APPENDIX J

Long Term Far Field Diffuser Modelling

TECHNICAL MEMO

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Subject:	Mt. Polley Long Term Far Field Diffuser Modelling		

1.0 INTRODUCTION

Following the August 4, 2014 failure of its Tailings Storage Facility (TSF), Mount Polley Mine (the Mine) suspended operations. The failure of the TSF necessitated a new water management strategy, and in December 2015 the Mine was approved for short-term discharge of treated effluent into Quesnel Lake through two diffusers at a depth of approximately 50 m. For the present work, Tetra Tech EBA was retained to assess the potential long-term effects of continued discharge through these diffusers, currently installed.

1.1 Previous Related Work

Tetra Tech EBA previously completed several field and modelling studies related to water quality in Quesnel Lake.

- **Quesnel Lake Water Column Observations and Modelling** (Tetra Tech EBA, 2015a): Tetra Tech EBA was retained to perform both field measurements and numerical analyses to develop a predictive model that evaluated the fate of the suspended particulate material in Quesnel Lake and the turbidity resulting from that material.
- **Bathymetry Analysis and Volume Balance** (Tetra Tech EBA, 2015b): Tetra Tech EBA assessed the overall volume balance of the TSF failure event, giving consideration to all available sources of data, both on land and within Quesnel Lake.
- **Dilution Modelling at Potential Outfalls in Quesnel Lake** (Tetra Tech EBA, 2015c): Tetra Tech EBA was retained to assess the performance of proposed outfall designs in Quesnel Lake, particularly the long-term far field performance.

Golder Associates (Golder) conducted near-field modelling using CORMIX and conceptual outfall design (Golder, 2015a).

1.2 Objectives

The present work was undertaken in support of Mount Polley Mining Corporation (MPMC) in its application for a long-term permit for discharge into Quesnel Lake. This memorandum will be incorporated into a long-term Technical Assessment Report (TAR) as an appendix. The objectives of the present work were as follows:

- Assess the potential for dilution in Quesnel Lake under two preliminary "bookend" discharge scenarios, with consideration of long-term buildup over a decade.

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- Assess the potential for dilution in Quesnel Lake under three "detailed" discharge scenarios, with consideration of long-term buildup during the period of resumed mining operations.

1.3 Limnology Background Discussion

Quesnel Lake is a long, narrow fjord lake reaching from the Cariboo Mountains into the Interior Plateau of BC. Its average and maximum depths are 157 and 511 m, respectively, making it the deepest fjord-type lake in the world (Laval et al, 2008). It has a surface area of about 266 km^2 and a volume of 42 km^3. With a mean annual outflow of 128 m^3/s through the Quesnel River, the lake has an average hydraulic residence time of 10 years. At the west end of the lake, a contraction and sill at Cariboo Island partially separates the main body of the lake from the so-called "West Basin," which represents 8.6% and 2.3% of Quesnel Lake's surface area and volume, respectively. The West Basin's average and maximum depths are 43 and 107 m, respectively.

In temperate lakes, the temperature of the surface water passes through 4°C, the temperature of maximum density, twice annually in a well-understood cycle. Summer warming produces a layer of warm, buoyant water at the surface of a lake. The temperature difference, and thus density difference, between this layer and the cooler water beneath creates a resistance to mixing which stabilizes or stratifies the lake. In the fall, the surface layer cools, reducing the density difference between surface and deeper waters, until the stratification is overcome by wind-induced mixing. This mixing typically involves the entire water column and is commonly referred to as "fall overturn." Under winter conditions, cooling of the entire lake continues until the surface is less than 4°C, at which point a reverse winter stratification appears: a cold, buoyant surface layer overlies a warmer (closer to 4°C) deep layer. In the spring, warming of the surface layer leads up to "spring overturn" when, again, the stratification is overcome by wind-induced mixing. Continued warming of the surface layer re-forms the summer stratification and completes the annual cycle. These mixing episodes have previously been observed in Quesnel Lake in December and April. See, for example, thermistor data presented in Potts (2004) and in Laval et al (2012).

In temperate lakes deeper than about 100-200 m, the seasonal overturn cycle is complicated by high-pressure effects. The temperature of maximum density decreases with pressure, to approximately 3°C at a depth of 500 m. This means that seasonal overturn events can only involve the upper 100-200 m of the water column and deeper water is only renewed or displaced by subtle three-dimensional dynamics. For more discussion and numerous references, refer to Potts (2004) and Laval et al (2012). The main body of Quesnel Lake is subject to these effects. The West Basin of Quesnel Lake, however, with a maximum depth of just over 100 m, follows the normal seasonal overturn cycle for temperate lakes.

The three largest inflows to the lake are east of the sill, whereas Quesnel River flows out of the western tip of the West Basin, meaning that nearly all of the hydraulic throughput of the lake must pass through the West Basin. Based on an average annual outflow of 128 m^3/s, the West Basin's average residence time is about 90 days.

The sill separating the West Basin and the main body of the lake has a maximum depth of 35 m and forks around Cariboo Island. Wind setup and internal waves, or seiches, between the upper and lower layers in the water column cause two-layer exchange flow over the sill following strong wind events. Using temperature measurements, Potts (2004) estimated the rate of exchange flow to be on the order of 1500 m^3/s, which dwarfs the river outflow by an order of magnitude. This exchange is frequent enough and large enough to fully replace the water in the cool, deeper layer in 6-8 weeks (Laval et al, 2008), although the duration of individual exchange events is on the order of hours to a few days.

The key physical drivers of the lake are meteorological fluxes, wind, and rivers. Meteorological fluxes create the seasonal stratification and are dominated by shortwave and longwave radiation and evaporative heat transfer (Potts, 2004; Laval et al, 2012). Wind events are responsible for the seiche activity which can result in upwelling of cold water at the western tip of the lake and exchange flows across the sill (Laval et al, 2008) as well as episodic deep water renewal (Laval et al, 2012). Rivers also influence circulation and deep water renewal, but to a lesser degree (Laval et al, 2012).

2.0 METHODS

2.1 Model Overview

Tetra Tech EBA used the EPA Visual Plumes UM3 model, embedded in the three-dimensional hydrodynamic model H3D, to evaluate the behaviour of an outfall plume in Quesnel Lake. UM3 is a numerical dilution model for outfall discharge into marine and freshwater environments, and is one of the models included in the Visual Plumes software. The model, developed and distributed by the US Environmental Protection Agency, is an accepted standard for determining environmental impacts from effluent discharge through an outfall. Tetra Tech EBA previously developed a three-dimensional hydrodynamic model of Quesnel Lake in order to describe the behaviour of the suspended material introduced to the lake after the August 4, 2014 TSF failure event. H3D is a three-dimensional hydrodynamic model that has been shown to accurately simulate the effects of tide, wind, river flow, density and time variability in receiving water bodies (Stronach et al., 1993). The Quesnel Lake implementation of the model was developed to simulate the temperature, turbidity, and total dissolved solids regime of the lake. The model is described in the report “Quesnel Lake Water Column Observations and Modelling” (Tetra Tech EBA, 2015a) including validation to historical data and simulation of the lake after the 2014 TSF failure event. The model grid for Quesnel Lake is shown in **Figure 2.1**, with diffuser locations and river inflow and outflow points labelled.

The existing hydrodynamic model of Quesnel Lake does not take into account pressure effects on water’s equation of state. Therefore, it does not reproduce the deep-water renewal processes of the main body of the lake. These processes are, however, inconsequential to the objectives of the present work focused in the West Basin, and generally only affect circulation in water bodies deeper than about 100-200 m.

For outfall assessments, the PLUMES UM3 code was integrated into H3D such that all of the simulated time-varying properties of velocity and density could have the appropriate influence on near-field plume behaviour, and the far-field behaviour could be simulated in a realistic manner. The UM3 model is valid in the near-field when boundary effects do not occur within the near-field, and when the plume dynamics do not cause significant recirculation in the receiving environment. The existing Quesnel Lake model resolution is relatively large (75 x 75 m at the diffuser location) in order to simulate the entire lake. As the point of interest for dilution modelling is 100 m from the outfall, the grid resolution is not suitable for near-field modelling. Near-field dilution is discussed in Golder (2015a) as well as Appendix H of the TAR; Golder used the CORMIX suite of near-field models to design and evaluate diffuser options. The salient difference between the long-term three dimensional approach (H3D-PLUMES) and the near-field approach (CORMIX) is the possibility of building up a background concentration of effluent in the three-dimensional model of the lake, reducing diffuser effectiveness regardless of near-field hydraulic performance.

Warm water is less dense than cool water, so a warm plume encountering the cool bottom waters of a lake is typically buoyant. On the other hand, given similar temperatures, a plume with higher suspended and dissolved solids than the receiving water will sink. The total dissolved solids (TDS) concentrations in the effluent (on the order of 1000 mg/L) are sufficient to overcome approximately 10°C worth of buoyancy. Therefore, the plume may tend either to sink or to rise, depending on its temperature and TDS concentration as well as those of the ambient water. The modelling method chosen is able to respond to these competing processes, including the background buildup of TDS and seasonal changes in effluent and lake temperature.

2.2 Representation of Effluent Characteristics

For modelling purposes, the diffuser effluent and receiving water were represented with the following properties: temperature, total suspended solids (TSS), TDS, and a dye tracer. Density was derived from temperature and TDS by Chen and Millero's lake-specific equation of state (1986) at zero pressure, and modified for TSS using an assumed solids density of 2650 kg/m^3.

To enable a determination of the degree of effluent dilution achieved at a given point in the lake, the effluent was assigned a dye tracer concentration of 1.0, while the lake's other inflows were assigned a dye concentration of 0.0. The units of measurement for the dye can be interpreted as "m^3 of effluent per m^3 of sample." The dye was modelled as an inert, massless, soluble component. The dilution ratio can be calculated from the dye concentration at a given point; for example, a dye concentration of 0.01 represents 1 part effluent mixed with 99 parts ambient water – a dilution of 99:1.

In the "detailed" scenarios, selenium was added to the list of scalar constituents simulated.

