APPENDIX G

Options Analysis for Long-Term Water Management Plan

TECHNICAL MEMORANDUM

DATE 17 October 2016 **REFERENCE No.** 1411734-164-TM-Rev0-16000

TO Dale Reimer, General Manager
Mount Polley Mining Corporation

FROM Janis Drozdiak and Jerry Vandenberg **EMAIL** Janis_Drozdiak@golder.com; Jerry_Vandenberg@golder.com

OPTIONS ANALYSIS FOR MOUNT POLLEY MINE LONG-TERM WATER MANAGEMENT PLAN

1.0 INTRODUCTION

Mount Polley Mining Corporation (MPMC) has developed a Long-Term Water Management Plan per Section 2.9 of British Columbia *Environmental Management Act* Permit 11678. One component of the Long-Term Water Management Plan is an options analysis, which considered potential discharge locations for treated effluent. The primary goal of the options analysis was to identify discharge options for the long-term water management strategy, which will be suitable for the remainder of Mount Polley Mine operations, closure, and post-closure. This document presents an introduction to the process that was used to screen, evaluate, and select options. It includes a list of options for discharge locations, as well as the weighting and ranking of these options.

2.0 OPTION EVALUATION METHOD

The Kepner-Tregoe (K-T) process was used to evaluate the discharge location for the long-term water management strategy. This method comprises the following steps:

1) **Identify and define potential options**—For the discharge location, a number of options are available. At this stage, all potentially viable options are included in a list, without assigning any preference or likelihood to any given option. A “do nothing” option is included for comparative purposes. A description is included for each option.

2) **Identify and define primary screening criteria**—Primary criteria, also called non-compensatory criteria, are those that have pass/fail or absolute minimum or maximum requirements. Primary criteria are intended to screen an initial list, which may include many options, down to a few options that can be evaluated in more detail.

3) **Identify and define the secondary criteria**—Secondary criteria are those that need to be weighed and evaluated against each other. They are often competing or conflicting demands that make a decision more difficult and less obvious to parties with different priorities. Secondary criteria are often categorized according to the “triple bottom line”: environmental, social, and economic factors; a fourth factor, technical feasibility, is sometimes also included as a separate category, as was done in this case. A description of what constitutes a better or worse option should be included so that options can be objectively ranked against each other. Only criteria that can differentiate options should be included.

4) **Agree on the rules for weighting and ranking**—Certain rules must be followed to make an objective and transparent decision. The following rules were applied in this options analysis:
   - Total weighting must equal 100.
   - Major categories (e.g., social, environmental, economic, technical) are assigned equal weighting.
   - Rankings are from one to five; the lowest score (i.e., least preferable) must be one and the highest must be five; intermediate ranks need not be evenly or linearly spaced.
   - Two options may tie on a given criterion, but all options may not tie evenly.
   - Final scores are non-binding because the options analysis is completed in advance of detailed engineering and scientific evaluation. The options analysis supports, but does not bind, a decision. If a leading option is later rejected, justification will be provided for its rejection.
5) **Arrange options and criteria**—In a spreadsheet, a matrix is arranged with options in a row at the top and criteria down a column on the left.
6) **Assign weightings to each criterion**—The weightings reflect the importance or priority of each criterion, with the most important criteria having higher weight. These weightings should be somewhat linear (i.e., a criterion that is twice as important as another criterion should be weighted approximately twice as heavily) because, upon completion of the process, they will directly affect a numerical score that indicates the optimal option.
7) **Apply the primary criteria**—Potential options are screened and options to be subjected to detailed evaluation are shortlisted. Options that fail primary criteria are not considered or evaluated further.
8) **Rank each option**—Moving through one criterion at a time, each option is ranked.
9) **Score each option**—Scores are calculated by multiplying each weighting by each ranking, and summing the products. The preferred option(s) are selected based on overall rankings.
10) **Conduct a sensitivity analysis**—In the case of either lack of consensus, or uncertainty regarding weightings or rankings, individual weightings and rankings can be adjusted to see if it would change the highest ranked option. A sensitivity analysis can also be done to explore "what if" scenarios to evaluate changing conditions.

Input for the each of the steps listed above was gained from previous options analyses (listed in the following section) as well as Water Workshops held by MPMC in Likely, BC and the MPMC Public Liaison Committee meeting at the Mine on 12 May 2016. Electronic copies of the options analysis (a blank version and a completed version) were distributed to MPMC's Public Liaison Committee for input in advance of a public meeting in Likely on 25 May 2016, during which additional feedback was gathered.

3.0 OPTIONS ANALYSIS – DISCHARGE LOCATION

3.1 Previous Analyses

Previous options analyses have been completed as part of the short-term *Technical Assessment Report in Support of an Effluent Permit Amendment* (Golder 2015) and the *Alternative Discharge Design and Construction Plan* (Golder 2016). Through these analyses, ten options were originally screened, feedback was obtained from interested parties, and five options were shortlisted as the most viable or popular options for the detailed analysis described herein.

3.2 Option Description

Five potential discharge locations and a "status quo" option have been identified, as described in Table 1.

Table 1: Description of Potential Discharge Location Options

Option	Title	Description
1	Pipeline to Quesnel Lake	Using pipeline to convey discharge to Quesnel Lake.
2	Relocating Hazeltine Creek discharge	Locating the point of discharge further downstream to allow rehabilitation of fish habitat in the upper reach of Hazeltine Creek and connection to Polley Lake.
3	Pipeline to Quesnel River	Using pipeline to convey discharge to Quesnel River.
4	Distributed to Bootjack Lake, Polley Lake, Hazeltine Creek	Distributing flows to multiple waterbodies, preferably in proportion to pre-development flows.
5	Science-based environmental benchmarks	Developing science-based environmental benchmarks, in accordance with provincial guidance, and discharging to the assimilative capacity of Hazeltine Creek while rehabilitating the creek to fish habitat.
6	Status quo	"Do nothing" option, evaluated for comparative purposes only. Not considered as a viable option beyond permitted date of November 2017.

3.3 Option Comparison

The major advantages and disadvantages of the potential discharge location options are listed in Table 2.

Table 2: Advantages and Disadvantages of Potential Discharge Location Options

Option	Title	Advantages	Disadvantages
1	Pipeline to Quesnel Lake	■ High predicted and measured dilution ■ Deep diffuser in low traffic area ■ Allows complete rehabilitation of Hazeltine Creek	■ High cost of pipeline installation
2	Relocating Hazeltine Creek discharge	■ Minimal pipeline along disturbed corridor ■ Short pipeline required	■ Low dilution at point of discharge ■ Risk of uncontrolled release to Quesnel Lake ■ Requires highly managed flows
3	Pipeline to Quesnel River	■ Stated preference of many Likely residents ■ Allows complete rehabilitation of Hazeltine Creek	■ Additional linear disturbance and diffuser construction ■ Large initial dilution zone required that may impinge fish spawning areas ■ Dilution variable with flow ■ Higher cost of pipeline installation due to distance

Option	Title	Advantages	Disadvantages
4	Distributed flows to Bootjack Lake, Polley Lake, Hazeltine Creek	■ Viable permanent solution that restores pre-mining flows ■ Stated preference of some stakeholders and First Nations	■ Most complex drainage and discharge systems ■ Long-term monitoring at multiple locations
5	Science-based environmental benchmarks	■ Minimal pipeline and infrastructure requirements ■ Low technological complexity	■ Difficult to scale flows ■ Anticipated low public acceptance ■ Long-term monitoring
6	Status quo	*Not evaluated*	*Not evaluated*

3.4 Primary Option Screening

A primary screening of discharge location options was carried out with the criteria listed below:

- **Environmental**—does not cause adverse impacts to aquatic, terrestrial, or human receptors
- **Legal**—complies with all applicable provincial and federal policy and law

The primary screening did not remove any options, but the criteria were maintained as requirements so that if any options were subsequently modified during detailed studies, they must adhere to these criteria.

