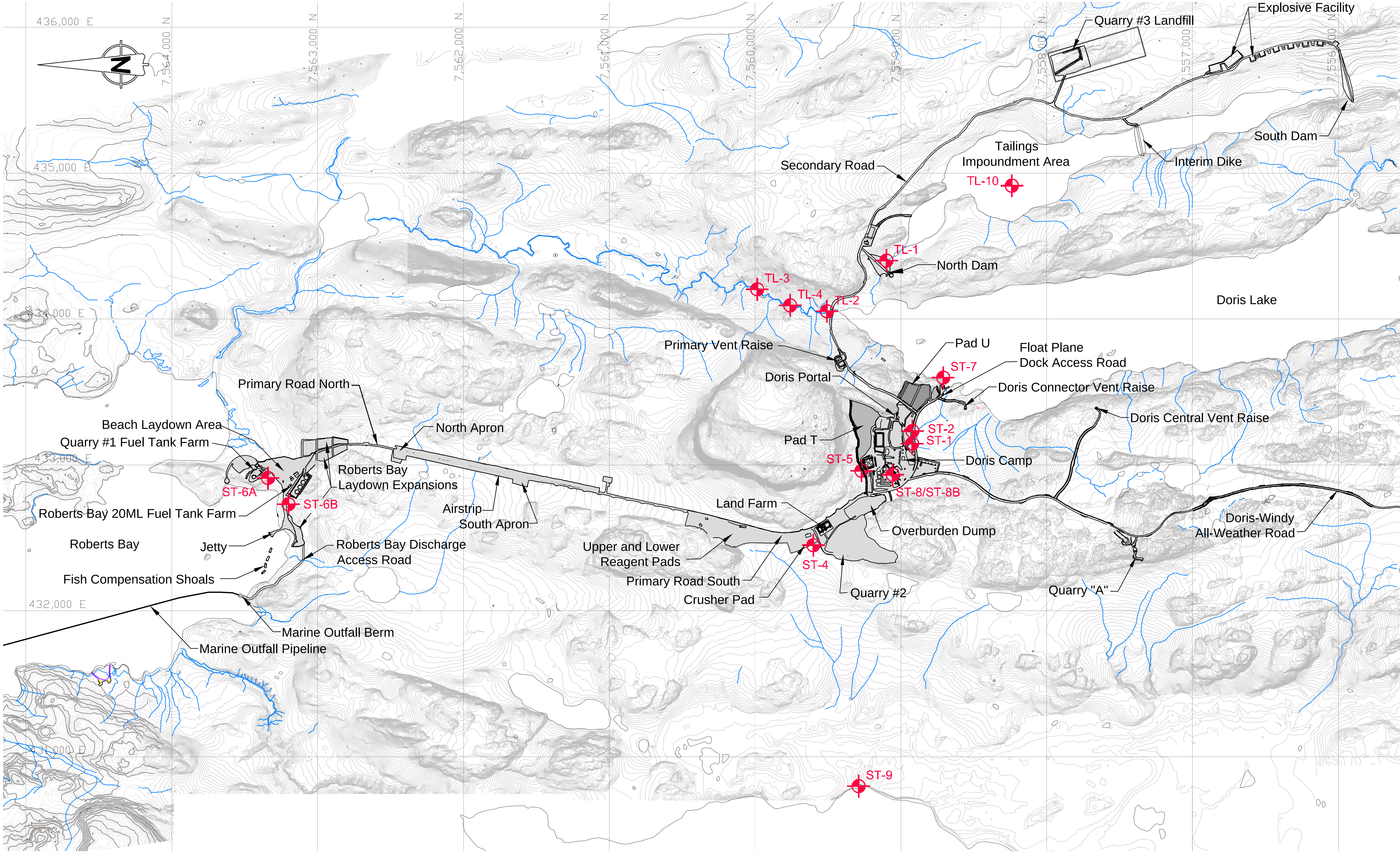

LEGEND

SNP Sample Stations

0 200 400 600 800 1000 Metres

srk consulting

SRK JOB NO.: 1CT022.002.200.700

FILE NAME: 1CT022.00_Fig 4-1.dwg

TMAC RESOURCES

Hope Bay Project

Water and Load Balance Model

Doris North SNP
Sample Stations

DATE:	APPROVED:	FIGURE:
June 2015	LW	4-1

c:\01_SITES\Hope Bay\TMAC 2014 Sample Sites\1CT022.00_Fig 4-1.dwg

4.2.3 Groundwater Inflows

Groundwater quality is based on results from Westbay Well data. The 75th percentile concentration from post-purging samples collected in zones 1, 6 and 10 of Westbay Well 10WBW001 were assumed to be representative of the groundwater quality of the Doris Central and Doris Connector zones (SRK 2015b).

Based on the groundwater prediction model, it was found that intercepted underground flows will be composed of water stored in the rock, Doris Lake and regional flows at the base of the talik. A mass balance was carried out to determine the expected concentration of intercepted water during mining. Table 4-2 provides a summary of the 95th percentile concentrations of the expected water quality, which were used as the input groundwater concentrations.

Table 4-2: Groundwater Source Term

Parameter	Concentration (mg/L)	Parameter	Concentration (mg/L)	Parameter	Concentration (mg/L)
Sulphate	1,900	Boron	2.8	Selenium	0.0019
Alkalinity	91	Cadmium	0.00012	Silicon	3.1
Chloride	18,000	Calcium	2,000	Silver	0.000097
Nitrate as N	0.93	Chromium	0.00086	Sodium	8700
Nitrite as N	0.098	Cobalt	0.0015	Strontium	27
Ammonia as N	3.4	Copper	0.0012	Tellurium	0.00048
TDS	39,000	Iron	4.7	Thallium	0.000086
Total CN as N	0.0036	Lead	0.00029	Thorium	0.00048
WAD as CN	0.0036	Lithium	0.34	Tin	0.036
Hardness	11,000	Magnesium	1,300	Titanium	0.0049
Aluminum	0.035	Manganese	1.7	Uranium	0.000089
Antimony	0.00095	Mercury	0.000049	Vanadium	0.00086
Arsenic	0.0024	Phosphorus	0.97	Zinc	0.15
Barium	0.12	Molybdenum	0.018	Zirconium	0.00048
Beryllium	0.00086	Nickel	0.0018		
Bismuth	0.00048	Potassium	240		

Source: <\\VAN-SVR0\Projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Analysis\Model_Results_GW_Flow_20150428_gf.xlsx>

In addition to the loading generated from the groundwater source term, 33% of the load from blasting residues associated with ore and waste rock is assumed lost to groundwater, and is added as a separate loading to groundwater (applicable only after the Central/Connector mining begins when groundwater is expected to be generated while mining in talik).

4.2.4 Process Water Effluent

Table 4-3 provides a summary of the process water chemistry included in the load balance. The source term is based on the historical geochemistry studies (SRK 2015a).

Table 4-3: Process Water Effluent Source Term

Parameter	Concentration (mg/L)	Parameter	Concentration (mg/L)	Parameter	Concentration (mg/L)
Sulphate	133	Boron	0.23	Nickel	0.013
Alkalinity	177	Cadmium	0.00050	Potassium	33
Nitrate as N	0.10	Calcium	127	Silver	0.015
Nitrite as N	0.15	Chromium	0.010	Sodium	137
Ammonia as N	0.40	Cobalt	0.0096	Strontium	0.27
Total CN as N	0.51	Copper	0.079	Thallium	0.00044
SCN as N	30	Iron	4.3	Thorium	0.00014
Aluminum	0.15	Lead	0.0027	Tin	0.046
Antimony	0.019	Lithium	0.021	Titanium	0.045
Arsenic	0.0079	Magnesium	17	Uranium	0.00039
Barium	0.20	Manganese	0.16	Vanadium	0.0027
Beryllium	0.00050	Phosphorus	1.2	Zinc	0.048
Bismuth	0.0012	Molybdenum	0.12		

Source: <\\VAN-SVR0\Projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\Mill Effluent WQ_Rev01_SPB.xlsx>

These parameters were used to calculate the discharge of tailings decant water during mine operations. The loading from the process water effluent was calculated from the process water flow at the above concentrations plus loading from the ammonium nitrate/fuel oil (ANFO) and brine associated with the processed ore (see Sections 4.2.10 and 4.2.11 for a description of these loadings). The nitrogen species present in the process water effluent source term are associated with cyanide. Nitrogen species from ANFO residues are not reflected in the source term and are accounted for with the ANFO load component.