2.3 Initial Conditions

The water temperature profile in the hydrodynamic model was initialized using the 26 November 2015 observation made by the Mine at QUL-66a (see **Figure 2.1**). This conductivity-temperature-depth (CTD) profile showed a nearly-homogeneous water column with temperature ranging from 5.7°C at the surface to 5.0°C at the maximum depth of the cast (90 m). Below 90 m, the initial temperature throughout the lake was assumed as 4.0°C.

For the "bookend" scenarios, the initial concentrations of TSS and TDS were taken as 1.5 and 78 mg/L, respectively, throughout the lake. These values were average measurements from sites near Hazeltine Creek mouth (Golder, 2015a). For the "detailed" scenarios, initial TSS was kept at 1.5 mg/L; however, initial TDS was adjusted to 69 mg/L and the initial selenium concentration was set to 0.00014 mg/L to match measurements east of Cariboo Island (values provided by Golder).

In all scenarios, the initial dye concentration was zero, to represent the absence of effluent.

2.4 Diffuser Discharge Hydrographs and Properties

The purpose of modelling the "bookend" scenarios was to provide preliminary estimates of dilution in Quesnel Lake before input data were available for a more detailed analysis. The defining characteristic of each of the two scenarios is the assumed hydrograph and properties of the discharge through the diffusers. The two "bookend" scenarios, Option 1 and Option 2, are described below.

The purpose of modelling the "detailed" scenarios was to provide best estimates of the resulting water quality in Quesnel Lake under a statistical range of predicted water quality in the discharge, from 5th to 95th percentile concentrations. The discharge characteristics for the "detailed" scenarios are described below.

2.4.1 Option 1 "Bookend" Discharge

Option 1 used a steady simulated flow rate of 0.33 m^3/s (10.4 Mm^3/yr). The steady flow represents discharge through a pipeline, bypassing the sedimentation ponds, and thus excluding any flow contribution from the lower reaches of Hazeltine Creek. Discharge was simulated beginning on 1 December 2005, to match the season that the Mine's discharge began under their short term discharge permit (1 December 2015). **Section 2.6.1** justifies the selection of 2005-2015 as the simulation period. The total simulated volume of effluent discharged from 1 December 2005 to 31 December 2015 was 105 Mm^3.

The temperature of the effluent was based on estimated monthly average temperatures at end of pipe, provided by Golder and consistent with the 2015 TAR (Golder, 2015a), and varied between 0.0 and 17.5°C. The TDS concentration in the effluent was assumed to be 1000 mg/L, based on the 75th percentile concentration in Springer Pit predicted by the Updated TAR Model (Golder, 2015b). Consistent with the Environmental Management Act permit, the TSS concentration in the effluent was assumed to be 15 mg/L. As there was no mixing with Hazeltine Creek, the dye concentration was a constant 1.0. **Figure 2.2** illustrates the diffuser discharge hydrograph and properties for Options 1 and 2.

2.4.2 Option 2 "Bookend" Discharge

For the Option 2 scenario, the discharge is assumed to pass through the sedimentation ponds, thus mixing with water from Hazeltine Creek. Since the capacity of the diffuser system is 0.60 m^3/s, the treatment plant was assumed to shut down whenever the Hazeltine Creek flow exceeded 0.27 m^3/s. The discharge through the diffusers was therefore defined as indicated in **Table 2.1**, below. The total simulated volume of effluent discharged from 1 December 2005 to 31 December 2015 was 80 Mm^3, which is 76% of the total discharge in Option 1.

Table 2.1: Discharge Definition for Option 2

When Hazeltine Creek Base Flow Was	The Discharge Was
Less than 0.27 m^3/s,	Hazeltine Creek base flow plus 0.33 m^3/s of effluent.
Between 0.27 and 0.60 m^3/s,	Hazeltine Creek base flow only.
Greater than 0.60 m^3/s,	Exactly 0.60 m^3/s of Hazeltine Creek base flow.

The temperature and other properties of the effluent were assumed to be the same as in Option 1. Properties of the combined effluent and Hazeltine Creek discharge were calculated according to the proportion of flow from each source (**see Figure 2.2**). The properties of the Hazeltine Creek base flow are described in **Section 2.7**, below.

2.4.3 "Detailed" Scenario Discharges

The three "detailed" scenarios used discharge flow rates representing average-year hydrology at the mine site. The discharge was a mixture comprised of up to three streams at any given time, coming from the Perimeter Embankment Till Borrow Pond, Springer Pit, and Hazeltine Creek. The flow rates and concentrations of TDS and selenium for each of these streams were provided digitally to Tetra Tech EBA by Golder. Effluent flows are mingled with Hazeltine Creek flows from the simulation start until the end of November 2017, at which time a pipeline is assumed to be commissioned. A bypass conveying flows from Springer Pit is active from May 2016 to May 2017, inclusive, at which time the dewatering of Springer Pit is projected to be completed. For the concentrations of TDS and selenium, three time series were provided, corresponding to 5^{th}-percentile, median, and 95^{th}-percentile predictions of Golder's probabilistic water quality model (see Appendix D of the TAR). In this context, the 95^{th}-percentile water quality predictions are relatively high values which are exceeded in only 5% of the model cases.

The discharge temperatures were estimated from the monthly temperatures of Hazeltine Creek and the effluent, discussed above, and combined in proportion to the respective flow rates. The TSS concentrations in Hazeltine Creek and the effluent were both assumed to be a constant 5.0 mg/L, matching the average concentration observed in Hazeltine Creek (sample location HAC-12) after the water treatment plant became operational (data provided by MPMC). The simulated dye concentration was 1.0 in the effluent streams, and was diluted appropriately when the discharge included water from Hazeltine Creek.

Figure 2.3 shows the discharge characteristics for the 5^{th}-percentile, median, and 95^{th}-percentile water quality "detailed" scenarios. Flow rates are presented as a total for the two diffusers.

2.5 Diffuser Physical Characteristics

The physical characteristics of the diffusers were modelled based on the information shown in drawings 101 through 105 in “HDPE PIPELINE - TEMPORARY DISCHARGE TO QUESNEL LAKE,” issued for record and sealed 13 November 2015. There are two diffusers, installed at depths of 45 and 50 m below the water surface. Each diffusers has two ports spaced 15 m apart, each 0.20 m (8 inches) in diameter, which angle up at 45° above the bed slope. The diffuser ports are approximately 1 m above the lake bed.

Although changes to the existing diffuser configuration may be considered for future operations, only the existing configuration was assessed by the modelling described in this memo.

2.6 Meteorological Inputs

One advantage of running a continuous simulation over a decade is the opportunity to see the effects of variable hydrologic and meteorological inputs year by year. Rather than constructing an artificial set of inputs by means of statistics, Tetra Tech EBA chose to use surrogate historical periods to represent the potential future conditions. This approach preserves the linkages between winds, temperatures, and precipitation that would be lost under a stochastic approach.

Meteorological inputs were chosen differently for the “bookend” scenarios than for the “detailed” scenario. The “bookend” runs aimed to make basic assumptions about effluent flow and assess long term buildup under a range of environmental conditions. By contrast, the “detailed” run aimed to make a best estimate of the discharge and assess long term buildup under unfavourable environmental conditions.

2.6.1 Inputs for “Bookend” Scenarios

For the “bookend” scenarios, a surrogate historical decade of hydrologic and meteorological inputs was used to simulate the natural range of environmental conditions, while the effluent flow was held constant. Selection of the most appropriate historical decade was based primarily on winds, which are the strongest driver of mixing in Quesnel Lake, and are therefore the dominant influence over long term buildup. Wind energy is most effective at mixing the lake during the spring and fall overturn processes, which typically happen during the April-May-June and October-November-December periods, respectively.

In keeping with the modelling completed for the short-term discharge permit, wind and other meteorological inputs to the model were derived from the Williams Lake Airport (YWL) records. The period of record at YWL runs from 1961 to present. This period was screened for wind mixing energy by evaluating the root-mean-square (RMS) wind speeds during the two sensitive periods for overturn: April-May-June and October-November-December. The decade with the greatest variation in wind mixing energy was 2006-2015. This decade was therefore selected for the “bookend” models.

Other meteorological parameters of interest are temperature and precipitation, which influence stratification and flow through the lake, respectively. Temperatures were characterized by calculating the average temperature during the expected summer stratification period – May through October. Precipitation was characterized using an annual total. Since river flows are significantly influenced by snow pack, the precipitation for a given year was totaled between September 1st of the preceding year and August 31st to account for winter accumulation.

Table 2.2 below summarizes the variability of wind mixing energy, summer temperatures, and annual precipitation in the decade chosen for the “bookend” simulations. Each parameter is described in terms of its variation from the mean over the period of record at YWL. For example, in 2013 the RMS wind speed in the sensitive periods was 13% lower than average, summer temperatures were 1.1°C warmer than average, and precipitation was 2% less than average.

Table 2.2: Variability in Meteorological Conditions during "Bookend" Decade

	Yearly Variation In		
Year	**Windiness**	**Summer T (°C)**	**Precipitation**
2005	0%	-0.2	24%
2006	-1%	0.7	-16%
2007	-7%	-0.1	0%
2008	-6%	-0.1	15%
2009	-2%	0.7	-1%
2010	9%	0.2	-15%
2011	0%	-0.6	24%
2012	1%	0.2	-7%
2013	-13%	1.1	-2%
2014	4%	1.2	18%
2015	2%	1.3	-5%

2.6.2 Inputs for "Detailed" Scenarios

For the "detailed" scenarios, the buildup of effluent in the lake was assessed in relatively unfavourable environmental conditions. Maximum buildup of effluent in the lake would be expected when the least amount of wind energy is available for mixing. The year with the lowest wind energy was 2013, so this year was selected for the "detailed" scenarios. Since the simulations require multi-year duration, the hydrologic and meteorological inputs from 2013 were repeated, or looped, to extend the input period.

Results from the Option 1 "bookend" scenario confirmed that, as expected, the greatest increase in background effluent concentrations in the lake occurred in 2013 (see **Section 3.2**).