3.5 Detailed Evaluation

Secondary criteria were applied to differentiate options, as presented in Table 3.

Table 3: Evaluation Criteria for Discharge Locations

Environmental	
Assimilative capacity	Minimum of 10× dilution; >100× dilution preferred
Aquatic effects	Minimize effects on receiving environment
Terrestrial effects	Minimize disturbance (land clearing, construction area, linear disturbance)
Long-term sustainability	Location should be viable for long term, preferably for the remainder of operations and through to post-closure
Technological	
Risk and consequence of failure	Minimize likelihood of failure and potential effect of failure
Complexity	Prefer lower complexity
Flexible design	Prefer adaptable and scalable
Risk of non-compliance	Prefer higher reliability
Social	
Restoration of fish habitat	Preference to rehabilitate more habitat in Hazeltine Creek sooner
Acceptance of option	Stated preference of stakeholders
Economic	
Capital cost	Prefer lower capital cost
Operating cost	Prefer lower operating cost

3.6 Option Weighting and Ranking

The evaluation criteria described in Table 3 were used in the K-T analysis of discharge location options. Weights were assigned to the criteria based on the relative importance of each specific criterion. Quantitative ratings were assigned to each option using the numeric values 1 to 5 (5 being the most preferable, 1 the least preferable). Rankings for each option were multiplied by the relative weighting for each criterion. These weighted scores were summed to determine the total score for each option.

Where possible, quantitative analyses were completed to rank the proposed discharge options.

3.6.1 Noted Considerations for Assimilative Capacity

The assimilative capacity of the discharge location was assessed to determine the following:

- The minimum dilution factors as outlined in Table 3.
- The length of the mixing zone required to achieve the target dilution range.
- Likelihood that the proposed dilution zone impinges on fish spawning habitat.

Calculations of the dilution factors for discharges to Quesnel Lake (Appendix H of the TAR), Quesnel River (Attachment 1 of this Appendix) and Hazeltine Creek (Golder 2015) indicated the following:

- A greater than 40 times dilution can be achieved in Quesnel Lake at the edge of a 100 metre initial dilution zone – for most modelled scenarios a greater than 100 times dilution was achieved.
- For a centreline discharge to the Quesnel River, a 91x dilution factor can be achieved during the 7Q2 low flow and the site generally provides sufficient dilution to achieve equal to or greater than 100x dilution at the edge of a 100 metre mixing zone (see Attachment 1).
- There are periods when the minimum dilution of 10x will not be achievable in Hazeltine Creek.

The Quesnel Lake discharge was ranked over the Quesnel River option since the modelling work considered a centreline discharge. In reality, the discharge from the Mine would be at the edge of the river, which would reduce the modelled dilution by half or, the mixing zone length would have to be doubled to 200 metres to achieve the same dilution. The Hazeltine Creek option was given the lowest ranking due to the lack of dilution.

3.6.2 Noted Considerations for Aquatic Effects

As noted above, the quantitative analysis was also completed to determine if the mixing zone length would impinge on fish spawning habitat. The Quesnel Lake option is considered favorable to both the Quesnel River and Hazeltine Creek discharge options in this context, since the diffusers could be located at depth and away from the shore allowing the discharge to be designed in a manner that would not impinge on fish spawning habitat (in this instance, in the lake). A description of habitat considerations for Quesnel River is included below.

The upper mainstem of the Quesnel River provides valuable spawning habitat for numerous fish species (Pederson 1998). Kokanee salmon utilize the Narrows of Quesnel River near the town of Likely for spawning (Pederson 1998). A large portion of the Interior Fraser coho salmon population spawns in Quesnel River between Quesnel Lake and the UNBC Quesnel River Research Centre (Pederson 1998). Chinook salmon spawn in the Narrows and at the bridge near Likely (Pederson 1998). Dolly Varden spawn in Quesnel River from the Likely Bridge downstream to the UNBC Quesnel River Research Centre (Pederson 1998). The Quesnel River has also been identified as critical habitat for Quesnel Lake rainbow trout, which are believed to spawn in the river. The spawning habitat in the upper mainstem is not continuous but it is widely distributed and it will be determined by the presence of suitable depth, velocity and substrate conditions that are appropriate for the needs of each individual species.

As noted above, the Quesnel River would require a mixing zone of approximately 200 metres to achieve a similar dilution to the achievable dilution in Quesnel Lake. Although, fish spawning habitat is discontinuous in Quesnel River, discharge to this waterbody was given a lower ranking in comparison to Quesnel Lake due to the increased likelihood of the long mixing zone (e.g., 200 metres long and one-quarter river width) coming into contact with fish habitat.

4.0 RESULTS

A populated matrix is included as Attachment 2, and Table 4 shows the total final score for each option. The results indicate that, to balance environmental, technological, social, and economic criteria, the pipeline to Quesnel Lake is the best overall option for the Long-Term Water Management Plan.

Table 4: Options Analysis Final Results

Option	Title	Score	Overall Rank[(a)]
1	Pipeline to Quesnel Lake	393.75	1
2	Relocating Hazeltine Creek discharge	180	5
3	Pipeline to Quesnel River	315	4
4	Distributed to Bootjack Lake, Polley Lake, Hazeltine Creek	321.25	3
5	Science-based environmental benchmarks	332.5	2
6	Status quo	182.5	-

(a) For the overall rank, the lowest number indicates the most preferred overall option

Science-based environmental benchmarks (SBEBs) were ranked as the second most viable option based on the criteria employed in the current options analysis. After the options analysis was completed, MPMC discussed SBEBs with the MoE, and based on the outcomes of these discussions, MPMC will not be considering SBEBs at this time in the proposal of the Long-Term Water Management Plan. SBEBs are, however, left in this options analysis to maintain the information that has been presented to community members and to provide a comprehensive overview of the options that have been considered in the development of the Long-Term Water Management plan.

With the exclusion of SBEBs from this analysis, the option of distributed flows becomes the second most preferable option. MPMC continues to pursue this option in the context of closure and post-closure water management.

4.1 Sensitivity Analysis

As part of the analysis, a number of perspectives were sought to evaluate whether the analysis is sensitive to a particular discipline or lens through which it is viewed. The analysis was first completed by an environmental scientist for an environmental perspective, second by a design engineer for a technical perspective, and third by MPMC for an operator perspective. Each of these perspectives came to the same conclusion on the overall rankings, with little variation in numerical scores. Finally, the options analysis was distributed to MPMC's Public Liaison Committee and other interested members of the public in May 2016 for the social perspective. The feedback received indicated that, if environmental, technological, social, and economic factors are weighted evenly, the overall rankings are not sensitive to any particular lens or perspective.