4.2.5 Sewage Water

Concentrations of treated effluent discharged to the TIA during operations are based on typical performance estimates from packaged sewage treatment plants. Table 4-4 provides the estimated sewage concentrations applied to the sewage effluent of 42 m^3/day during operations and for one year after closure.

Table 4-4: Sewage Effluent Source Term

Parameter	Concentration (mg/L)	Parameter	Concentration (mg/L)
Ammonia as N	10	Iron	0.025
Nitrate as N	1.0	Lead	0.0001
Nitrite as N	30	Molybdenum	0.0001
Aluminum	0.052	Nickel	0.0005
Arsenic	0.0002	Phosphorus	1.0
Cadmium	0.0001	Uranium	0.0002
Chromium	0.0025	Zinc	0.002

Copper	0.0020		

Source: <\\VAN-SVR0\Projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\Inputs\Chemistry\Sewage_WQ.xlsx>

4.2.6 Exposed Tailings Beaches

Oxidation and weathering of the exposed tailings beach is expected to contribute to the release of soluble components into seepage and runoff that comes into contact with the tailings. These include major ions such as sulphate, alkalinity, calcium and magnesium, and trace elements such as arsenic. Source concentrations were estimated based on solute release rates derived from the geochemical testing programs (SRK 2015a), scaled to reflect differences between laboratory and field solute release rates and differences in flow conditions.

Due to the low permeability of the tailings, the majority of precipitation will flow over the surface of the tailings, and will only interact with the uppermost surface of the tailings. Therefore, for the purposes of estimating source concentrations, it was assumed that the upper 0.1 m of tailings would be fully exposed to oxidation and weathering, while tailings at depth would be close to saturation, and would not contribute significantly to solute release. It was further assumed that all of the soluble oxidation products from the upper 0.1 m of tailings would be released into solution. In reality, there will be physical and geochemical limitations on solute release from the uppermost 0.1 m of tailings, and there will also be some oxidation and release of solutes from the tailings at depth. Overall, the conservatism resulting from neglecting the limitations on solute release is thought to more than compensate for neglecting the potential contribution from tailings at depth.

Key steps in this calculation were: 1) determine the mass of solute released per hectare of exposed tailings under field conditions, and 2) divide the mass of solute released by the flow rate per hectare. The resulting concentrations were reviewed to assess whether any geochemical controls such as equilibrium with secondary minerals or attenuation were likely to be limiting concentrations. However, in general, the results were well below typical thresholds for these controls, and no further adjustments were made. Further details on the calculations are as follows:

- The humidity cell test results (SRK 2015a) for flotation tailings samples representing the Doris Connector (HC-57), Doris Central (HC-1), and Doris North (HC-66) zones of the deposit were compiled and used to calculate median laboratory solute release rates in units of mg/kg/week (Table A- 3 in Appendix A).
- Correction factors were applied to account for differences between laboratory and field conditions, as follows:
  - Temperatures were assumed to be approximately 5°C, while laboratory temperatures were in the range of 20°C. The effects of temperature on sulphide oxidation rates were determined using the Van’t Hoff–Arrhenius equation, assuming an activation energy of 70,000 J/mole. The calculations indicated that release rates could be reduced by a factor of five to account for the differences in temperature.
  - Other contact effects were not taken into consideration due to fine particle size and near surface exposure of this material.

- The above rates were converted from weekly to annual values.
- The median solute release rate for field conditions (mg/kg/yr) was calculated by multiplying the above correction factor of 0.2 by the laboratory release rates, and by the number of weeks in a year.
- Mass loading per hectare of exposed tailings was calculated by multiplying the volume of the uppermost 0.1 m of tailings (i.e. 0.1 x 100 x 100 m^3 = 1,000 m^3) by a density of 1.4 t/m^3, and then by the field based solute release rates.
- Runoff in contact with the tailings surface was assumed to be approximately 176 mm/year based on the average total precipitation and an assumed runoff coefficient. This was converted to a flow per hectare of exposed tailings of 1,760 m^3/yr.
- Concentrations were calculated by dividing the mass loading by flow. The resulting source concentrations for the tailings beach are provided in Table 4-5.

Table 4-5: Tailings Beach Source Term

Parameter	Concentration (mg/L)	Parameter	Concentration (mg/L)	Parameter	Concentration (mg/L)
Sulphate	39	Chromium	0.00055	Mercury	0.000016
Alkalinity	200	Cobalt	0.00051	Molybdenum	0.0056
Aluminum	0.14	Copper	0.0074	Nickel	0.0000034
Antimony	0.00088	Iron	0.044	Selenium	0.0011
Arsenic	0.022	Lead	0.0023	Silver	0.00026
Cadmium	0.000045	Magnesium	22	Uranium	0.000079
Calcium	51	Manganese	0.13	Zinc	0.0027

Source: \\VAN-SVR0\Projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\HB_Tailings_WQ_Pred_REV01_kss.xlsx

At closure, the tailings beach will be covered with 0.3 m of quarry rock. It is anticipated that the cover work will be begin at closure (April 2021) and be completed by December 2021. A source term for the covered tailings beach was derived by selecting the maximum of the tailings beach and surface infrastructure area source terms. As a result, there is no benefit from the cover applied in the load balance model. Instead, the cover incurs additional loadings where parameters in the surface infrastructure area source term are higher than those in the tailings beach source term. The concentrations applied to the tailings beach runoff were changed linearly over time between the start and completion dates of the cover application.

4.2.7 Surface Infrastructure Areas

Concentrations for surface infrastructure areas such as roads and mill pads were derived based on the 95th percentile concentrations from seepage data measured in 2013 and 2014 at non-waste rock impacted locations at Doris Wind and Doris North, as shown in Table 4-6.

Table 4-6: Surface infrastructure Area Source Term

Parameter	Concentration (mg/L)	Parameter	Concentration (mg/L)	Parameter	Concentration (mg/L)
Sulphate	27	Cadmium	0.000018	Potassium	2.7
Alkalinity	86	Calcium	33	Selenium	0.00030
Chloride	41	Chromium	0.00038	Silicon	1.6
Nitrate as N	1.3	Cobalt	0.00024	Silver	0.000010
Nitrite as N	0.088	Copper	0.014	Sodium	23
Ammonia as N	0.083	Iron	0.14	Strontium	0.073
TDS	170	Lead	0.00013	Tellurium	8.9
Aluminum	0.060	Lithium	0.0027	Thallium	0.000010
Antimony	0.00013	Magnesium	6.5	Tin	0.00010
Arsenic	0.0020	Manganese	0.066	Titanium	0.010
Barium	0.0077	Mercury	0.000010	Uranium	0.00033
Beryllium	0.00010	Phosphorus	0.050	Vanadium	0.0011
Bismuth	0.00050	Molybdenum	0.0010	Zinc	0.0051
Boron	0.047	Nickel	0.0024		

Source: \\VAN-SVR0\Projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\Loadings_Rev00_SPB.xlsx

4.2.8 Mine Site Collection Ponds

Water from sumps and ponds in the mine area is pumped to the TIA. The loadings from these ponds and sumps are driven by ore and waste rock stockpiles, which are discussed in the following section.