2.7 Hydrologic Inputs

The West Basin of Quesnel Lake, into which the diffusers discharge, is at the "downstream" end of the Lake, meaning that the hydraulic throughput of the Lake must all pass through the West Basin. Quesnel River, which flows out of the West Basin, has an annual average flow rate of 128 m^3/s. Based on this flow rate, the average hydraulic residence time of the West Basin is about 90 days.

The major rivers flowing into Quesnel Lake are Horsefly River, Mitchell River, and Niagara Creek. Numerous smaller streams enter the lake as well, including Hazeltine Creek. Inflows to the Quesnel Lake model were represented using the three major rivers, with flows from the lesser streams lumped together with the most appropriate major rivers, following the methods of Potts (2004). Potts's methods predict average monthly inflows to Quesnel Lake, based on historically gauged catchments within and surrounding the Quesnel Lake watershed. To account for yearly differences in precipitation, the average monthly inflows in each year were scaled up or down according to the year's variance in precipitation, as shown in **Table 2.2** above. For example, monthly inflows for 2006 were scaled down from the average by 16%.

For the major rivers, temperatures were taken as the average monthly temperatures measured by Potts (2004). TSS in the Horsefly and Mitchell Rivers was assumed to be 1.5 mg/L, matching the initial condition in the Lake, while TSS in Niagara Creek was taken as 81 mg/L, a value derived from the observations of James (2004). All three major rivers were assumed to have TDS and selenium concentrations matching the initial concentrations in the Lake for the respective runs.

Despite its very small annual average flow rate of approximately 0.24 m^3/s, Hazeltine Creek was included in the "bookend" scenarios as a distinct inflow since estimated flows were available. The flow rate for Hazeltine Creek was derived from synthetic data created by SNC-Lavalin, extrapolated from the gauge location to the creek mouth by a ratio of catchment areas. For simulation years in which the synthetic data had gaps, the gaps were filled by inserting data from other years with similar annual precipitation; for example, gaps in 2014 data were filled with values from the same dates in 1991 (precipitation year totals 516.8 and 518.1 mm, respectively, at YWL). For the "detailed" scenarios, Hazeltine Creek was not included as a distinct inflow to avoid conflict with the monthly flows provided by Golder.

Average monthly temperatures for Hazeltine Creek were taken from MPMC (2009). For the "bookend" scenarios, TSS and TDS were assumed to be 3.3 and 81 mg/L, respectively (Golder, 2015a). For the "detailed" scenarios, TSS was assumed to be 5.0 mg/L, matching the average concentration observed in Hazeltine Creek (sample location HAC-12) after the water treatment plant became operational (data provided by MPMC). TDS and selenium concentrations were assumed to be 247 and 0.001 mg/L, respectively, matching baseline water quality values provided by Golder.

The outflow from the Quesnel Lake model was managed using a weir-type condition to represent Quesnel River's stage-discharge relationship.

Tetra Tech EBA validated the model's hydrology by comparing the simulated lake level against observed lake level at the Water Survey of Canada gauge near Likely from 2006 to 2014. The observed lake level varies 2.4 m in an average year, with a mean lake level of 0.8 m gauge; the simulated lake level varies 2.0 m in an average year with a mean level of 0.9 m gauge. This validation demonstrates that the weir-type outflow condition and the estimated inflows reasonably reproduce the natural rise and fall of the lake level. This degree of agreement is adequate for the present purpose, considering the scarcity of input data and the relatively small influence of hydrology on the model's predictions of long term effluent buildup.

2.8 Sources of Uncertainty

Table 2.3 lists sources of uncertainty in the predictions of water quality in Quesnel Lake stemming from the modelling approach and assumptions described above. Comments are provided describing how the uncertainty is addressed and what bias may be expected in the model's predictions.

Table 2.3: Uncertainty Analysis for Long Term Water Quality Predictions in Quesnel Lake

Source of Uncertainty	How Uncertainty is Addressed in Modelling	Expected Bias to Predicted Water Quality in Quesnel Lake
Future meteorological conditions.	Conditions from past years are used as surrogate data to represent future conditions.	No bias expected; however, random extremes or a changing climate could influence future outcomes.
Wind speed and direction over Quesnel Lake.	Wind speeds are assumed to match those measured at YWL; wind direction is rotated locally so that the dominant wind direction aligns with the lake's axis.	No bias expected; validations done in previous work support these assumptions as making the best use of the available data.
Hydrology in Quesnel Lake catchment area.	Average monthly inflows to the lake are modified by a factor for each year, based on precipitation at YWL.	No bias expected to long-term water quality; short-term variability (days to months) may be underestimated.
Coarseness of hydrodynamic model's horizontal resolution.	Complete mixing implicitly assumed in the model cell where EPA Plumes places the plume; results are reported only outside a 1-cell radius around the diffusers.	Dilution may be overestimated in the few cells closest to the diffusers; no bias expected in the far field.
Effluent flow rates in "bookend" scenarios.	High flow rates assumed, subject to simple rules.	Predictions biased toward worse water quality.
Effluent flow rates in "detailed" scenarios.	Monthly flow rates were provided by Golder as best estimates of average future conditions.	No bias expected to long-term water quality; short-term variability (days to months) may be underestimated.
Effluent temperatures and Hazeltine Creek temperatures, which strongly influence plume density.	Average monthly temperatures were applied in the model.	No bias expected to long-term water quality; short-term variability (days to months) may be underestimated.
Effluent quality in "bookend" scenarios.	Constant concentrations were assumed.	Variability due to effluent quality is not reflected.
Effluent quality in "detailed" scenarios.	Model included daily variation in concentrations, predicted at three probabilistic levels (5^{th}, 50^{th} and 95^{th} percentiles).	The 5^{th} and 95^{th} percentile predictions are expected to bias the predicted lake water quality downwards and upwards, respectively.

In general, the uncertainties described above were addressed in ways that resulted in the best estimate of long-term far field water quality. This was the primary objective of the modelling effort.

The corollary of this approach is that short-term variability and near-field dilution were lower priorities for modelling. For example, short-term variability due to effluent temperatures and flow rates is not reflected in the model due to the use of monthly averages for these parameters. Furthermore, near-field dilution (within a few cells of the diffuser) may be overestimated due to the coarseness of the model's horizontal resolution.

3.0 RESULTS

This section presents the results of the modelling introduced above. First, some example maps and sections are presented to orient the reader to the model's capabilities. Next, the results of the "bookend" scenarios are presented and discussed; and finally the results of the "detailed" scenarios are presented and discussed.

3.1 Example Model Outputs

Figures 3.1 and 3.2 show some examples of model output from the "bookend" scenarios. These examples facilitate discussion of some important model dynamics and set the background for further results presentation.

Figure 3.1 shows a snapshot of the West Basin condition on 12 August 2010 in the Option 1 scenario simulation. The main panel is a plan view or map showing most of the West Basin, with black line contours showing depth at 25-m intervals. The colour scheme represents dilution of the effluent as computed from the dye concentration in the model. The colour shown in each model cell represents the worst (lowest) dilution in the water column at that location and at the snapshot time.

For regulatory purposes, an initial dilution zone (IDZ) is commonly defined as a 100-m radius around the point of discharge. The horizontal resolution of the model is approximately 75 m at the diffuser location. To represent the IDZ, therefore, a 1-cell buffer has been applied around diffuser cells. The buffer was applied as a post-processing step and did not affect model dynamics. In the plan view, dilution within this IDZ has been blanked (light grey). In **Figure 3.1**, the worst dilution outside the IDZ is in the yellow cells southeast of the diffusers, in the range of 20:1 to 30:1.

The inset in **Figure 3.1** shows a cross-section of the West Basin at the diffuser location (see dashed red line on the map), viewed as if looking northwest. The diffusers are marked on the left slope of the lake bottom. The black line contours are temperature, at varying intervals chosen for visual effect. Colours represent dilution again, on the same colour scale as on the map. This section illustrates a strong temperature stratification in the West Basin, typical of summer conditions. The warm effluent discharging into the cool, deep ambient water is buoyant despite its TDS concentration, and the plume rises to approximately 20 m depth (yellow band above diffusers). The IDZ is not blanked on the inset.

Figure 3.2 shows a snapshot of the West Basin condition on 5 November 2014 in the Option 2 scenario simulation. The main panel is identical to **Figure 3.1** in its layout. The worst dilution outside the IDZ is in the yellow cells northeast of the diffusers, again in the range of 20:1 to 30:1.

The inset in **Figure 3.2** shows a longitudinal cross-section of the West Basin along its thalweg (path of greatest depth – see dashed red line on the map), viewed as if looking northeast. The diffusers are marked with dashed circles where the section passes them. At this point in the simulation, the summer temperature stratification has weakened significantly, and wind events can cause internal waves with vertical amplitudes in the tens of metres. These seiches draw the plume back and forth along the long axis of the basin, and can result in "re-dosing," where water carrying moderately-diluted effluent is drawn back past the diffusers to receive a second "dose" of effluent. The highest concentrations of effluent are off the section line and therefore do not appear in the inset.

3.2 Results from "Bookend" Scenarios

The objective of the "bookend" scenarios was to evaluate the capacity for dilution in Quesnel Lake, under a long-term discharge through a range of hydrologic and meteorological conditions. **Figure 3.3** provides time series of dilution for Option 1 (red; steady effluent flows) and Option 2 (black; effluent mixing with Hazeltine Creek). The vertical axis is dilution ratio on a log scale, with smaller numbers (worse water quality) towards the top. The dots mark the lowest dilution in the model domain, outside the IDZ, from data archived at 24-hour intervals. The bold solid lines are 30-day moving averages of the worst dilution (dots). The fine dotted lines are 30-day moving averages of the worst dilution *at the water surface*. The 30-day moving averages were computed because some constituents, such as selenium, are subject to guidelines defined in those terms.

In Option 1, the worst predicted dilution was 23:1, occurring in summer while the plume was buoyant and subject to trapping under the thermocline. The example model output shown in **Figure 3.1** corresponds to this point in the Option 1 simulation: that is, the red dot at 12 August 2010 in **Figure 3.3** represents the 23:1 dilution in the worst yellow cell in **Figure 3.1**.