5.0 CLOSURE

We trust this memorandum meets your current requirements. If you have any questions or require additional details, please contact the undersigned.

GOLDER ASSOCIATES LTD.

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Associate, Senior Pipeline Engineer

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Principal, Senior Environmental Chemist

Attachments: Study Limitations
Attachment 1: Preliminary Analysis of Hydrological Capacity and Initial Dilution Zone Mixing for the Quesnel River Discharge Option
Attachment 2: Options Analysis Matrix

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Pedersen. R., 1998. Overview Report. Quesnel River Study Area. Fish Habitat Assessment Procedure. Prepared for Weldwood of Canada Ltd. March 1998.

STUDY LIMITATIONS

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ATTACHMENT 1

Preliminary Analysis of Hydrological Capacity and Initial Dilution Zone Mixing for the Quesnel River Discharge Option

TECHNICAL MEMORANDUM

DATE 17 October 2016 REFERENCE No. 1411734-201-TM-Rev0-16000

TO Luke Moger
Mount Polley Mining Corporation

FROM Shouhong Wu, Robert Millar and Jerry Vandenberg EMAIL Shouhong_Wu@golder.com; Robert_Millar@golder.com; Jerry_Vandenberg@golder.com

PRELIMINARY ANALYSIS OF HYDROLOGICAL CAPACITY AND INITIAL DILUTION ZONE MIXING FOR THE QUESNEL RIVER DISCHARGE OPTION

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by Mount Polley Mining Corporation (MPMC) to undertake a preliminary analysis of the hydrologic capacity and initial dilution zone (IDZ) of the Quesnel River Discharge Option. This location is being considered as a potential long-term option for discharge of treated mine water from the Mount Polley Mine (the Mine). The approximate location of the proposed discharge site (the site), as considered in the Quesnel River Discharge Option, is 4.2 km downstream of the Likely Bridge (Figure 1).

MPMC is applying for an amendment of *Environmental Management Act* (EMA) Permit 11678 for a maximum annual discharge rate of 10 million metric metres (Mm^3). A discharge rate of 0.33 cubic metres per second (m^3/s) reflects the constant rate required to discharge the maximum annual volume of 10 Mm^3, which would be sufficient to manage water under the 99.5 percentile wet-year scenario (i.e., 199 years out of 200) based on hydrologic analysis found in Appendix B of this Technical Assessment Report. However, to balance larger flows during freshet, MPMC is also applying for a maximum instantaneous discharge rate of 0.6 m^3/s. This would allow for increased operational capability to manage water levels in the Springer Pit and peak flows during freshet: minimizing the volume of surplus water required to be stored on site.

The approach presented below represents a desktop analysis using general equations and parameter values from the literature. Additional field measurements would be required to refine or confirm the results.

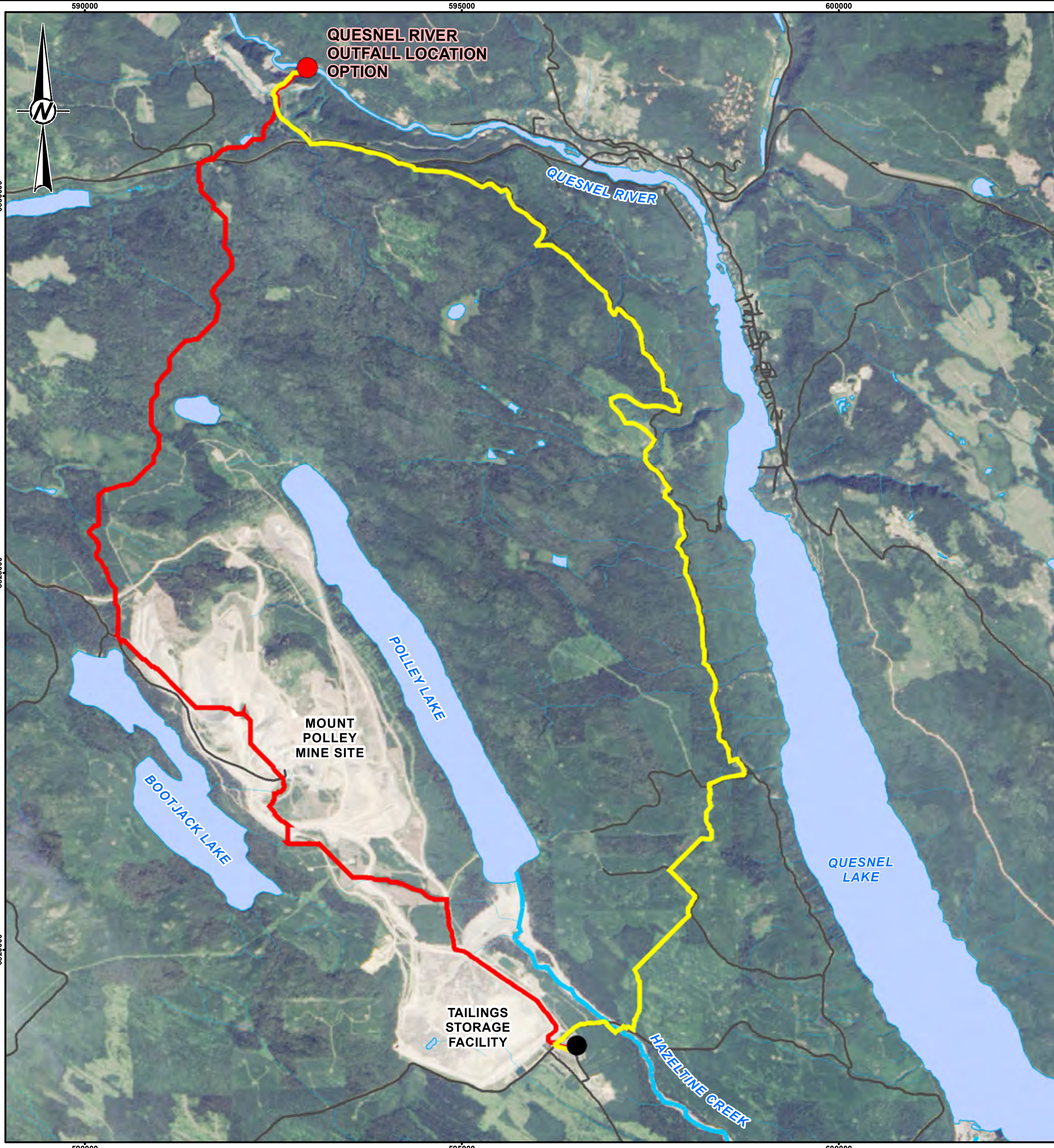
2.0 HYDROLOGICAL CAPACITY AND FAR FIELD DILUTION RATIOS

The average far-field hydrologic capacity at the site can be determined by the ratio of the mean annual discharge (MAD) at the site divided by the effluent discharge rate. This provides the average dilution ratio. The hydrology in the Quesnel River is well established, with an Environment Canada flow gauge (08KH001) installed near the Likely Bridge. The flow gauge has been in operation since 1924, with continuous data since 1948.