4.2.9 Ore and Waste Rock Stockpiles

Water in contact with waste rock and ore stockpiles is collected in mine site collection sumps and Pollution Control and Sedimentation ponds. This water is pumped and hauled to the TIA. Loadings from these sources were calculated using two methodologies depending on the timeframe.

Currently, there is approximately 183,000 tonnes of waste rock and 9,400 tonnes of ore onsite. This remained in place until April 2015, when mining resumed. After that date, additional waste rock and ore is being added to the stockpiles. For the period prior to April 2015, it was assumed that the loadings would remain as they have in the past. Loadings associated with water in contact with waste rock and ore stockpiles were calculated by multiplying the flow by the median concentrations measured at ST-2 from 2011 to 2014. The source concentrations applied in the model are provided in Table A- 4 (Appendix A).

Once new ore and waste rock is produced, additional loadings need to be incorporated. Source loadings per unit of rock mass (per day) for water in contact with the waste rock and ore stockpiles were derived based on existing monitoring data collected in the Pollution Control Pond 1 and Sedimentation Pond. The unit loading rates derived are provided in Table 4-7.

Table 4-7: Unit Loading Rates for Ore and Waste Rock Stockpiles

Parameter	Loading (mg/kg/day)	Parameter	Loading (mg/kg/day)	Parameter	Loading (mg/kg/day)
Sulphate	0.02	Cobalt	0.0000009	Potassium	0.00497
Aluminum	0.00002	Copper	0.0000015	Selenium	0.00497
Antimony	0.00000009	Iron	0.000070	Silver	0.00497
Arsenic	0.00000014	Lead	0.00000006	Sodium	0.08
Barium	0.000019	Lithium	0.000021	Thallium	0.00000004
Beryllium	0.0000002	Magnesium	0.01	Tin	0.000009
Boron	0.000049	Manganese	0.00016	Titanium	0.0000011
Cadmium	0.000049	Mercury	0.00000002	Uranium	0.0000002
Calcium	0.09	Molybdenum	0.00000002	Vanadium	0.0000002
Chromium	0.000001	Nickel	0.000001	Zinc	0.0000038

Source: \\VAN-SVR0\Projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\Loading_Calcs.xlsx

These loading rates apply to parameters where the source can be assumed to be unlimited and release rates are proportional to the rock mass present. For chloride and blasting residues, a finite mass of brine and ANFO are associated with the mass of rock produced. This mass is slowly released or “flushed” over time. These loadings were modeled as described in sections 4.2.10 and 4.2.11, and added to the loadings generated for the other parameters in Table 4-7.

4.2.10 Blasting and Drilling Residuals

Modeled blasting residues (ammonia, nitrite, and nitrate) applied to blasted rock placed as stockpiles on the surface were derived from the methods described by Ferguson and Leask (1988). The following equation and input parameters (Table 4-8) were included in the load balance to evaluate nutrient loading from blasting.

$$NH_4NO_3 - N = Wr * Pf * ANc * Nc * Rf$$

Where:

NH_4NO_3 – N = annual release of total ammonium nitrate as nitrogen

Wr = waste rock production

Pf = powder factor

ANc = fraction of ammonium nitrate in ANFO

Nc = fraction of nitrogen content in ammonium nitrate

Rf = residual nitrogen remaining

Table 4-8: Blast Residue Assumptions

Parameter	Label	Value
ANFO : NH_4NO_3	Anc	1 : 0.94
NH_4NO_3 : NH_4NO_3 as N	Nc	1 : 0.35
Surface Rock Powder Factor	Pf	0.40 kg ANFO / tonne rock
Underground Powder Factor	Pf	1.14 kg ANFO / tonne rock
Residual ANFO Factor*	Rf	5%
Annual Flush Rate		40%

Note: * The residual ANFO factor (1%) specified by Ferguson and Leask (1998) was increased by a factor of five.

The inventory of nitrogen loadings were tracked by accumulating the mass inflows and outflows and allowing 40% of the inventory to be flushed each year. This flushed mass was proportioned to ammonia, nitrate, and nitrite based on the following speciation of nitrogen in the blast residues: 37% ammonia, 60% nitrate, and 3% nitrite. The masses of nitrogen species released were added to the waste rock and ore stockpile contact water loadings and the processed ore loadings.

4.2.11 Brine Residuals

The Project will require the use of calcium chloride during mining. This will result in brine residuals on ore and waste rock stockpiles and in the ore processed in the mill. As with blasting residues, a finite mass of brine is associated with the rock or ore, and this mass flushes out over time.

A unit loading rate of 780 mg of chloride per kg of rock/ore was estimated based on shake flask data of waste rock from the Project. This was validated using release rates calculated from measured chloride in the mine site collection ponds (as measured at ST-2), based on the existing mass of rock and ore onsite and assuming a 20% annual flush rate. This rate was assumed to be the base case scenario where all mining is done using calcium chloride. For future mining, it is anticipated that some mining will be carried out using freshwater. Additionally, TMAC will be implementing a low salt drilling procedure, which will reduce the chloride on waste rock and ore. With that in mind, the loading rates shown in Table 4-9 were derived and applied in the model.

As with the ANFO residues, the mass of brine was tracked by modeling inflows and outflows. The inflows are based on the estimated concentrations and the mass of rock/ore produced, and the outflows are flushing and ore routed to the mill. The 20% flush rate applies only to the waste rock and ore stockpiles. For ore processed in the mill, it is assumed that 100% of the brine mass present in the ore is released to the mill, and subsequently the TIA. The ratios of calcium and chloride to brine ($CaCl_2$) are 0.36 and 0.64, respectively.

Table 4-9: Chloride Concentrations

Material	Location	Cl Concentration (mg/kg)	Reasoning
Waste Rock (on surface)	Permafrost	780	Base case calibrated numbers based on shake flask testing and model calibration
Waste Rock (on surface)	Talik	195	Plan to do all talik zone drilling with fresh water; Assume that 25% of that does not materialize
Ore	Permafrost	390	Plan to do all drifting and longhole upward holes with fresh water; Ratio of upwards vs. downward drilling about 50/50 (more efficient to do upwards); Bulk mining method will generally reduce contact with pooled brine, so no added conservatism applied
Ore	Talik	98	Plan to do all talik zone drilling with fresh water; Assume that 25% of that does not materialize

Source: Z:\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_ Water_License\700_Site_Wide_WQ_Model\Inputs\ Doris Amendment Mine Plan 15-02-04_Rev2_EMR_KPW with Chloride Flush.xlsx

4.2.12 Total Metals Concentrations

Estimates of total metals concentrations were made to allow comparisons of predicted water quality against water quality guidelines based on total metals. The predictions assume the solids are comprised of tailings solids and the total suspended solids (TSS) concentration is at the maximum of the monthly background water quality inputs. The total metals component is calculated by multiplying the assumed TSS by the loadings shown in Table 4-10.

Table 4-10: Total Solids Loadings for Tailings

Parameter	Loading (mg/kg)	Parameter	Loading (mg/kg)
Aluminum	13,820	Phosphorus	410
Antimony	1.1	Molybdenum	4.25
Arsenic	8.1	Nickel	37
Barium	82	Potassium	1,810
Bismuth	0.4	Selenium	0.82
Boron	14	Silver	0.39
Cadmium	0.16	Sodium	1,649
Calcium	28,050	Strontium	29
Chromium	146	Tellurium	0.25
Cobalt	9.5	Thallium	0.28
Copper	32	Thorium	0.18
Iron	35,510	Titanium	376
Lead	5.9	Uranium	0.088
Magnesium	11,800	Vanadium	35
Manganese	1,032	Zinc	63
Mercury	0.37	Zirconium	14

Source: Z:\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_ Water_License\700_Site_Wide_WQ_Model\Inputs\ Dissolved_to_Total_Hope_Bay_rev00.xlsx

4.2.13 Cryoconcentration

During the winter season, the model conservatively assumes that there will be 100% exclusion of parameters from the ice, resulting in higher concentrations in the water bodies. Cryoconcentration was applied to water bodies modeled as reservoirs in the load balance (TIA and Doris Lake).