In Option 2, the worst predicted dilution was 27:1, occurring in fall with stratification weakening and significant seiche activity leading to local re-dosing. The example model output shown in **Figure 3.2** corresponds to this point in the Option 2 simulation: that is, the black dot at 5 November 2014 in **Figure 3.3** represents the 27:1 dilution in the worst yellow cell in **Figure 3.2**.

Simulated dilution in Option 2 is generally better than in Option 1 for two reasons. First, the Option 2 discharge was only 76% of the Option 1 volume, so there is less total buildup of effluent in the basin. Second, Option 2 involved mixing the effluent with Hazeltine Creek base flow, pre-diluting the effluent as well as affecting density.

To aid understanding of the circulation dynamics, Tetra Tech EBA computed a mass balance of the effluent in the West Basin for the Option 1 simulation. **Figure 3.4** presents a time series of the terms of the mass balance: cumulative effluent discharge, cumulative effluent exited via Quesnel River, cumulative effluent exited over the sill into the main body of the lake, and instantaneous effluent content of the West Basin. At any time, the cumulative effluent discharge must equal the sum of the other three terms. The Option 1 discharge was 0.33 m^3/s, or about 10.4 $Mm^3/year$. The buildup of effluent in the West Basin reached a quasi-steady state within 2 years. After this time, the West Basin generally contained about 3.5 to 6 Mm^3 of effluent (thick black line), or roughly half a year's worth of discharge. Of the remaining effluent, about 80% was transported out the Quesnel River, and 20% was exchanged over the sill into the main body of the lake. Exchange over the sill was episodic and occurred most often in late fall, whereas transport out Quesnel River was continuous and had its maximum rate during spring overturn (May and June). After steady state was reached, the only differences year-to-year were due to environmental conditions. The year with the greatest buildup of effluent was 2013, measured as the change in West Basin effluent content from 31 December to 31 December. Therefore, 2013 was deemed the worst year of the simulated decade in terms of effluent buildup.

3.3 Results from "Detailed" Scenarios

The objective of the "detailed" scenarios was to evaluate the capacity for dilution in Quesnel Lake, under a long-term discharge of varying properties estimated to represent discharge from the resumed operations of the Mine. **Figure 3.5** provides time series of dilution for discharges with 5th percentile (black), median (blue), and 95th percentile (red) estimated water quality. The layout of the figure is very similar to that of **Figure 3.3**, with dots representing instantaneous values at 24-hour intervals, and lines representing 30-day moving averages. The worst predicted dilutions occur in early summer, when the plume is buoyant, in the years 2018 through 2020. In these years the pipeline is in use, meaning that the effluent is not pre-diluted by Hazeltine Creek.

Examination of model outputs at hourly intervals (not shown) revealed that variations can occur at time scales as short as 3-6 hours. These variations could be due to changes in wind, solar heating, and internal waves in the lake. Instantaneous worst dilutions appearing in the simulations may not reflect daily averages, which are generally used for effects assessment. Therefore, data archived at hourly intervals were combined to produce daily-average worst dilutions during the critical periods of the "detailed" scenarios. **Table 3.1** lists the worst instantaneous dilutions found at 24-hour intervals (midnights) beside the corresponding worst daily averages and worst 30-day averages, for the three water quality scenarios.

The "detailed" scenarios included selenium as a specific water quality parameter. **Figure 3.6** presents time series of the predicted selenium concentrations. The baseline Quesnel Lake concentration, 0.00014 mg/L, is indicated with a faint grid line, as is the British Columbia Ministry of Environment (MoE) 30-day average guideline of 0.002 mg/L (MoE, 2014). Similar to dilution, the worst selenium concentrations outside the IDZ were archived at 24-hour intervals. The thick lines plotted in **Figure 3.6** represent 30-day moving averages of these concentrations. The fine dotted lines represent 30-day moving averages of worst selenium concentrations *at the water surface*. **Table 3.1** also lists the worst 30-day average selenium concentrations for each scenario.

Table 3.1: Worst Conditions Predicted in "Detailed" Scenarios

Water Quality Scenario	Worst Instantaneous Dilution at Midnight	Worst Daily-Average Dilution	Worst 30-Day Average Dilution	Worst 30-Day Average Selenium Concentration (mg/L)
5th Percentile	24:1	23:1	38:1	0.0009
Median	26:1	28:1	39:1	0.0010
95th Percentile	27:1	28:1	40:1	0.0015

The worst predicted dilutions occur in the 5th-percentile water quality scenario. Worst dilutions generally occurred in summer when the plume was buoyant and was trapped below the thermocline. The 5th-percentile scenario had lesser TDS concentrations, and was therefore more buoyant in summer and more affected by the trapping dynamic, leading to worse predicted dilutions during the summer period. However, the worst predicted selenium concentrations occurred in the 95th-percentile scenario. The higher selenium concentrations in the effluent outweighed the slightly better dilutions generally achieved.

4.0 CONCLUSIONS

Tetra Tech EBA used a hydrodynamic model of Quesnel Lake in combination with the EPA Visual Plumes UM3 model to simulate water quality in Quesnel Lake with long-term discharge of mine water from the existing diffusers near the mouth of Hazeltine Creek.

Two "bookend" scenarios were simulated, with constant discharge characteristics and variable environmental conditions. Results from these scenarios indicated that:

- The worst water quality outside the IDZ typically occurs in summer when the effluent plume is buoyant and gets trapped below the thermocline;
- Buildup of background effluent concentration in the West Basin of Quesnel Lake reaches a quasi-steady state within 2 years, and this state represents approximately half a year's worth of discharge; and
- The strength of the wind during spring and fall overturn periods is the most significant environmental factor for long-term buildup.

Three "detailed" scenarios were simulated, with relatively unfavourable environmental conditions and varying discharge characteristics representative of resumed operations at the Mine. Results from these scenarios indicated that:

- The worst predicted daily-average dilution outside the IDZ would range from 23:1 to 28:1, depending on the concentration of TDS in the effluent;
- The worst predicted 30-day average dilution outside the IDZ would range from 38:1 to 40:1, depending on the concentration of TDS in the effluent;
- The worst predicted selenium concentration outside the IDZ would range from 0.0009 to 0.0015 mg/L, depending on the concentrations of selenium and TDS in the effluent; and
- Higher TDS and selenium concentrations in the effluent led to higher selenium concentrations outside the IDZ, despite an improvement in summer dilution due to reduced buoyancy of the effluent plume.

5.0 LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of Mount Polley Mining Corporation and their agents. Tetra Tech EBA Inc. does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than Mount Polley Mining Corporation, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this report is subject to the terms and conditions stated in Tetra Tech EBA's Services Agreement. Tetra Tech EBA's General Conditions are attached to this memo.

6.0 CLOSURE

We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech EBA Inc.

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DJP/JS/TAK

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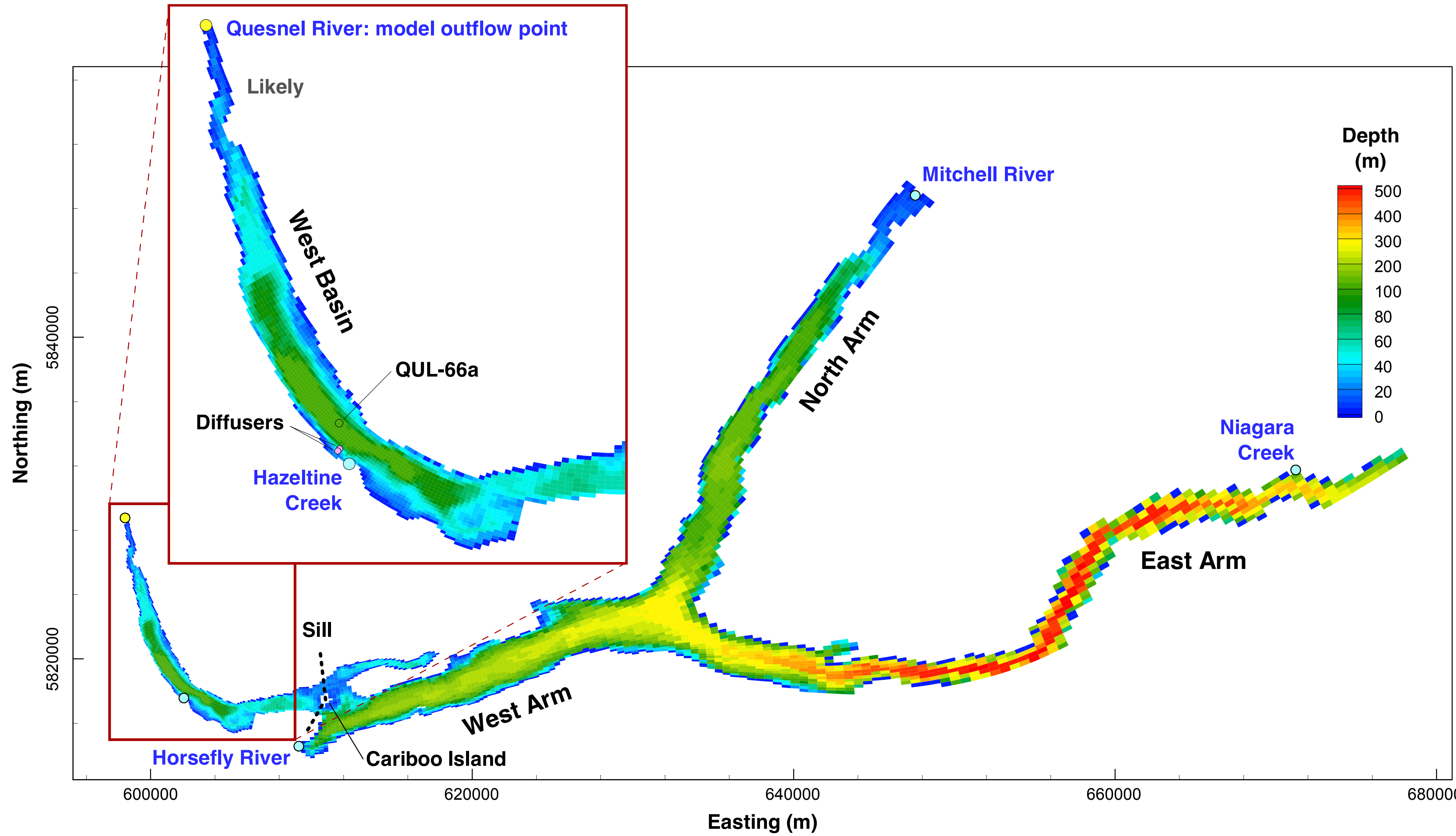
Tetra Tech EBA, 2015b. Bathymetry Analysis and Volume Balance. Prepared for MPMC, May 2015.