The 2010 annual hydrograph for Quesnel River near the Likely Bridge, together with the mean, minimum, and maximum recorded flows for the period of record, are shown in Figure 2. The MAD is 130 m^3/s; the mean seven-day low water flow (7Q2) is 30 m^3/s; and the mean annual peak flow (mean annual flood) is 394 m^3/s.

In general, a dilution ratio greater than 100:1 is desired under the EMA regulations. Dilution ratios as low as 10:1 may be acceptable with additional assessment, but are likely not acceptable. The average dilution ratio for the design effluent discharge is 394:1 (130/0.33). For the mean seven-day mean low water (7Q2), the dilution ratio is 91:1 (30/0.33).

Based on the hydrology, after complete mixing, the Quesnel River discharge site would generally provide sufficient far-field dilution (greater than 100:1) for all flows, although the minimum dilution for the 7Q2 low flow (91:1) is slightly less than the desired 100:1. However, these dilution ratios are based on complete mixing in the Quesnel River flow. Additional analysis is required for the near-field, or IDZ, which is discussed below.



LEGEND

- SOURCE LOCATION
- LONG-TERM OUTFALL LOCATION

LONG-TERM QUESNEL RIVER PIPELINE ROUTE OPTIONS

- OPTION QR-C
- OPTION QR-D
- ROAD
- WATERCOURSE
- WATERBODY

0 1.5 3

1:75,000 KILOMETRES

REFERENCE(S)

1. WATERCOURSE AND LAKE DATA OBTAINED FROM CANVEC © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
2. ORTHOPHOTO OBTAINED FROM NASA 20140217
3. PROJECTION: UTM ZONE 10; DATUM: NAD 1983

CLIENT

IMPERIAL METALS
MOUNT POLLEY MINING CORPORATION

PROJECT

MOUNT POLLEY MINE
TECHNICAL ASSESSMENT REPORT

TITLE

QUESNEL RIVER OUTFALL LOCATION OPTION

CONSULTANT

Golder Associates

YYYY-MM-DD	2016-09-19
DESIGNED	RM
PREPARED	CD
REVIEWED	RM
APPROVED	JV

PROJECT NO.	CONTROL	REV.	FIGURE
1411734	16000	0	1

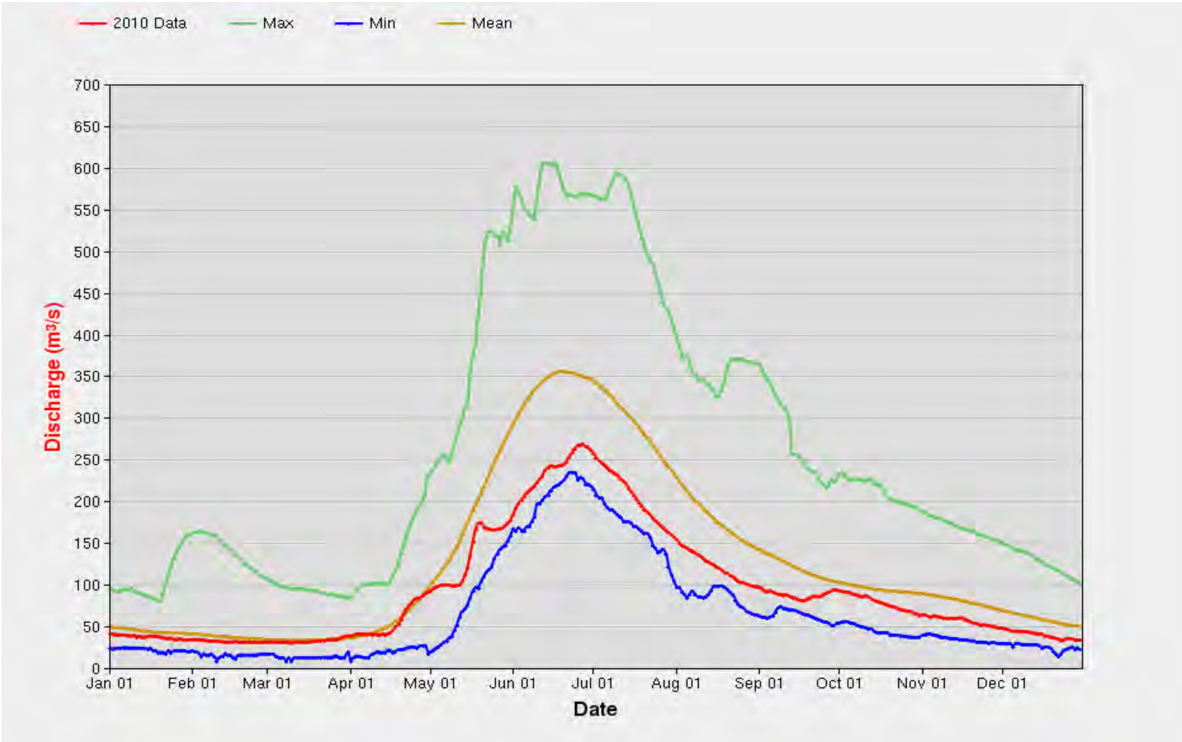


Figure 2: Annual Hydrograph for the Quesnel River at Likely (1924-2010)

3.0 INITIAL DILUTION ZONE

Under the *BC EMA, Municipal Wastewater Regulation* (Government of British Columbia, 2012), the length and width of the IDZ for streams and rivers are defined from mean low water (7Q2):

1) The width, perpendicular to the path of the stream, is the lesser of:

   a. 100 m

   b. 25% of the width of the stream

2) The length, parallel to the path of the stream, is the distance between a point 100-m upstream and a point that is the lesser of:

   c. 100 m downstream

   d. a distance downstream at which the width of the effluent plume equals the width determined under paragraph (1)

For mean low water, the width of the flow is estimated to be approximately 33.3 m (which is approximately half the bankfull width of 65.1 m), and therefore the width of the plume must be less than 8.3 m.

Based on the above, the IDZ for the Quesnel River site is defined as a zone that is 8.3 m wide, and within 100 m downstream of the discharge location (Figure 3). The desired minimum dilution at the boundary of the IDZ is 100:1.