A maximum ice thickness of 2.1 m was applied. Ice thickness was gradually increased from October to February and then gradually reduced to zero in June. During the TIA refilling period, to avoid discontinuities in the model where loads are divided by a small (or zero) water volume, the frozen volume in the TIA was limited to 50% of the TIA volume.

4.2.14 Degradation Reactions

Cyanide degradation (oxidation) occurs naturally, but can be enhanced by adding nutrients to promote biological activity (enhanced natural removal, ENR). Mass balance calculations on cyanide and intermediate degradation products can be used to estimate degradation rates.

SRK derived degradation rates for total cyanide (TCN), cyanate (OCN-), thiocyanate (SCN-), and ammonia (NH4+). There are four relevant degradation reactions for these species, which are summarized in Table 4-11. Other species involved in the reactions (such as sulphate and carbon dioxide) are omitted for clarity.

Table 4-11: Degradation Reactions and Relevant Species

No.	Degradation Reaction	Losing Species	Gaining Species
1	TCN degrades to OCN-	TCN	OCN-
2	OCN- degrades to NH4+	OCN-	NH4+
3	SCN- degrades to NH4+	SCN-	NH4+
4	NH4+ degrades to a variety of other forms of nitrogen	NH4+	Various N forms

SRK used mass balance data from the Colomac Mine[3] to estimate both natural and enhanced degradation rates. The masses of TCN, OCN-, SCN-, and NH4+ in the Colomac tailings lake had been calculated periodically before adding nutrients (2000 and 2001) and after adding nutrients (2002 and 2003), so it was possible to calculate the net change in mass for each of these species (SRK 2004).

To determine degradation rates, SRK performed the following calculations:

- The masses of TCN, OCN-, SCN-, and NH4+ from the Colomac dataset were converted to an equivalent mass on a nitrogen basis (e.g., TCN as N) to easily track mass changes between species.
- The total change in mass (on a nitrogen basis) for each species was calculated for each of the four years of data. The losses of TCN and SCN- were straightforward, but OCN- and NH4+ are both degradation products from other species and are themselves degraded.

[3] Colomac Mine, Closed Mine (1997), Northwest Territories

- The total mass change for each species was divided by the duration to calculate daily rates of mass change (in tonnes as N per day), which were then converted to daily rates of mg/m^2/day using the area of the Colomac tailings lake.
- The lowest degradation rates were extracted to represent enhanced degradation and the average of observed rates were selected to represent natural degradation (Table 4-12).
- In the Doris North water and load balance model, natural degradation rates were used.

Table 4-12: Summary of Degradation Rates

Parameter	Enhanced Degradation Rate	Natural Degradation Rate	Units
TCN-N	-291	**-218**	mg/m^2/day
CNO-N	-439	**-300**	mg/m^2/day
CNS-N	-1033	**-674**	mg/m^2/day
NH4-N	-1113	**-249**	mg/m^2/day

Source: \\VAN-SVR0\Projects\01_SITES\Back River\1CS020.006_FS_Study\!020_Project_Data\010_SRK\Water Balance\WaterQuality\Ndegradation rates 20141230 for use in Back River_LMC.xlsx

5 Model Implementation

5.1 Version

The water and load balance model for the Project was developed using the GoldSim software package (version 11.1.2).

5.2 Modelling Approach

The water and load balance model for the Doris North Project was run from 2010 to 2035 on a daily time step. The run time was selected to cover multiple phases, including a calibration period from 2010 to 2014 (Years -7 to -3), mine operations from 2015 to 2021 (Years -2 to 5), closure in 2021 and post-closure. Post-closure conditions were modeled 15 years after closure.

The water balance was run using probabilistic simulations, with multiple realizations and variable hydrology. During the calibration period, available measured climate and flow data were applied, including flows reporting to the TIA from mine site collection ponds and discharge to Doris Creek. For future predictions, climate data was generated based on the historical record, with discharge predicted based on empirical rating curves and/or pumping capacities.

The load balance was run as a deterministic simulation under average hydrological conditions. This is consistent with the application of source terms derived based on an average hydrological year.

5.3 Model Calibration

The model was run from 2010 to 2014 to provide a calibration period. The TIA was used for calibration purposes as it has a number of measured parameters, including elevations, pumped inflows and pumped discharge. The known measured parameters were input in the model to reduce the number of unknowns. The measured elevation in the TIA at the start of the modeling period was applied. Measured climate inputs were used to generate runoff and the measured volumes pumped and hauled to the TIA from mine site collection ponds and discharged from the TIA to Doris Creek were applied.

Assuming the measured inputs are relatively accurate, this allowed the unknown parameters to be confined to uncontrolled inflows and outflows, which are direct precipitation on the pond surface, catchment runoff and evaporation. The comparison between predicted and measured elevations in the TIA was used to gauge the model calibration. The snowmelt model parameters and runoff coefficients were adjusted to obtain the optimum agreement between predicted and measured elevations. Additionally, sensitivity analyses were run on other variables, such as the source of lake evaporation and rainfall data. The results of the model calibration are presented in Section 6.1.

5.4 Limitations

Limitations of the model include:

- The water balance was calibrated based on measured data collected at the site. Any errors in this data would directly affect the reliability of the model calibration.
- Solubility limits have not been applied in the model. Consequently, some parameters may precipitate prior to reaching the modeled concentrations.
- Although degradation of some parameters was modeled, geochemical factors such as attenuation along flow paths and removal of loads in storage facilities are not simulated.
- The model assumes fully mixed conditions and instantaneous mixing, which may not occur in the facilities modeled.
- During ice conditions, the model simulates 100% exclusion of parameters from the ice, causing a cryoconcentration of parameters in the winter. As there is no available chemistry data measured at the site in the winter, this simulated phenomenon cannot be validated. The assumptions are conservative and may result in an over-prediction of parameters in the winter.
- Total metals are calculated assuming the total solids in the TIA are comprised of tailings solids from the tailings beach and based on the maximum background TSS of 5.9 mg/L. In reality, the TSS will vary. Additionally, the configuration of the TIA will allow for solids to settle out, with approximately 1.5 km from the edge of the tailings beach to the lake outflow and the Interim Dike separating the beach from the Recycle Pond. Therefore, total metals concentrations are likely to be conservative.

5.5 Water Quality Objectives

The objectives of the water and load balance model are to predict water quality in the TIA and the effluent from the Marine Outfall Mixing Box.

Current operations are regulated under Water License No 2AM-DOH1323, which includes specifications relating to discharge from ponds and the TIA, and water quality limits in Doris Creek. The water quality limits for the TIA and at TL-3 are shown in Table 5-1.