Tetra Tech EBA, 2015c. Dilution Modelling at Potential Outfalls in Quesnel Lake. Memorandum #005 to MPMC, May 2015. Appendix F to TAR submitted to MPMC, May 2015.

FIGURES



NOTES

Horizontal model resolution varies as shown, with higher resolution in the West Basin and West Arm, and lower resolution in the North and East Arms.

Modelled inflowing and outflowing rivers are labelled. The inset of the West Basin shows the diffuser locations.

STATUS
ISSUED FOR USE

CLIENT
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TETRA TECH EBA

QUESNEL LAKE DIFFUSER MODELLING

Quesnel Lake
Hydrodynamic Model Bathymetry

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03015	DP	JAS	JAS	0

OFFICE: Tetra Tech EBA - VANC

DATE: May 16, 2016

Figure 2.1

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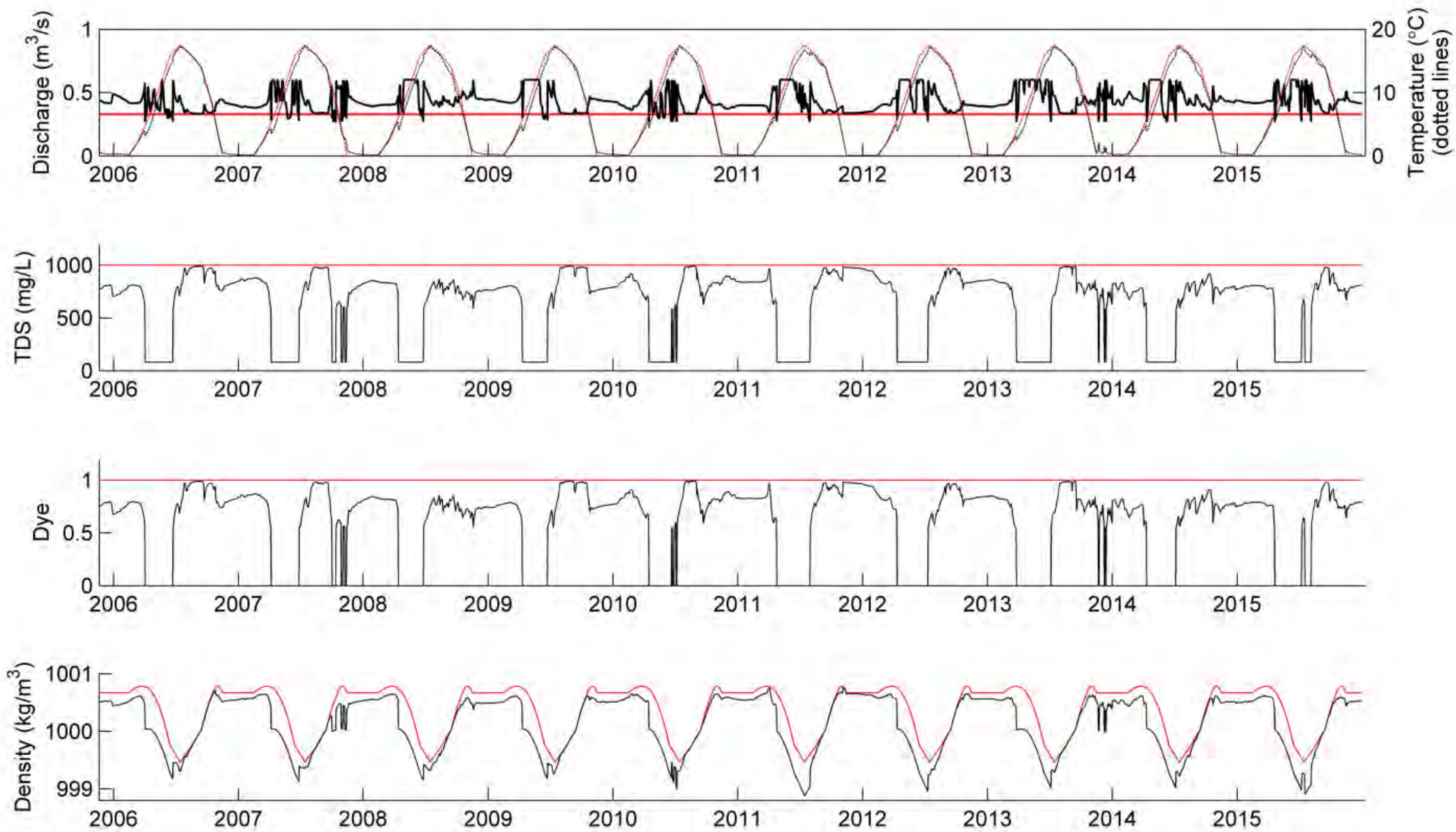
27 Jun 2016 14:33:14



NOTES

Legend:

- Option 1
- Option 2

STATUS
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CLIENT
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TETRA TECH EBA

QUESNEL LAKE DIFFUSER MODELLING

Diffuser Discharge Properties for "Bookend" Scenarios

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03015	DP	JAS	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	June 13, 2016

Figure 2.2

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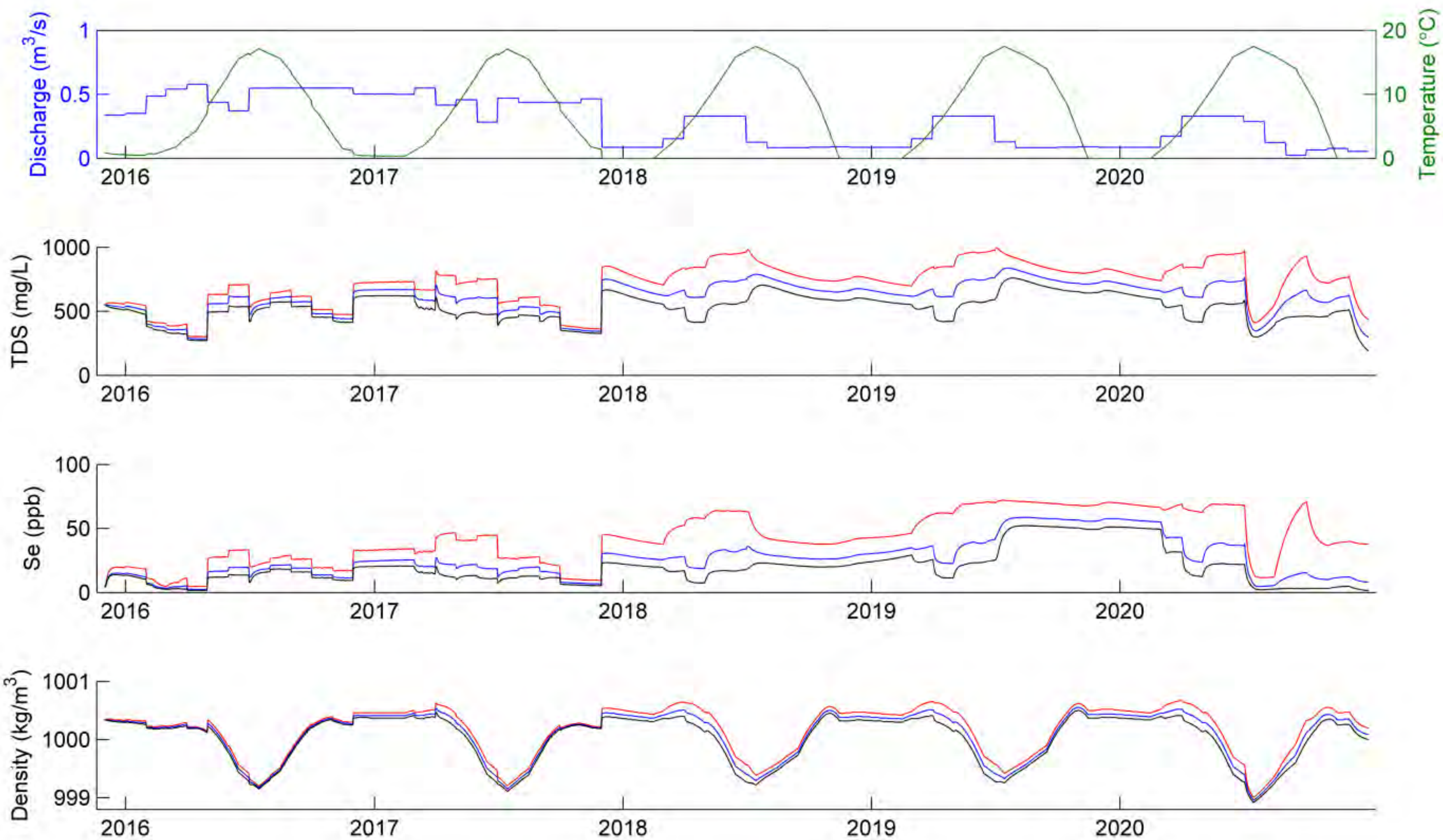
27 Jun 2016 14:33:44