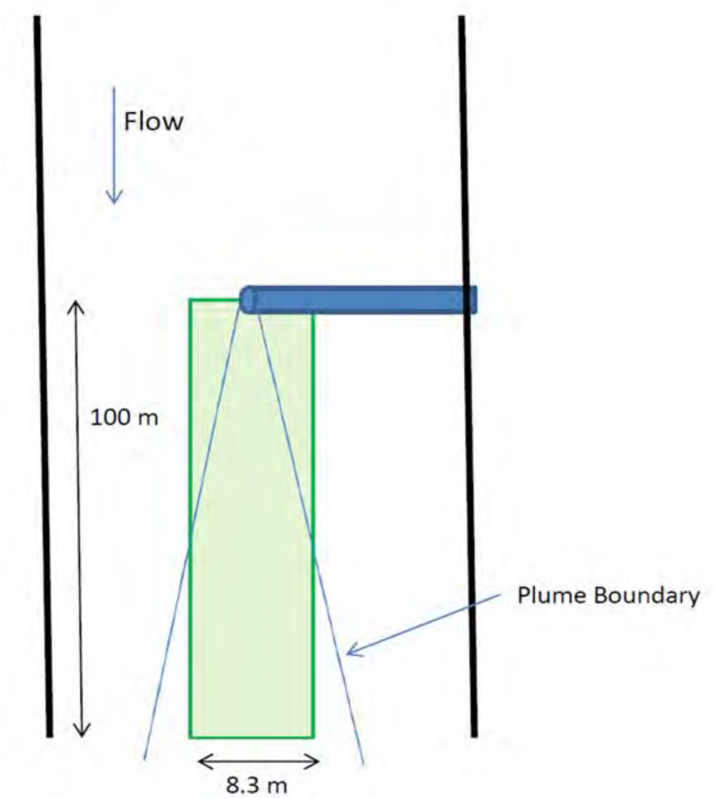


Figure 3: Definition Sketch for the IDZ for a Centreline Discharge

3.1 IDZ Dimensions for Quesnel River

The estimated IDZ for the site has been estimated through a two-dimensional advection-dispersion mixing analysis (see Attachment 1). The mixing parameter values have been assumed from literature values (Fischer et al. 1979). The variation in width, depth, and velocity with discharge have been estimated using hydraulic geometry relations (Leopold and Maddock, 1953). Details of the analysis are provided in Attachment 1.

3.1.1 Results

The key results for a single-point, centreline discharge with no diffuser are summarized in Table 1.

The minimum dilution ratios at the boundary of the IDZ for the design effluent discharge of 0.33 m^3/s under a range of Quesnel River flows are provided in column 5. For the design effluent discharge of 0.33 m^3/s, the minimum dilution rate of 100:1 at the boundary of the IDZ could only be achieved when flow in the Quesnel River was 119 m^3/s or greater. At mean low water (30 m^3/s), a minimum dilution ratio of 30:1 was estimated.

For each Quesnel River flow assessed (column 1) the corresponding maximum effluent discharge that would achieve a minimum dilution ratio of 100:1 at the boundary of the IDZ was also estimated (column 6). For the 7Q2 mean low flow (30 m^3/s), an effluent discharge of 0.1 m^3/s or less would achieve a minimum dilution ratio of 100:1 at the boundary of the IDZ. For flows in Quesnel River greater than 237 m^3/s, the minimum dilution of 100:1 would be achieved for the discharge of 0.6 m^3/s (column 6).

Table 1: Summary of IDZ Results for a Single-point, Centreline Discharge

Quesnel River Flow (m^3/s)	River Top Width (m)	Water Depth (m)	Flow Velocity (m/s)	Minimum Dilution Ratio ([a])	Maximum Effluent Discharge to Meet 100:1 Dilution (m^3/s)
[1]	[2]	[3]	[4]	[5]	[6]
30	33.3	0.78	1.16	30	0.10
50	37.9	0.96	1.38	47	0.16
119	**47.5**	**1.35**	**1.85**	**100**	**0.33**
150	50.4	1.48	2.01	122	0.40
237	56.7	1.78	2.34	182	0.60
264	58.4	1.86	2.43	200	0.66
400	65.1	2.20	2.80	287	0.95

Note: (a) At the boundary of the IDZ for the design effluent discharge of 0.33 m^3/s.

A single bank discharge point and multiple point discharges were also assessed (see Attachment 1). The single bank discharge resulted in lower dilution ratios (0.5 times those in Column [5]). The diffuser length was constrained by the plume width, and a two-port diffuser at the channel centreline provided a modest (+5%) increase in the maximum effluent discharge values (Column [6]).

4.0 ANNUAL EFFLUENT DISCHARGE

Based on the maximum effluent discharges that achieved a minimum dilution ratio of 100:1 at the boundary of the IDZ (Table 1 Column [6]), it is possible to determine the annual discharge volume that satisfies the near-field dilution requirements. To do so, discharge of treated effluent from the Mine was adjusted daily up to the maximum rate of 0.6 m^3/s based on real-time water levels recorded by Environment Canada at flow gauge 08KH001 near the Likely Bridge[1].

Annual discharge capacity estimates are provided based on historical Quesnel River daily flows (1948 through 2010) for maximum discharge rates of 0.33 m^3/s and 0.6 m^3/s (Table 2). For a maximum discharge rate of 0.33 m^3/s, the average annual discharge capacity is 7.5 Mm^3 (0.24 m^3/s). For a maximum instantaneous discharge rate of 0.6 m^3/s, the average annual discharge capacity is 9.8 Mm^3 (0.31 m^3/s). To achieve a discharge of 10 Mm^3 under 1:200-yer wet conditions, the maximum instantaneous discharge of 0.6 m^3/s would be required.

Table 2: Annual Effluent Discharge Capacity

Scenario	Maximum Discharge 0.33 m^3/s		Maximum Discharge 0.6 m^3/s	
	Mm^3	m^3/s	Mm^3	m^3/s
99.5% (Wet)	8.9	0.28	11.6	0.37
Average	7.5	0.24	9.8	0.31
0.05% (Dry)	6.1	0.19	7.7	0.24

[1] https://wateroffice.ec.gc.ca/report/report_e.html?type=realTime&stn=08KH001

5.0 CONCLUSIONS

The following conclusions are based on the above analysis (for a single-point centreline discharge port):

1) For an effluent discharge rate of 0.33 m^3/s the Quesnel River site generally provides adequate capacity to provide far-field dilution ratio of greater than, or equal to 100:1; although for mean 7Q2 low flow the dilution is 91:1.

2) The near-field dilution in the IDZ is limiting when flow in the Quesnel River is less than 119 m^3/s, which occurs on about 227 days per year (62%), on average.

3) To achieve a dilution ratio of greater than or equal to 100:1 at the boundary of the IDZ, the effluent discharge rate would need to be reduced below 0.33 m^3/s when the flow in the Quesnel River is less than 119 m^3/s.

4) A diffuser length would be limited by the mixing zone width, and would increase centreline dilution by approximately 5%.

5) Subject to a minimum dilution ratio of 100:1 at the boundary of the IDZ, the maximum instantaneous discharge rate of 0.6 m^3, requested by MPMC in the EMA Permit 11678 amendment application, would be required to provide 10 Mm^3 annual discharge capacity for 99.5% (1:200-year) wet conditions. Under this scenario, effluent flow rates would need to be continuously managed such that effluent flow is reduced or curtailed in response to changing river discharge rates.

6.0 CLOSURE

We trust that the information presented in this memo is sufficient for your present requirements. If you have any questions or concerns, please do not hesitate to contact the undersigned.

GOLDER ASSOCIATES LTD.

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Jerry Vandenberg, MSc, PChem
Principal, Senior Environmental Chemist

SW/RGM/JV/kp

Attachment : Mixing Calculations

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ATTACHMENT 1
Mixing Calculations

TECHNICAL MEMORANDUM

DATE	17 October 2016	**REFERENCE No.**	1411734-204-TM-Rev0-16000
TO	Luke Moger Mount Polley Mining Corporation		
FROM	Shouhong Wu and Robert Millar	**EMAIL**	Shouhong_Wu@golder.com; Robert_Millar@golder.com

MIXING CALCULATIONS

1.0 INTRODUCTION

The two-dimensional advection-dispersion analysis is based on the following assumptions.