Table 5-1: Water License Water Quality Limits

Parameter	TIA Effluent Discharged to TL-4		TL-3
	Maximum Average Concentration (mg/L)	Maximum Concentration of Any Grab Sample (mg/L)	Maximum Concentration of Any Grab Sample (mg/L)
pH	Between 6.0 – 9.5	Between 6.0 – 9.5	Between 6.0 – 9.0
TSS	15.00	30.00	15.0
Total Oil and Grease			5
Chloride			150
Free Cyanide			0.005
Total Cyanide	1.00	2.00	0.010
Biological Oxygen Demand	80	160	
Fecal Coliform	10,000 CFU/100 mL	10,000 CFU/100 mL	
Radium 226	0.37 Bq/L	1.11 Bq/L	
Total Ammonia-N	6		1.54
Nitrate N			2.9
Nitrite N			0.060
Total Aluminum			0.100
Total Arsenic	0.50	1.00	0.0050
Total Cadmium			0.000017
Chromium (VI)			0.0010
Total Copper	0.30	0.60	0.002
Total Iron			0.300
Total Mercury			0.000026
Total Molybdenum			0.073
Total Nickel	0.50	1.00	0.025
Total Lead	0.20	0.40	0.001
Total Selenium			0.0010
Total Silver			0.0001
Total Thallium			0.0008
Total Zinc	0.50	1.00	0.030

Source: 20130816 2AM-DOH1323 Licence.pdf

Marine water quality guidelines from the following jurisdictions were compiled to evaluate the water quality requirements for a proposed discharge from the Marine Outfall Mixing Box to the marine environment for the Project:

- Canadian Council of Ministers of the Environment (CCME) water quality guidelines for the protection of marine aquatic life (CCME 2015).

- Metal Mining Effluent Regulations (MMER) water quality limits for deleterious substances discharged at the end of the Marine Outfall Pipeline (MMER 2015).

Preference was given to the CCME marine guidelines. Table 5-2 provides a summary of proposed water quality guidelines for the discharge from the Marine Outfall Mixing Box (i.e. MMER guidelines) and for the protection of aquatic life within Roberts Bay (i.e. CCME guidelines).

Table 5-2: Marine Water Quality Guidelines

Parameter	Units	MMER	CCME
pH		6 to 9.5	7.0 to 8.7
Total Suspended Solids (TSS)	mg/L	15	
Total Cyanide	mg/L	1	
Salinity	%		10% change
Nitrate Nitrogen (N)	mg/L as N		16
Arsenic (As)	mg/L	0.5	0.0125
Cadmium (Cd)	mg/L		0.00012
Chromium (Cr III & Cr VI)	mg/L		0.0575
Copper	mg/L	0.3	
Lead	mg/L	0.2	
Mercury	mg/L		0.000016
Nickel	mg/L	0.5	
Zinc	mg/L	0.5	
Radium	Bg/L	0.37	

Sources: CCME 2015, MMER 2015

Post-closure predicted water quality in the TIA after it refills was compared to the CCME water quality guidelines for the long-term protection of freshwater aquatic life (CCME 2015), shown in Table 5-3. A hardness value of 40 mg/L was used to calculate hardness-based guidelines, which is the minimum monthly hardness from the background water quality data (measured at TL-2). Comparisons between post-closure TIA water quality and CCME guidelines were made for reference purposes only. The CCME guidelines apply to natural watercourses, while the TIA is a permitted tailings impoundment facility.

Table 5-3: CCME Water Quality Guidelines for the Long-term Protection of Freshwater Aquatic Life

Parameter	Units	Guideline
Free_CN	mg/L	0.005
Chloride	mg/L	120
Ammonia	mg/L as N	1.54 (at pH 7.5, temperature 20°C)
Nitrate_N	mg/L as N	13
Nitrite_N	mg/L as N	0.06
Aluminum	mg/L	0.10
Arsenic	mg/L	0.005
Boron	mg/L	1.5
Cadmium	mg/L	0.000070
Chromium (VI)	mg/L	0.001
Copper	mg/L	0.002
Iron	mg/L	0.30
Lead	mg/L	0.001
Mercury	mg/L	0.000026
Molybdenum	mg/L	0.073
Nickel	mg/L	0.025
Selenium	mg/L	0.0010
Silver	mg/L	0.0001
Thallium	mg/L	0.0008
Uranium	mg/L	0.015
Zinc	mg/L	0.030

Source: CCME 2015

6 Results and Discussion

6.1 Context

The water and load balance model for the Doris North Project was run from 2010 to 2035 on a daily time step. This run time covers multiple phases, including a calibration period from 2010 to 2014 (Years -7 to -3), mine operations from 2015 to 2021 (Years -2 to 5), closure in 2021 and post-closure. Post-closure conditions were modeled 15 years after closure.

The water balance was run using probabilistic simulations, with multiple realizations and variable hydrology. The load balance was run as a deterministic simulation under average hydrological conditions. This is consistent with the application of source terms derived based on an average hydrological year.

6.2 Water Balance Results

6.2.1 Tailings Impoundment Area

During operations, the TIA inflows include direct precipitation, catchment runoff, tailings beach runoff, grey water, mill effluent, water from mine site collection ponds, and tailings solids. After closure, water will continue to be pumped from the mine site collection ponds until the site is reclaimed, which is expected to be completed by December 2021. Runoff from the mine area, which is within the Doris Lake catchment, would then report back to Doris Lake. The only post-closure inflows are direct precipitation and runoff from the catchment and tailings beach.

The predicted mean total annual inflows to the TIA are shown on Figure 6-1. Direct precipitation and runoff inflows are on average 500,000 m^3/year, which is reflective of post-closure flows. During operations, the mill effluent increases from approximately 450,000 m^3/year to 900,000 m^3/year when the milling rate reaches its maximum. The mill effluent total in the last year (2021) is based on four months of milling, with closure in April 2021. The total inflow to the TIA during operations increases to approximately 1.5 million m^3/year (mean results) in the last two years of operations.

Outflows from the TIA include pond evaporation, mill reclaim (during operations), and discharge to Doris Creek, Roberts Bay and the Tail Lake Outflow channel. The predicted mean total annual outflows from the TIA are shown on Figure 6-2. The mean total annual discharge to Roberts Bay is approximately 500,000 m^3/year during operations. This increases at closure when the TIA is dewatered with year-round pumping to just under 1.5 million m^3/year (mean results).