NOTES

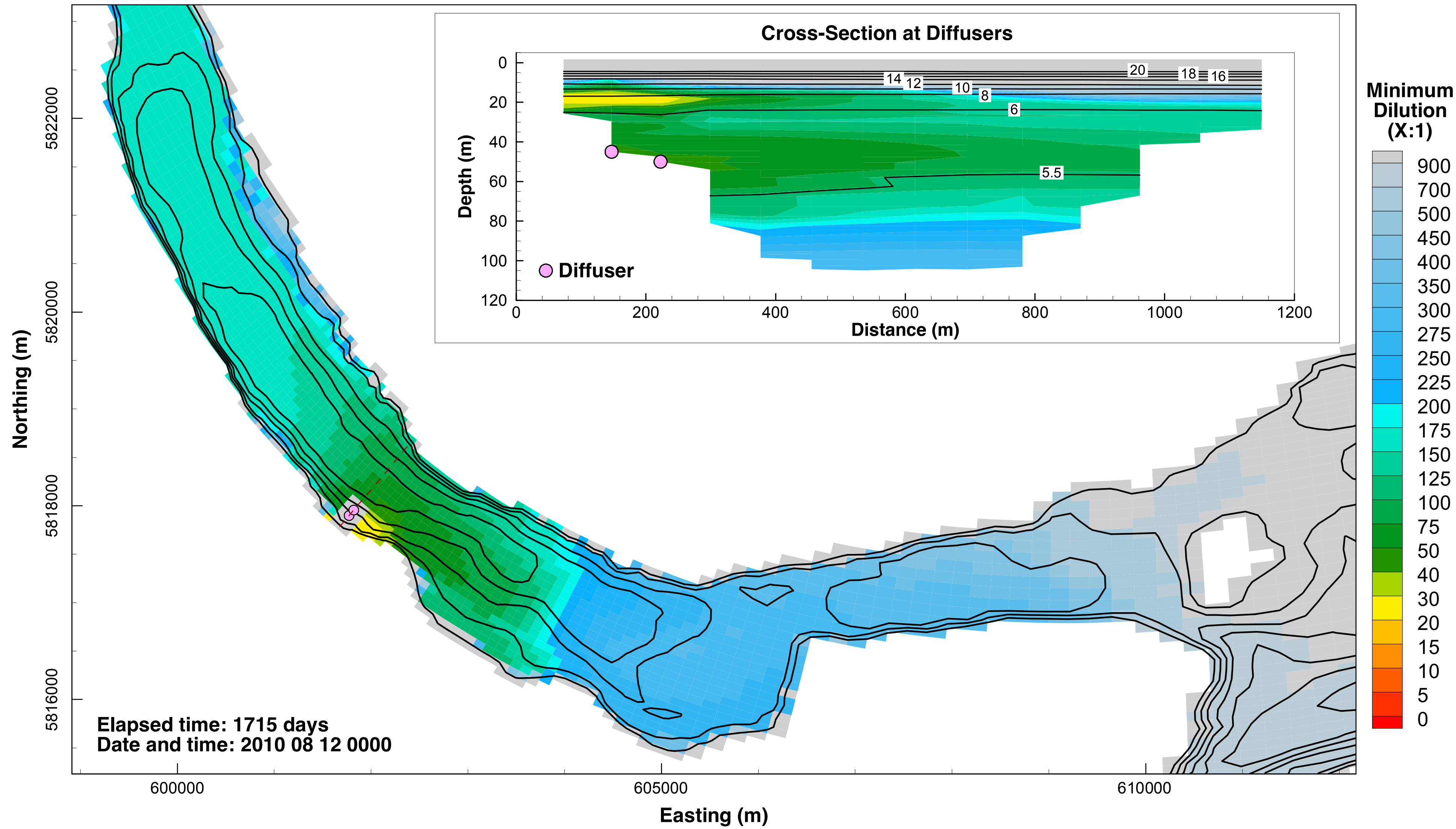
Legend:

- 95th Percentile WQ
- Median WQ
- 5th Percentile WQ

STATUS
ISSUED FOR USE

CLIENT MPMC	QUESNEL LAKE DIFFUSER MODELLING			
	Diffuser Discharge Properties for "Detailed" Scenarios			
TETRA TECH EBA	PROJECT NO. WTRM03015	DWN DP	CKD JAS	APVD JAS	REV 0
	OFFICE Tetra Tech EBA - VANC	DATE June 9, 2016		

Figure 2.3



NOTES

Effluent flow rate: 0.33 m^3/s.

Plan view shows minimum dilution at any depth, with bathymetric line contours @ 25 m.
Section view shows dilution across West Basin, with temperature line contours.

STATUS
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MPMC

TETRA TECH EBA

QUESNEL LAKE DIFFUSER MODELLING

Option 1 "Bookend" Scenario Example Model Output: Dilution - Plan and Section

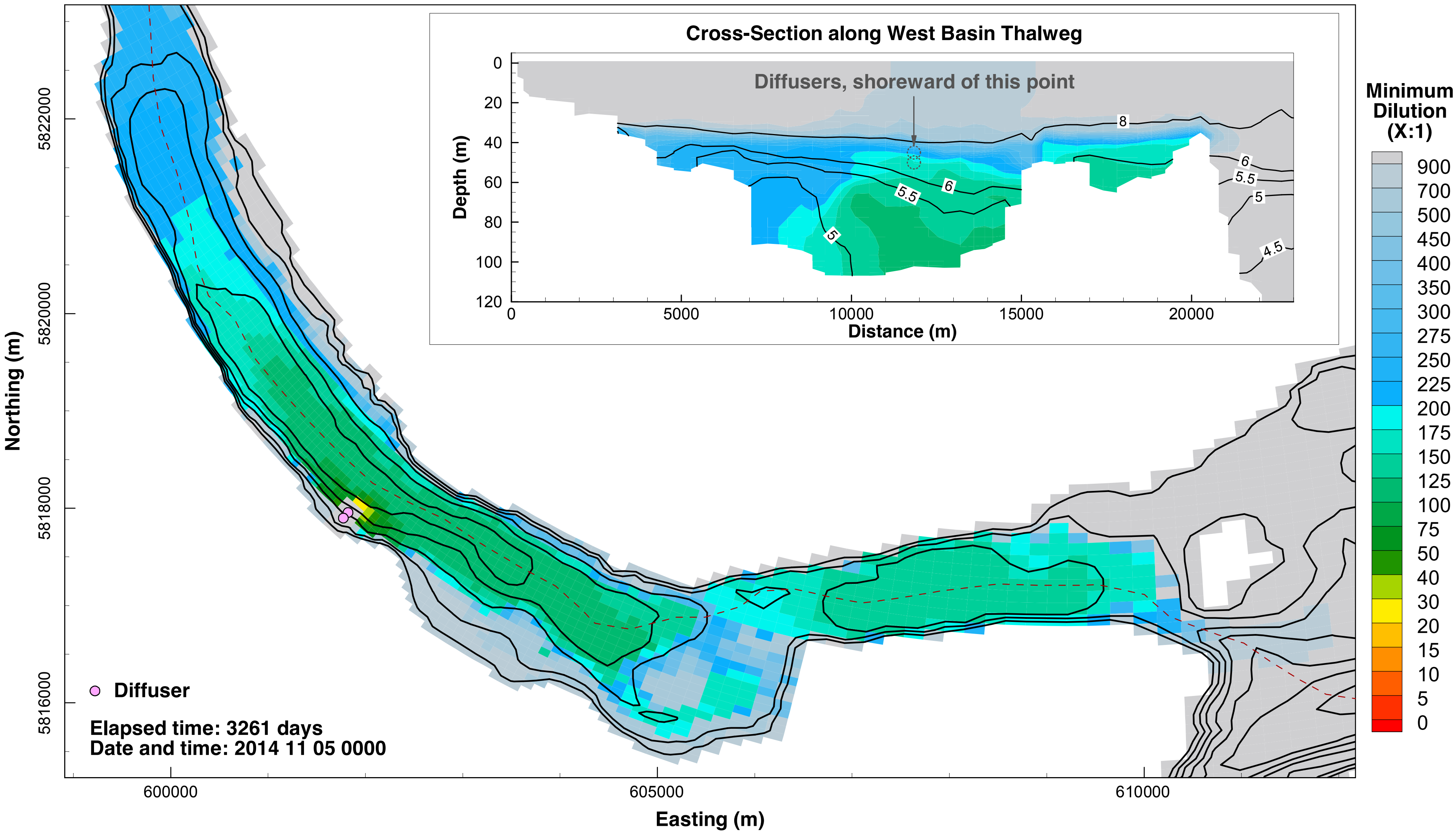
PROJECT NO.	DWN	CKD	APVD	REV
WTRM03015	DP	JAS	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	June 8, 2016

Figure 3.1

E:\Projects\MtPolley\12-H3D\tecplot\Fig_example_928_worstdil.lay

27 Jun 2016 14:28:20



NOTES

Effluent flow rate: max 0.33 m^3/s, details per Option 2.

Plan view shows minimum dilution at any depth, with bathymetric line contours @ 25 m.
Section view shows dilution across West Basin, with temperature line contours.