- The 7Q2 (mean annual low flow) of the Quesnel River is 30.3 m^3/s.
- River bankfull width is 65 m.
- Bankfull flow is 400 m^3/s.
- The maximum, average, and minimum effluent discharge are, respectively, 0.3, 0.2, and 0.1 m^3/s.
- River bed slope $S_o = 0.0075$.

2.0 CALCULATION OF TOP WIDTH AND WATER DEPTH FOR DIFFERENT RIVER FLOW RATES

The river top width and water depth for different flow rates were estimated by the regime equations from Leopold and Maddock (1953):

$$\begin{cases} W = aQ^{0.26} \\ H = bQ^{0.40} \end{cases} \quad [1]$$

where Q is river flow; W and H are, respectively, top width and water depth (m); and a and b are coefficients to be calibrated. The coefficient a has a value of 13.7 that is obtained using the provided bankfull top width and flow rate. A value of 0.2 was used for b that resulted in reasonable values for Manning's roughness n.

The estimated W, H and n values corresponding to different flow rates are listed in columns 2, 3 and 5 of Table A1 respectively.

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3.0 CALCULATION OF TURBULENT MIXING COEFFICIENT

The turbulent mixing coefficient ε_t was calculated based on the equation by Fischer et al. (1979):

$$\varepsilon_t = 0.6Hu^* \qquad [2]$$

where 0.6 is assumed for irregular natural rivers, and u^* is shear velocity:

$$u^* = \sqrt{g * H * S_0} \qquad [3]$$

and g is gravitational acceleration. The calculated u^* and ε_t values corresponding to different discharges are listed in columns 6 and 7 of Table A1, respectively.

4.0 FULL DEPTH MIXING ASSUMPTION

Table A1 indicates that the water depth ranges from 0.78 m to 2.2 m for discharges ranging from 30 m^3/s to 400 m^3/s, and the mean velocity (listed in column 4 of Table A1) varies from 1.2 m/s to 2.8 m/s. A full depth mixing was assumed because of the shallow river depth and high velocity.

Table A1: Lowest Dilution Factor at Edge of IDZ for Maximum Effluent Discharge (Centreline or Bank)

River Flow	Width	Water Depth	Flow Velocity	Manning's Roughness	Shear Velocity	Mixing Coefficient	Froude Number	Minimum Dilution [a]		Maximum Effluent Discharge [b]		
								Single-point Discharge at Centreline	Single Bank Discharge Point	Single-point Discharge at Centerline	Single Bank Discharge Point	Maximum IDZ Width for q_{m1}
Q (m^3/s)	W (m)	H (m)	V (m/s)	n	u* (m/s)	ε_t (m^2/s)	Fr	S_{m1}	S_{m2}	q_{m1}(m^3/s)	q_{m2} m^3/s)	L (m)
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]
30.3	33.3	0.78	1.16	0.063	0.240	0.113	0.420	30	15	0.100	0.050	5.4
50.0	37.9	0.96	1.38	0.061	0.265	0.152	0.451	47	24	0.155	0.078	5.7
119	47.5	1.35	1.85	0.057	0.315	0.256	0.509	100	50	**0.330**	0.165	6.4
150.0	50.4	1.48	2.01	0.056	0.330	0.294	0.526	122	61	0.404	0.202	6.6
236.5	56.7	1.78	2.34	0.054	0.362	0.386	0.560	182	91	0.600	**0.300**	7.0
264	58.4	1.86	2.43	0.052	0.372	0.413	0.569	200	100	0.661	0.330	7.1
400.0	65.1	2.20	2.80	0.052	0.402	0.530	0.603	287	144	0.948	0.474	7.5

Notes

(a) At the boundary of the IDZ for the design effluent discharge of 0.33 m^3/s.

(b) To have dilution factor of 100 at edge of the IDZ.

5.0 CALCULATION OF THE LOWEST DILUTION FACTOR S_M AT THE EDGE OF INITIAL DILUTION ZONE FOR CENTRELINE EFFLUENT DISCHARGE

Let us first assume that the effluent is discharged into the river by a single point directly at the river centreline. At any cross section downstream of the discharge point, a constituent concentration is calculated by the equation from Fischer et al. (1979):

$$C = \frac{qC_0}{VH\sqrt{\frac{4\pi\varepsilon_t x}{V}}}\exp\left(-\frac{Vy^2}{4\varepsilon_t x}\right) \qquad [4]$$

where x and y are the longitudinal and lateral distances from the effluent, *q* is effluent discharge (m^3/s), C_0 is effluent's initial constituent concentration (mg/L). Eqn. [4] is valid for x in a range where the plume edge will not reach the river bank. By Eqn. [4], at any cross section downstream of the centreline discharge point, the highest concentration occurs at the river centreline (y=0). Because dilution factor $S=C_0/C$ we can evaluate the lowest dilution factor S_m at any downstream cross section by:

$$S_m = \frac{HV}{q}\sqrt{4\pi\varepsilon_t x/V} \qquad [5]$$

Eqn. [5] was used to evaluate the lowest dilution factor corresponding to the maximum effluent discharge of 0.3 m³/s and at the edge of initial dilution zone (IDZ), which has a length of x=100 m (Government of British Columbia 2012), and the results are listed in column 9 of Table A1. This column indicates that for 7Q2 in the Quesnel River, the dilution factor at the edge of the IDZ is as low as 30:1 (Column 9).

For effluent discharge at bank, the lowest dilution factor at any downstream cross section occurs at bank, and its value equals to half of the value calculated by Eqn. [5]. Column 10 of Table A1 lists the lowest dilution factor corresponding *q* = 0.33 m³/s and at the edge of IDZ. This column indicates that for 7Q2 on the Quesnel River, the dilution factor at the edge of IDZ is as low as 15. Table A1 also indicates that the allowable effluent discharge at bank is 0.474 m³/s when river discharge equals bankfull discharge of 400 m^3/s.

6.0 CALCULATION OF THE ALLOWABLE MAXIMUM EFFLUENT DISCHARGE

Under the *Environmental Management Act, Municipal Wastewater Regulation* of BC (2012) at the edge of IDZ, the dilution ratio ≥ 100:1 is preferred. This dilution ratio can be achieved by controlling the effluent discharge. In Eqn. [5] when *H, V* and ε_t are known, if given *x* and S_m values, a corresponding *q* value can be calculated. In Table A1, column 11 shows the calculated *q* values for centreline discharge by setting *x* =100 m and S_m = 100 in Eqn. [5]. This column indicates that when the river flow is less than approximately 119 m³/s, the allowable effluent discharge is less than 0.33 m³/s. The maximum allowable discharge (to meet the criterion of S>=100) at the bank are listed in column 12 of Table A1. This column indicates that when the river flow is less than about 264 m³/s the allowable effluent discharge is less than 0.33 m³/s. The variations of the allowable maximum allowable discharge, centreline and at the bank, with river flow are shown in Figure A1.