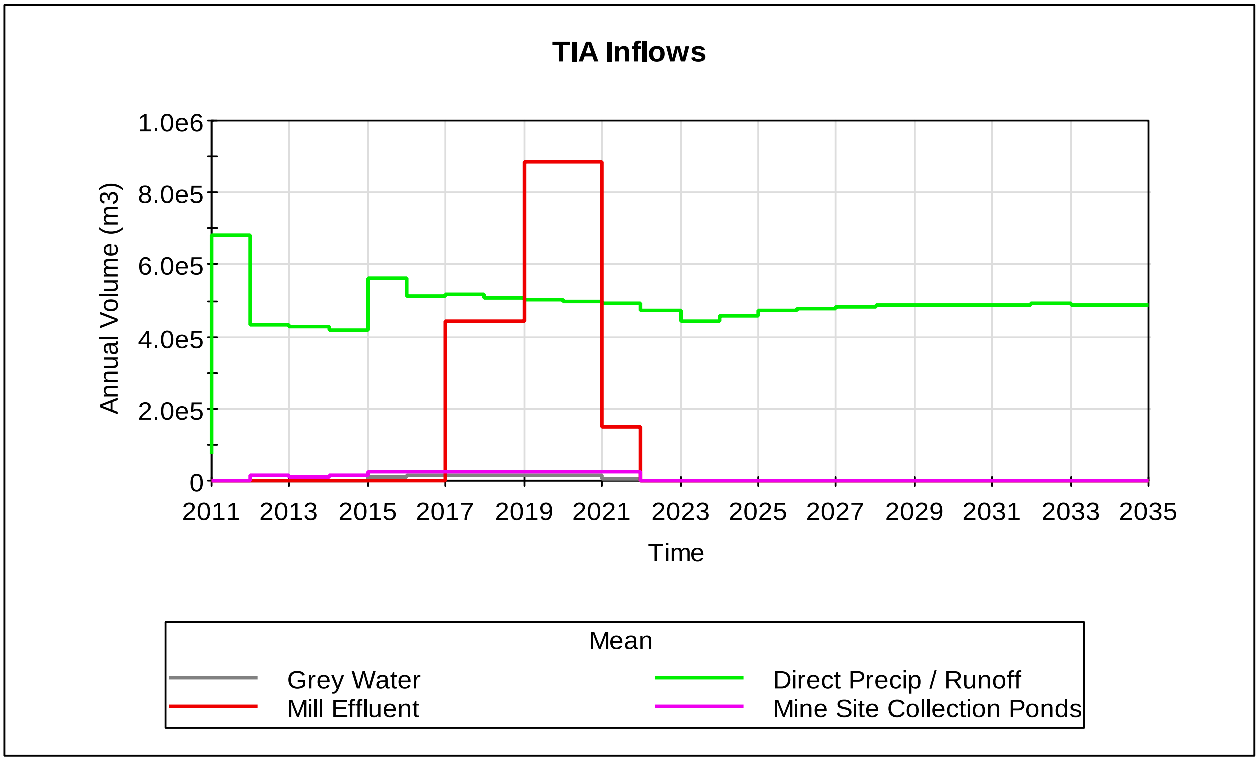

Figure 6-1: Total Mean Annual Inflows to the TIA

Source: \\Van-svr0\projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\HopeBay_WLBalance_TypeA_Rev19_SPB_KPW.gsm

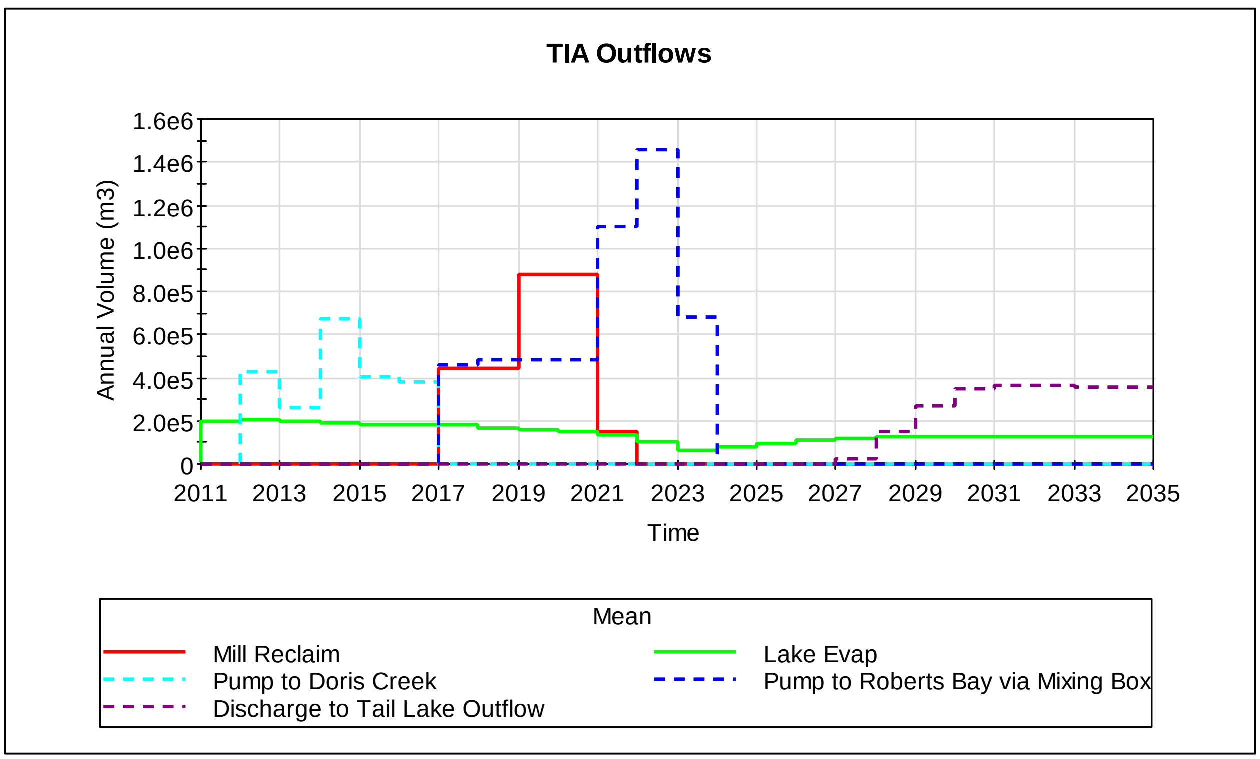

Figure 6-2: Total Mean Annual Outflows from the TIA

Source: \\Van-svr0\projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\HopeBay_WLBalance_TypeA_Rev19_SPB_KPW.gsm

Water levels in the TIA are currently maintained by pumping to Doris Creek during the open water season, which will continue until 2016. Discharge is limited to the allowable discharge, which is 10% of the background flow in Doris Creek (TL-2), or the pumping capacity, whichever is smaller. During the calibration period, the measured discharge rates to Doris Creek were applied.

The predicted elevations in the TIA are shown alongside measured elevations in Figure 6-3[4]. The input hydrological parameters such as runoff coefficients and snowmelt factors were calibrated to optimize the agreement between predicted and measured elevations.

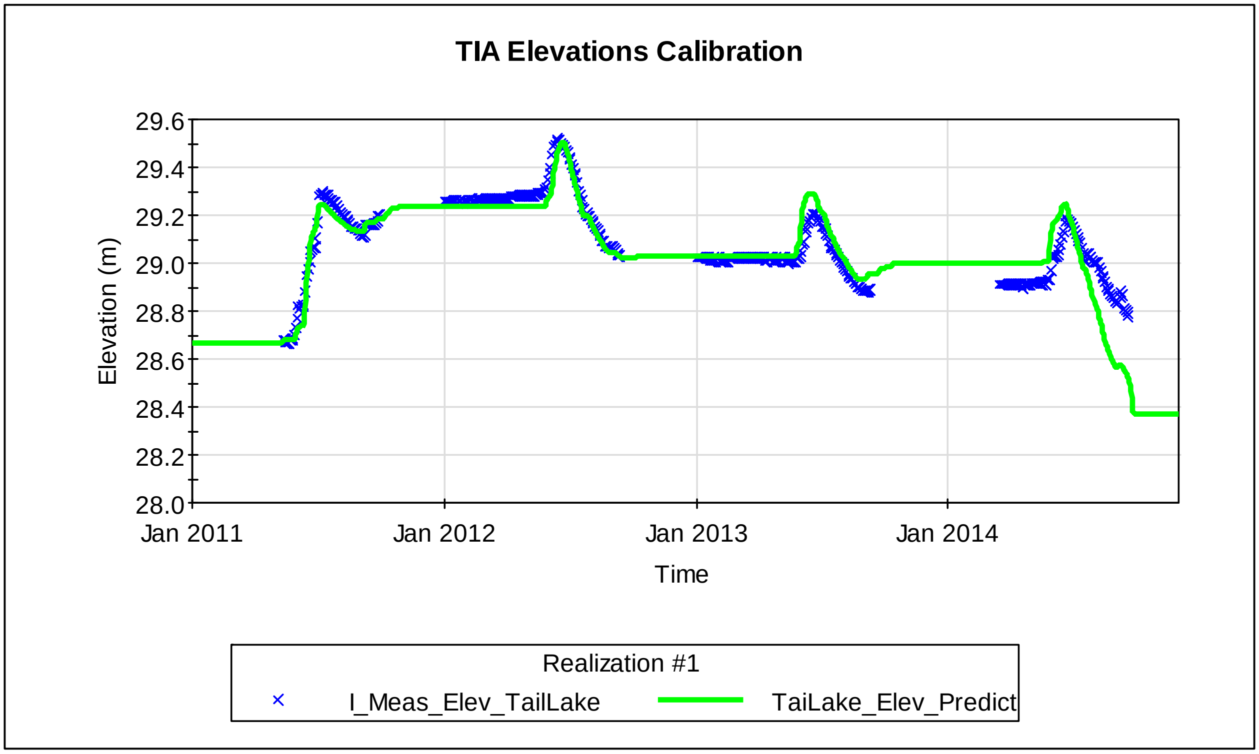

Figure 6-3: Predicted and Measured TIA Elevations

Source: \\Van-svr0\projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\HopeBay_WLBalance_TypeA_Rev19_SPB_KPW.gsm

Under predictive conditions, discharge to Doris Creek is assumed to be the allowable discharge up to a pumping capacity of 0.14 m^3/s. Discharge ceases when the target elevation of 28.3 m is reached or the open season ends. The allowable discharge to Doris Creek is calculated as 10% of the background discharge from Doris Lake using a baseline model of Doris Lake.

