone 14N.

200 100 0 200 Meters

Scale - 1:10,000

PROJECT

MEADOWBANK
MINING CORPORATION

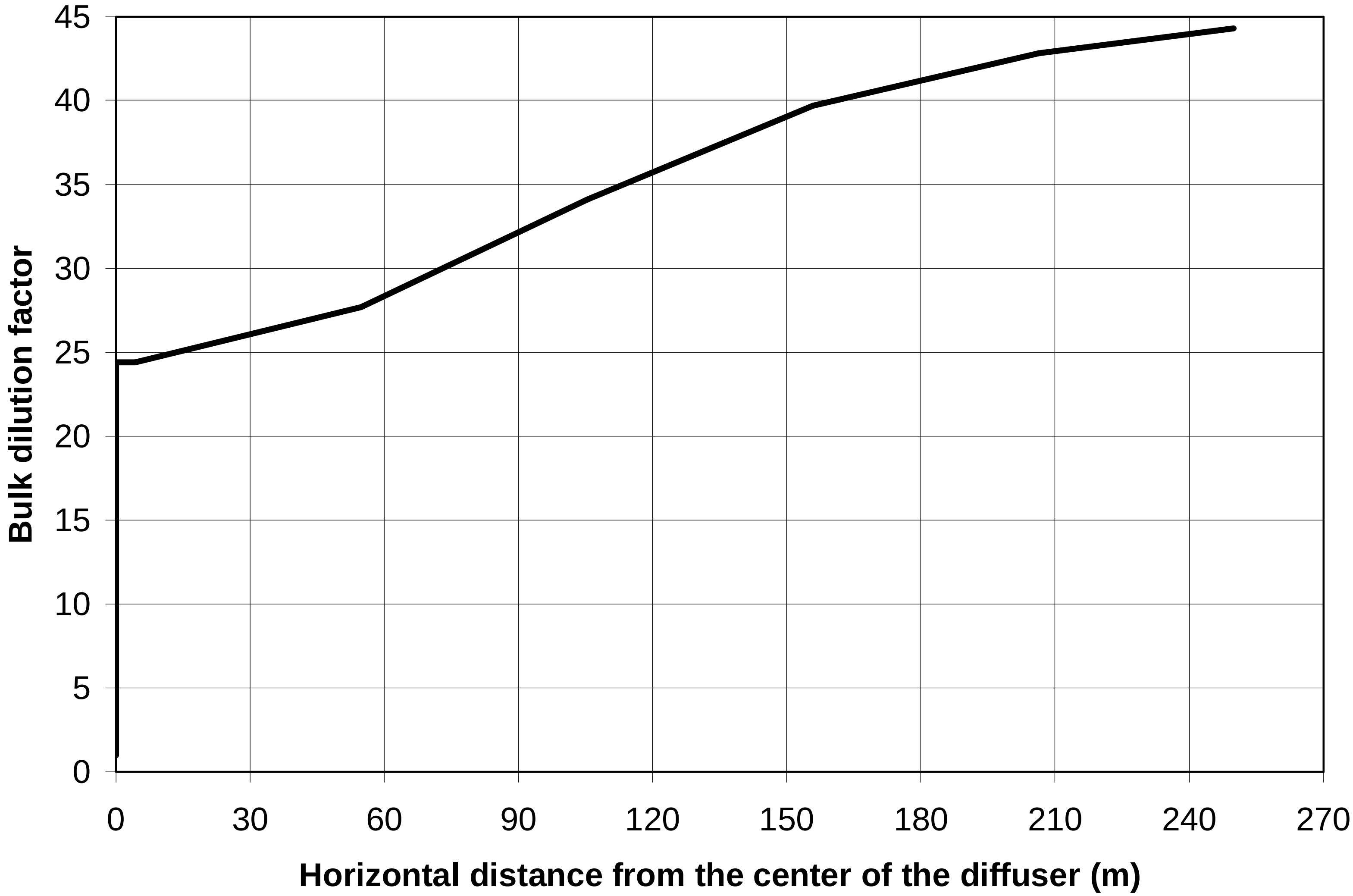
TITLE

BATHYMETRY OF VAULT LAKE OUTLET AND WALLY LAKE NEAR DIFFUSER

Golder Associates
Burnaby, B.C.

PROJECT No. 07-1413-0039			SCALE AS SHOWN	REV. 0
DESIGN	NL	18 Jul. 2007	FIGURE 1	
GIS	MCM	18 Jul. 2007		
CHECK				
REVIEW				

REVISION DATE: 07/07/23 09:39AM By: ASalvador CADD FILE: N:\Bur-Graphics\Projects\2007\1413\07-1413-0039\Drafting\5000\0714130039-FIG_2.dwg



NOTE

Bulk dilution for a diffuser with five 75mm diameter ports spaced at every 10m, with exit velocity of 4m/s.