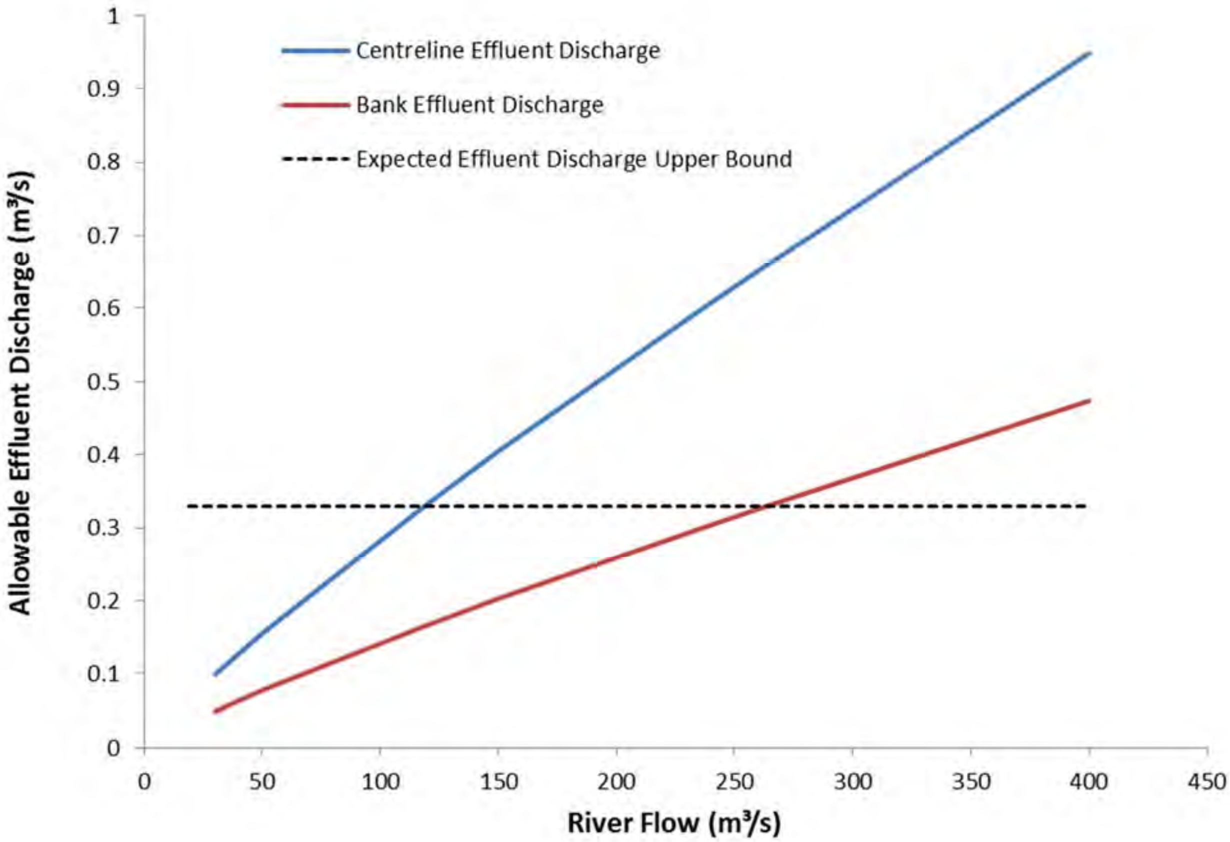

Figure A1: Variation of Allowable Effluent Discharge with River Flow to Meet Dilution Factor no less than 100 at Edge of IDZ

7.0 MAXIMUM WIDTH OF IDZ

To solve y^2 as a function of x from Eqn. [4]:

$$y^2 = \frac{Bx}{2} ln(\frac{A^2}{x})$$ [6]

where

$$A = \frac{qC_0/C}{H\sqrt{4\pi\varepsilon_t V}}$$ and [7]

$$B = \frac{4\varepsilon_t}{V}$$ [8]

Eqn. [6] can be used to plot the contour for a given dilution factor S and Figure A2 shows an example.

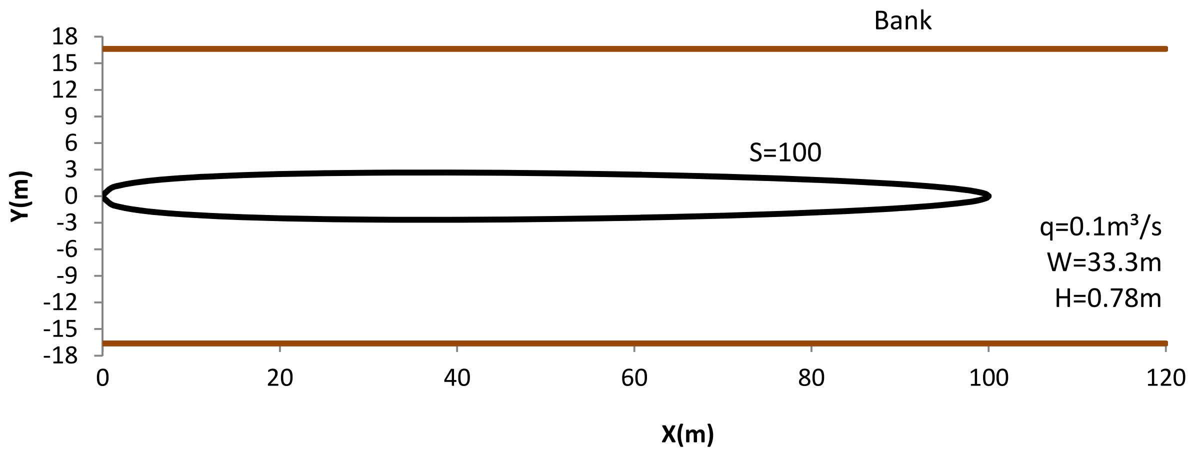

Figure A2: IDZ Boundary Contour for q=0.1 m³/s

It can be proved that y^2 has maximum value at $x = A^2/e$ (where *e* is natural log constant [2.7183]) and the maximum width L for a constant C contour is:

$$L = 2y = A\sqrt{2B/e} \quad [9]$$

In Table A1, column 13 lists the *L* values for the different controlled *q* values listed in column 11. Column 13 indicates that for 7Q2 river flow, the maximum IDZ width is 5.4 m for controlled effluent discharge, which is about 16% of the river width of 33.3 m, and that for a bank discharge, the maximum IDZ width is 7.5 m, which is about 12% of the river width of 65.1 m.

8.0 DIFFUSER WITH MULTIPLE PORTS

If a diffuser with multiple ports is used, the discharge will be fully mixed across the diffuser length in a short downstream distance from the diffuser, and this will improve dilution. For a diffuser across the river and positioned at the river centerline, Eqn. [10] is used to estimate the constituent concentration at the center of a cross section *x* metres downstream of the diffuser:

$$C = \frac{\frac{q}{n} * C_0}{VH\sqrt{\frac{4\pi\varepsilon_t x}{V}}} \sum_{i=1}^{N} \exp\left(-\frac{Vy_i^2}{4\varepsilon_t x}\right) \quad [10]$$

where N is number of diffuser ports and y_i is the distance between port i centreline and the river centerline. The concentration calculated by Eqn. [10] will be lower than actual concentrations because Eqn. [10] is the result of superimposing the constituent concentration profiles of N independent plumes.