STATUS
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CLIENT
MPMC

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QUESNEL LAKE DIFFUSER MODELLING

Option 2 "Bookend" Scenario Example Model Output: Dilution - Plan and Section

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03015	DP	JAS	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	June 8, 2016

Figure 3.2

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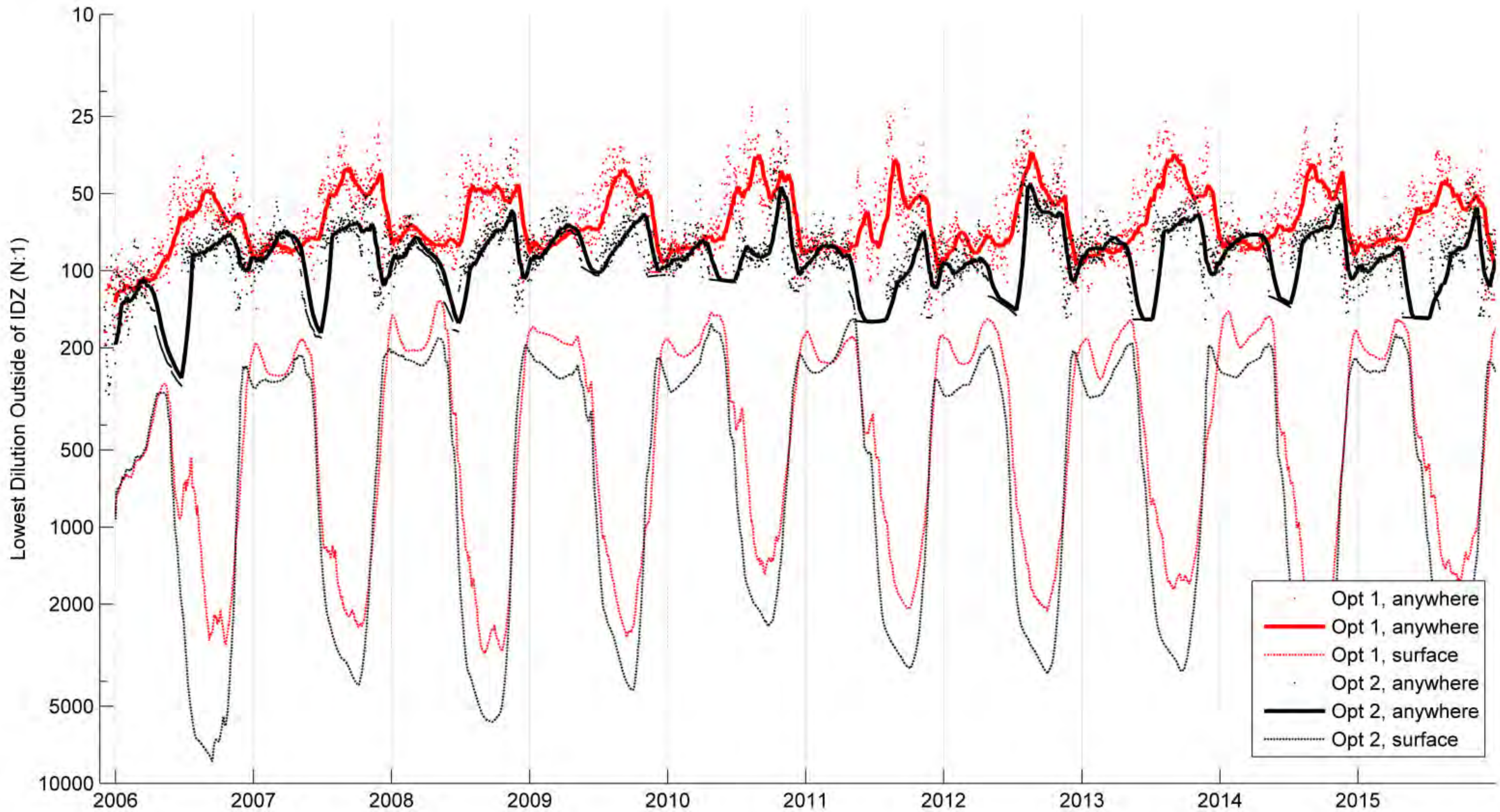
27 Jun 2016 14:29:14



NOTES

Dots represent daily snapshot values.
Lines represent 30-day moving average.

Effluent flow rate: 0.33 m^3/s, details per Option.

STATUS
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CLIENT

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TETRA TECH EBA

QUESNEL LAKE DIFFUSER MODELLING

Simulated Dilution in Quesnel Lake "Bookend" Decadal Runs Options 1 and 2

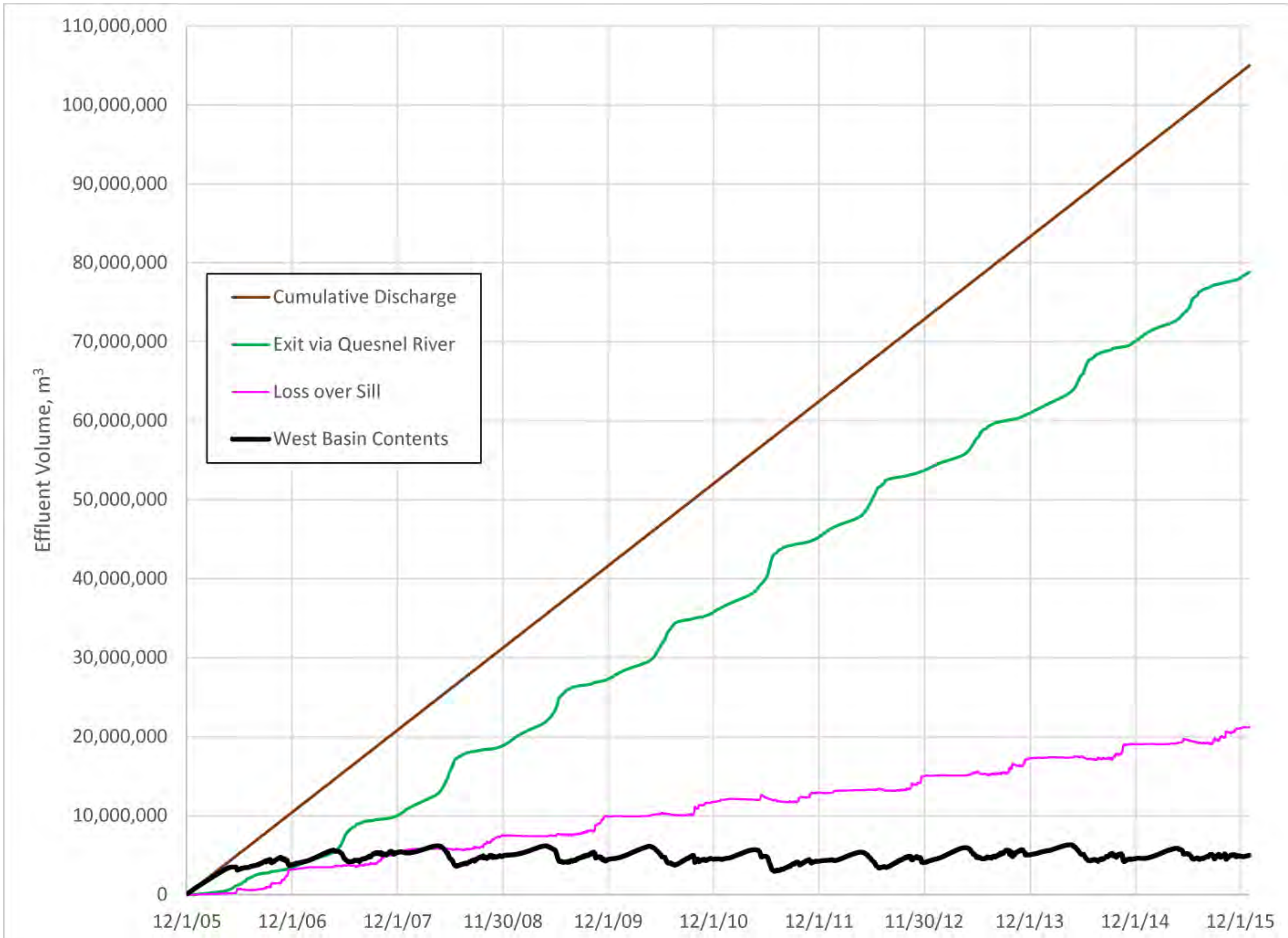
PROJECT NO.	DWN	CKD	APVD	REV
WTRM03015	DP	JAS	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	June 8, 2016

Figure 3.3

E:\Projects\MtPolley\12-H3D\tecplot\Fig_timeseries_bookend_dil.lay

27 Jun 2016 14:30:56



NOTES

Effluent flow rate: 0.33 m^3/s.
Effluent TDS: assumed 1000 mg/L, constant.