Beginning in 2017 when the mill comes online, water from the TIA will be discharged to Roberts Bay during the open water season via the Marine Outfall Mixing Box at an average rate of 4,000 m^3/day. The rate was selected to ensure that water demands for the mill could be met year-round and that sufficient water depth is available for proper operation of reclaim barge pumps, particularly during the winter when ice forms. This results in an accumulation of water above the natural elevation of 28.3 m during the operational period.

[4] Measured elevations are provided as relative measurements that are not referenced to a geodetic datum. The values shown have been adjusted based on a factor derived from a coincident surveyed elevation of the water elevation in the TIA.

At closure, the TIA will be dewatered to Roberts Bay to accelerate improved water quality. Discharge will occur year-round at a rate of 4,000 m^3/day. It is estimated that the TIA will be drawn down to a target elevation of 23 m (approximately 1 m from the bottom of the impoundment) in 2023 (Year 7).

Once the TIA refills, natural discharge to the Tail Lake Outflow channel will resume by breaching the North Dam, provided the water quality meets the applicable guidelines and/or license limits. Under average hydrological conditions, it is expected to take until 2028 (Year 12) for the water level to reach an elevation of 28.3 m. Predicted discharge after this time was maintained at 10% of background flows at Doris Creek (TL-2) without the limitation of pumping capacity as discharge will be natural.

The probabilistic results of the predicted elevations are provided in Figure 6-4. The increase in elevation during operations can be seen, where water is accumulated for operational requirements. The drawdown begins at closure in April 2021. Once the elevation reaches 23 m, dewatering ceases and the TIA is allowed to refill.

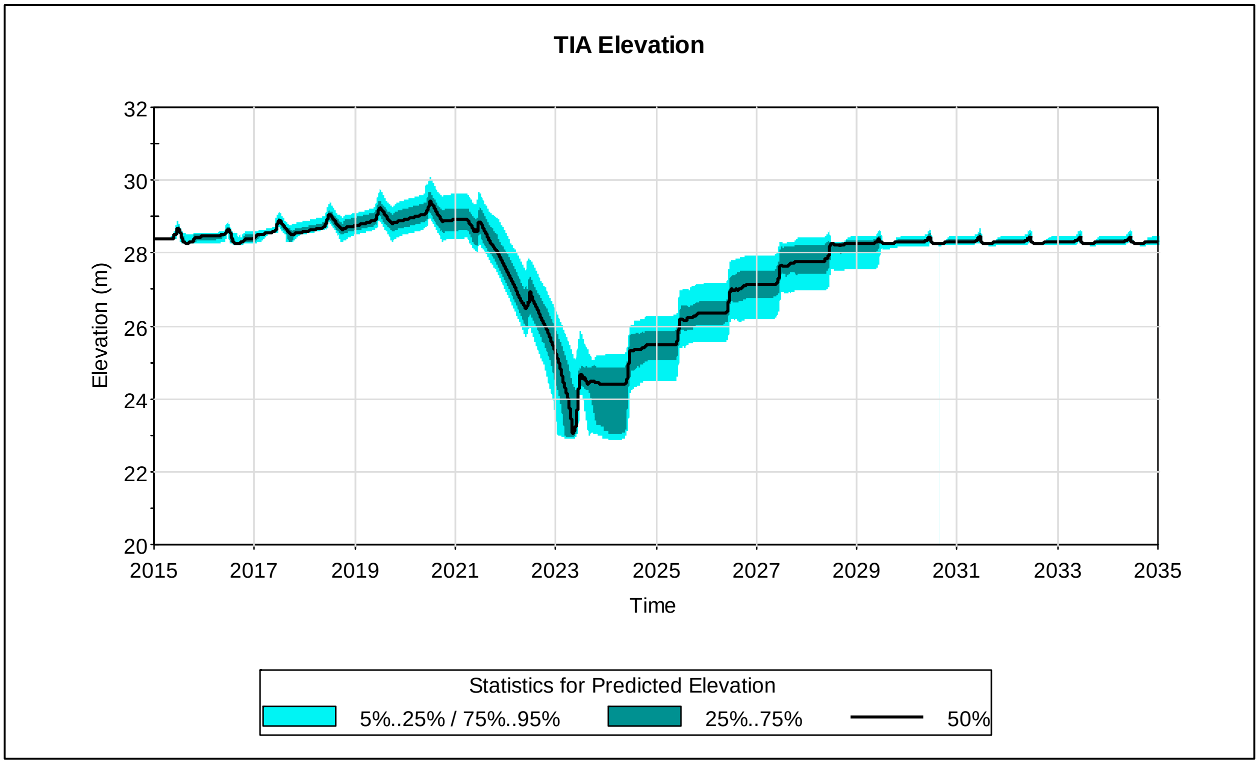

Figure 6-4: Predicted TIA Elevation – Probabilistic Results

Source: \\Van-svr0\projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\HopeBay_WLBalance_TypeA_Rev19_SPB_KPW.gsm

The sequencing of discharge can be seen in Figure 6-5, which shows the mean monthly discharge from the TIA to Doris Creek, Roberts Bay and the Tail Lake Outflow channel. Discharge to Doris Creek occurs in 2015 and 2016, followed by discharge to Roberts Bay commencing in 2017. Discharge occurs in open water season in the production years, and subsequently year-round during the dewatering period from 2021 to 2023, when water is pumped continuously to Roberts Bay. After the TIA refills, natural discharge to the Tail Lake Outflow channel resumes in 2028.