The Government of British Columbia (2012) specifies that the width of IDZ at its downstream extent is less than 25% of the river width, which is approximately 8.0 m wide for 7Q2 river flow. The maximum IDZ width is 5.4 m for single-point centreline discharge, and therefore the diffuser length should be less than approximately 2.6 m.

If a 2.6-m diffuser with two ports is used, for 7Q2 flow of 30.3 m³/s, the allowable effluent discharge via the river centreline can be increased by approximately 5% from 0.1 m³/s to 0.105 m³/s.

9.0 CLOSURE

We trust that the information presented in this memo is sufficient for your present requirements. If you have any questions or concerns, please do not hesitate to contact the undersigned.

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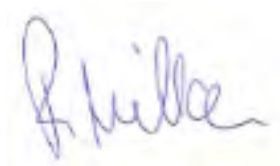

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ATTACHMENT 2
Options Analysis Matrix

Primary Criteria

Criteria	Description	Status Quo (for comparison only)	Option 1 - Pipeline to Quesnel Lake	Option 2 - Re-locating Hazeltine Creek Discharge	Option 3 - Pipeline to Quesnel River	Option 4 - Distributed to Bootjack Lake, Polley Lake, Hazeltine Creek	Option 5 - Science based environmental benchmarks
Environmental	Does not cause adverse impacts to aquatic, terrestrial or human	✓	✓	✓	✓	✓	✓
Legal	Complies with all applicable provincial and federal policy and law	✓	✓	✓	✓	✓	✓

Secondary Criteria

	Criteria	Description	Weighting	Status Quo (for comparison only)			Option 1 - Pipeline to Quesnel Lake			Option 2 - Re-locating Hazeltine Creek Discharge			Option 3 - Pipeline to Quesnel River			Option 4 - Distributed to Bootjack Lake, Polley Lake, Hazeltine Creek			Option 5 - Science based environmental benchmarks		
				Rank	Score	Comments	Rank	Score	Comments	Rank	Score	Comments	Rank	Score	Comments	Rank	Score	Comments	Rank	Score	Comments
Environmental	Assimilative Capacity	Minimum of 10x dilution, >100x dilution preferred	5	1	5	Low dilution at point of discharge	5	25	High predicted and measured dilution	1	5	Low dilution at point of discharge	3	15	>10x dilution, large IDZ required at low flows	4	20	Effluent distributed to multiple locations	2	10	Benchmarks and treatment tailored to receiving environment
	Aquatic Effects	Minimize receiving effects on receiving environment	10	1	10	Prevents or prolongs rehabilitation	5	50	All WQG met at IDZ	2	20	Incomplete restoration of Hazeltine Creek	3	30	IDZ may impinge on fish spawning habitat	3	30	Discharge distributed but into unimpacted water body	4	40	Benchmarks would be derived to minimize aquatic effects
	Terrestrial Effects	Minimize disturbance (land clearing, construction area, linear disturbance)	5	5	25	Minimal pipeline and infrastructure required	2	10	Use of existing infrastructure; some new linear disturbance	4	20	Minimal pipeline along disturbed corridor	1	5	Additional linear disturbance and diffuser construction	3	15	Low terrestrial disturbance	5	25	Minimal pipeline and infrastructure required
	Long Term Sustainability	Ensure location will be viable for long term	5	1	5	Short-term solution	3	15	Suitable for long term but not permanent	2	10	Allows progressive rehabilitation	3	15	Suitable for long term but not permanent	5	25	Viable permanent solution that restores pre-mining flows	4	20	Viable permanent solution
Technological	Risk and Consequence of Failure	Minimize likelihood of failure and potential effect of failure	6.25	1	6.25	Risk of uncontrolled release to Quesnel Lake	5	31.25	Deep diffuser in low traffic area	1	6.25	Risk of uncontrolled release to Quesnel River	2	12.5	Diffuser located in shallow flow	3	18.75	Distributed flows disperse risk	4	25	Low risk of failure; minimal infrastructure
	Complexity	Prefer lower complexity	6.25	3	18.75	Low complexity of system; high complexity of flow management	4	25	Single pipeline and use of existing diffuser	3	18.75	Low complexity of system; high complexity of flow management	2	12.5	Long pipeline; river diffuser	1	6.25	Most complex drainage and discharge systems	5	31.25	Low complexity
	Flexible Design	Adaptable and scalable	6.25	1	6.25	No flexibility - current system is already limited	5	31.25	Readily adaptable to higher flows	1	6.25	No flexibility - current system is already limited	4	25	Some flexibility but may be limited seasonally	3	18.75	Limited scalability; readily adaptable	2	12.5	Difficult to scale
	Risk of Non-compliance	Prefer higher reliability	6.25	1	6.25	Requires highly managed flows	5	31.25	Lowest variability in receiving environment	1	6.25	Requires highly managed flows	2	12.5	Dilution impacted by variable flow rate in receiving environment	4	25	Lake systems less variable than lotic	3	18.75	Dependent upon derivation
Social	Restoration of Fish Habitat	Preference to restore more habitat in Hazeltine Creek sooner	12.5	1	12.5	Prevents or prolongs rehabilitation	5	62.5	Allows complete restoration	2	25	Partial restoration Short timeline	5	62.5	Allows complete restoration	3	37.5	Allows complete restoration but in longer time frame	3	37.5	Allows complete restoration but in longer time frame
	Acceptance of Option	Stated preference of stakeholders	12.5	1	12.5	Not favoured by any stakeholder	2	25	Allows restoration of Hazeltine Creek but entails discharge upgradient of Likely	1	12.5	Not favoured by any stakeholder	5	62.5	Preferred by Likely residents	4	50	Stated preference of some stakeholders	2	25	Anticipated low acceptance
Economic	Capital Cost	Lower capital cost	12.5	5	62.5	No capital cost	2	25	Higher cost of pipeline installation	3	37.5	Short pipeline required	1	12.5	Higher cost of pipeline installation	4	50	Multiple discharge locations, all nearby	4	50	Low infrastructure cost; additional studies required
	Operating Cost	Lower operating cost	12.5	1	12.5	High management and monitoring effort	5	62.5	Minimize maintenance and monitoring locations	1	12.5	High management and monitoring effort	4	50	Long pipeline and river diffuser to maintain	2	25	Long-term monitoring at multiple locations	3	37.5	Long-term monitoring

Final Scoring

Environmental		25	Subtotal	45		Subtotal	100		Subtotal	55		Subtotal	65		Subtotal	90		Subtotal	95
Technological		25	Subtotal	37.5		Subtotal	118.75		Subtotal	37.5		Subtotal	62.5		Subtotal	68.75		Subtotal	87.5
Social		25	Subtotal	25		Subtotal	87.5		Subtotal	37.5		Subtotal	125		Subtotal	87.5		Subtotal	62.5
Economic		25	Subtotal	75		Subtotal	87.5		Subtotal	50		Subtotal	62.5		Subtotal	75		Subtotal	87.5
TOTAL SCORE		100	**TOTAL**	**182.5**	**not ranked**	**TOTAL**	**393.75**	**Rank: 1**	**TOTAL**	**180**	**Rank: 5**	**TOTAL**	**315**	**Rank: 4**	**TOTAL**	**321.25**	**Rank: 3**	**TOTAL**	**332.5**

Final column (Option 5 comments): **Rank: 2**