STATUS
ISSUED FOR USE

CLIENT

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TETRA TECH EBA

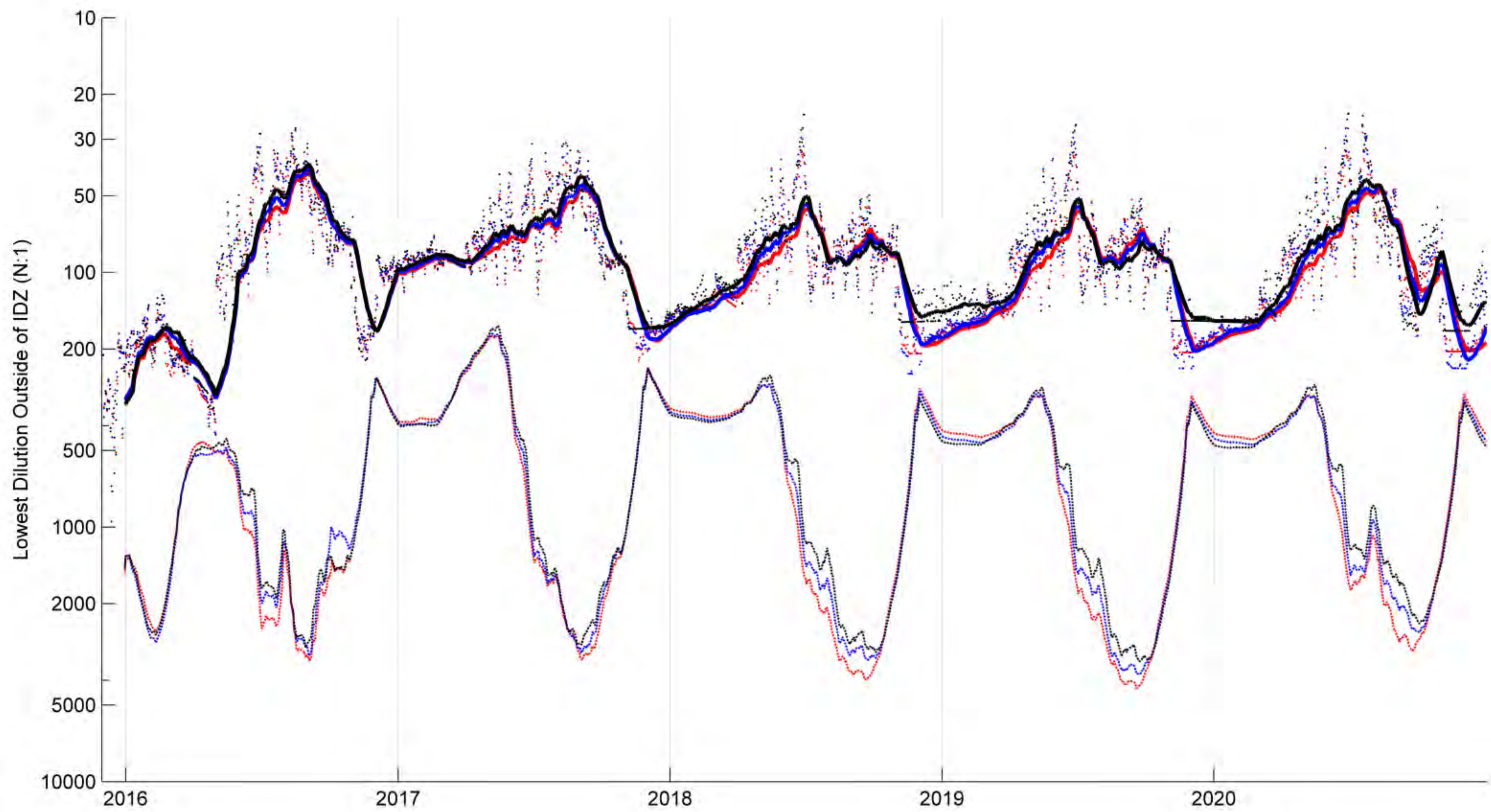
QUESNEL LAKE DIFFUSER MODELLING

Option 1 "Bookend" Scenario Effluent Volume Balance

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03015	DP	JAS	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	June 8, 2016

Figure 3.4



NOTES

Dots represent daily snapshot values.
Lines represent 30-day moving average.

STATUS
ISSUED FOR USE

CLIENT

MPMC

TETRA TECH EBA

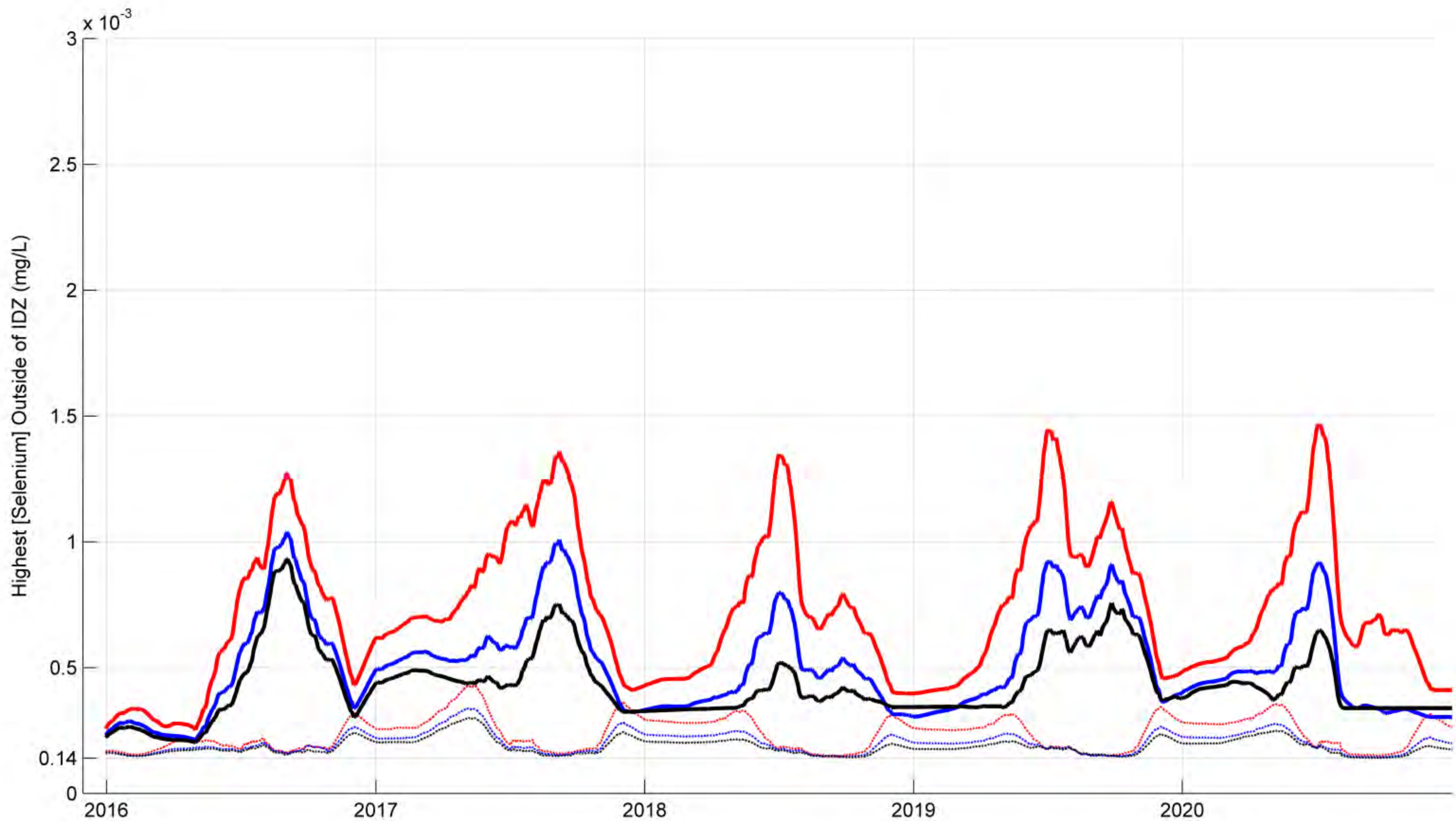
QUESNEL LAKE DIFFUSER MODELLING

Simulated Dilution in Quesnel Lake "Detailed" Scenario Runs

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03015	DP	JAS	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	June 8, 2016

Figure 3.5



NOTES

Lines represent 30-day moving average.

STATUS
ISSUED FOR USE

CLIENT

MPMC

TETRA TECH EBA

QUESNEL LAKE DIFFUSER MODELLING

Simulated Selenium in Quesnel Lake "Detailed" Scenario Runs

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03015	DP	JAS	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	June 15, 2016

Figure 3.6

E:\Projects\MtPolley\06-Reports_and_memos\LTTAR\figures\detailed\Fig_3-6_detailed_sel_linear.lay

27 Jun 2016 14:35:46

APPENDIX A
TETRA TECH EBA'S GENERAL CONDITIONS

GENERAL CONDITIONS

HYDROTECHNICAL

This report incorporates and is subject to these “General Conditions”.

1.0 USE OF REPORTS AND OWNERSHIP

This report pertains to a specific site, a specific development, and a specific scope of work. The report may include plans, drawings, profiles and other supporting documents that collectively constitute the report (the “Report”).

The Report is intended for the sole use of Tetra Tech EBA’s Client (the “Client”) as specifically identified in the Tetra Tech EBA Services Agreement or other Contract entered into with the Client (either of which is termed the “Services Agreement” herein). Tetra Tech EBA does not accept any responsibility for the accuracy of any of the data, analyses, recommendations or other contents of the Report when it is used or relied upon by any party other than the Client, unless authorized in writing by Tetra Tech EBA.

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Where Tetra Tech EBA submits both electronic file and hard copy versions of the Report or any drawings or other project-related documents and deliverables (collectively termed Tetra Tech EBA’s “Instruments of Professional Service”), only the signed and/or sealed versions shall be considered final. The original signed and/or sealed version archived by Tetra Tech EBA shall be deemed to be the original. Tetra Tech EBA will archive the original signed and/or sealed version for a maximum period of 10 years.

Both electronic file and hard copy versions of Tetra Tech EBA’s Instruments of Professional Service shall not, under any circumstances, be altered by any party except Tetra Tech EBA. Tetra Tech EBA’s Instruments of Professional Service will be used only and exactly as submitted by Tetra Tech EBA.

Electronic files submitted by Tetra Tech EBA have been prepared and submitted using specific software and hardware systems. Tetra Tech EBA makes no representation about the compatibility of these files with the Client’s current or future software and hardware systems.

3.0 STANDARD OF CARE

Services performed by Tetra Tech EBA for the Report have been conducted in accordance with the Services Agreement, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Report. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Report.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of Tetra Tech EBA.

4.0 ENVIRONMENTAL AND REGULATORY ISSUES

Unless expressly agreed to in the Services Agreement, Tetra Tech EBA was not retained to investigate, address or consider, and has not investigated, addressed or considered any environmental or regulatory issues associated with the project.

5.0 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with Tetra Tech EBA with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for Tetra Tech EBA to properly provide the services contracted for in the Services Agreement, Tetra Tech EBA has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

6.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

During the performance of the work and the preparation of this Report, Tetra Tech EBA may have relied on information provided by persons other than the Client.

While Tetra Tech EBA endeavours to verify the accuracy of such information, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

7.0 GENERAL LIMITATIONS OF REPORT

This Report is based solely on the conditions present and the data available to Tetra Tech EBA at the time the Report was prepared.

The Client, and any Authorized Party, acknowledges that the Report is based on limited data and that the conclusions, opinions, and recommendations contained in the Report are the result of the application of professional judgment to such limited data.

The Report is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present at or the development proposed as of the date of the Report requires a supplementary investigation and assessment.

It is incumbent upon the Client and any Authorized Party, to be knowledgeable of the level of risk that has been incorporated into the project design, in consideration of the level of the hydrotechnical information that was reasonably acquired to facilitate completion of the design.

The Client acknowledges that Tetra Tech EBA is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

8.0 JOB SITE SAFETY

Tetra Tech EBA is only responsible for the activities of its employees on the job site and was not and will not be responsible for the supervision of any other persons whatsoever. The presence of Tetra Tech EBA personnel on site shall not be construed in any way to relieve the Client or any other persons on site from their responsibility for job site safety.