PROJECT

MEADOWBANK

MINING CORPORATION

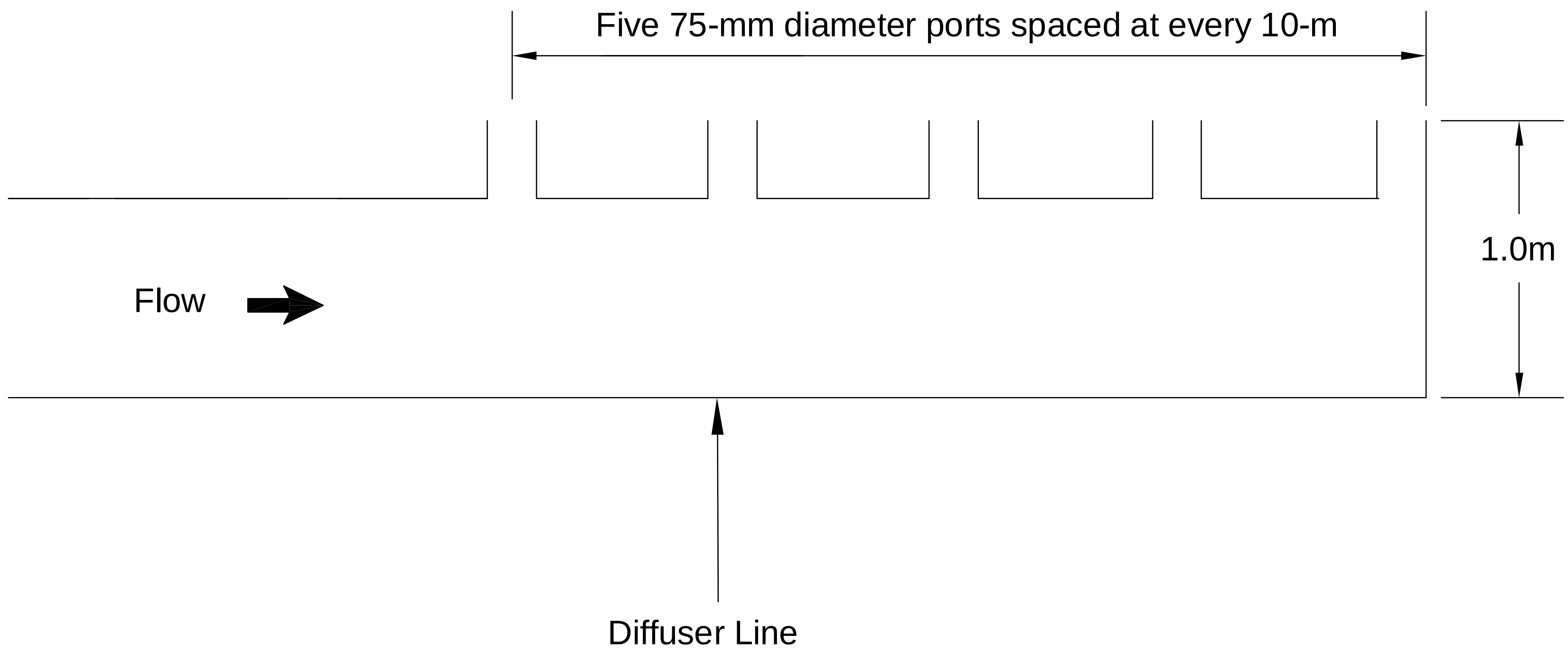
TITLE

BULK DILUTION WITH RESPECT TO THE HORIZONTAL DISTANCE FROM THE CENTER OF THE DIFFUSER

Golder Associates

PROJECT	No. 07-1413-0039		FILE No. 0714130039-FIG_2	
DESIGN	NL	23FEB07	SCALE NTS	REV. –
CADD	BAD	23FEB07	**FIGURE 2**	
CHECK				
REVIEW				

REVISION DATE: 07/07/23 09:39AM By: ASalvador CADD FILE: N:\Bur-Graphics\Projects\2007\1413\07-1413-0039\Drafting\5000\0714130039-FIG_2.dwg



PROJECT

MEADOWBANK
MINING CORPORATION

TITLE

SCHEMATIC OF MULTI-PORT DIFFUSER FOR THE MINE EFFLUENT DISCHARGE

Golder Associates

PROJECT No. 07-1413-0039			FILE No. 0714130039-FIG_1	
DESIGN	NL	23FEB07	SCALE NTS	REV. –
CADD	BAD	23FEB07	FIGURE 3	
CHECK				
REVIEW				