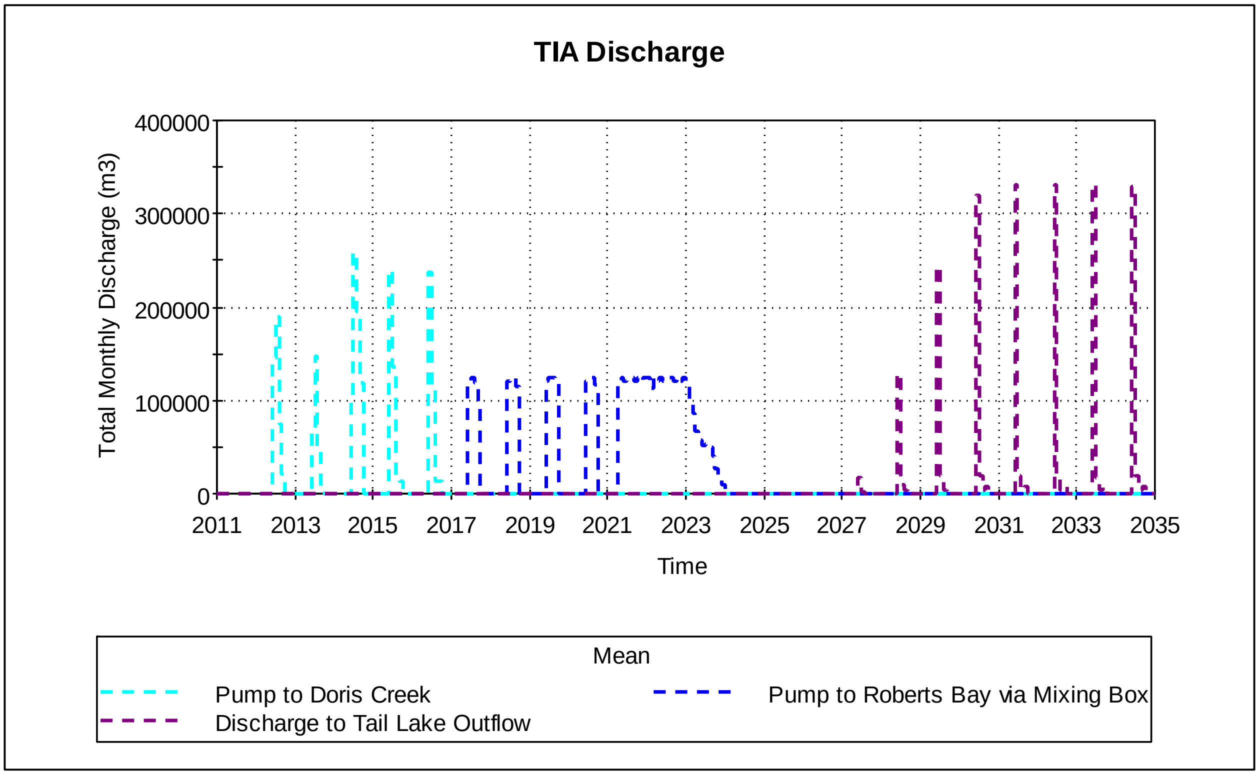

Figure 6-5: Mean Monthly Discharge from TIA

Source: \\Van-svr0\projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\HopeBay_WLBalance_TypeA_Rev19_SPB_KPW.gsm

Table 6-1 shows the 5th percentile, mean and 95th percentile results from the multiple model runs for annual TIA discharge volumes and total volume dewatered to Roberts Bay. The multiple runs under variable hydrology do not result in significantly different volumes of water pumped to Roberts Bay during operations due to the constant pumping rate of 4,000 m^3/day.

Table 6-1: TIA Discharge and Dewatering Volumes

Statistic	Discharge to Doris Creek Pre- Operations	Discharge to Roberts Bay During Operations	Discharge to Tail Lake Outflow Post-Operations	Total Dewatering Volume
	m^3/year	m^3/year	m^3/year	m^3
5th Percentile	270,000	475,000	220,000	2.6 million
Mean	400,000	490,000	365,000	3.1 million
95th Percentile	510,000	490,000	495,000	4.1 million

Source: \\Van-svr0\projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\HopeBay_WLBalance_TypeA_Rev19_SPB_KPW.gsm

6.2.2 Doris Lake

Calibration of the Doris Lake model was not possible. Water elevations are measured due to a relative reference, which is not a geodetic datum, and there was no surveyed data available at the time this document was prepared to adjust the relative elevations. Additionally, relative elevation measurements were only available in 2014 beginning at the end of July. Volume-elevation data, which is used to estimate elevations based on predicted volumes in the lake, are based on elevations referenced to mean sea level. Consequently, an initial elevation at the start of the modeling period was assumed, and the calibrated hydrology factors derived for Tail Lake were applied to Doris Lake.

The inflows to Doris Lake are precipitation and catchment runoff, and inflows from the Tail Lake Outflow channel after closure, once water quality in the TIA meets the applicable guidelines and/or license limits. Outflows include lake evaporation, industrial use, freshwater for the mill, and drawdown due to groundwater recharge, which is expected to occur during mining. The project affected flows occur only during milling, from 2017 to 2021 (Years 1 to 5). Figure 6-6 shows the predicted total annual inflows and outflows for Doris Lake. Outflows are represented by dashed lines.

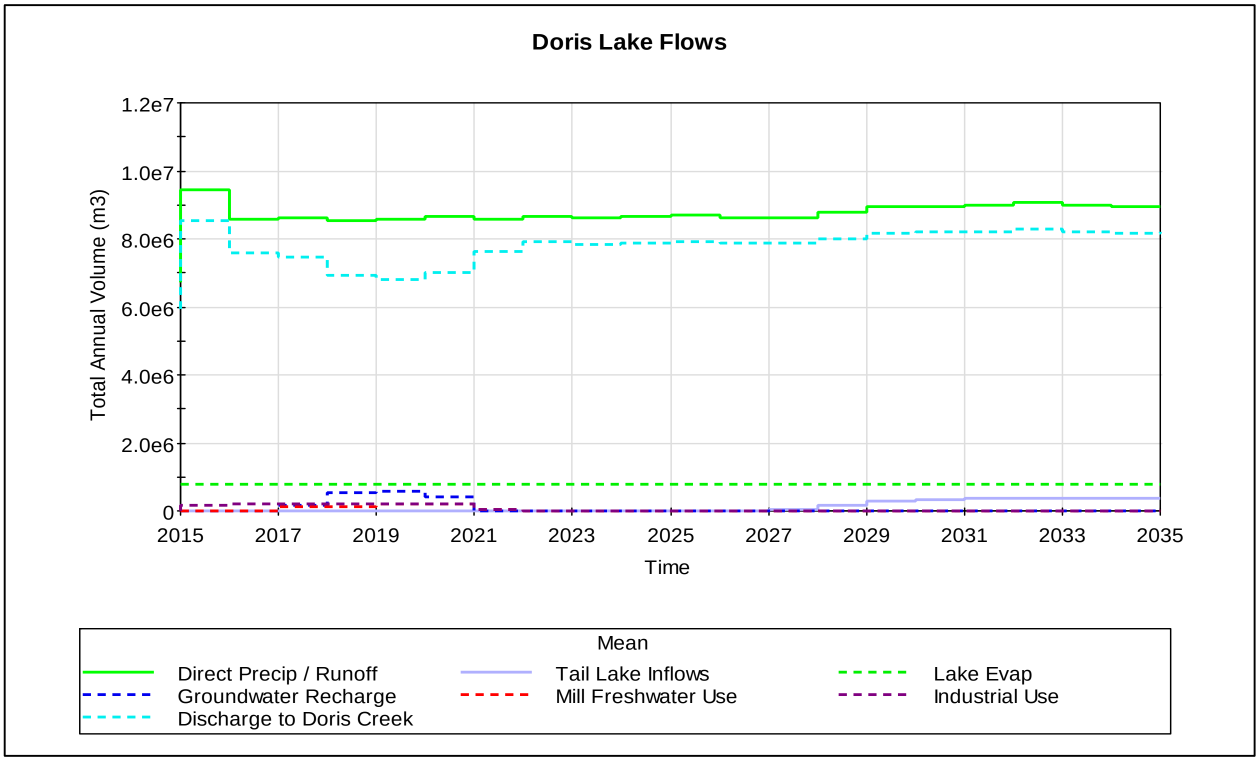

Figure 6-6: Doris Lake Mean Inflows and Outflows

Source: \\Van-svr0\projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\HopeBay_WLBalance_TypeA_Rev19_SPB_KPW.gsm

Discharge from Doris Lake to Doris Creek was estimated based on an empirical relationship between the measured height of the water in Doris Lake above the Doris Creek invert and measured discharge. The height above the invert was estimated assuming the invert is at an elevation of 21.5 m based on recent LIDAR data.

The withdrawals during operations result in a slight reduction in discharge from Doris Lake to Doris Creek. On average, these withdrawals constitute less than 10% of baseline discharge from Doris Lake. This results in a slight drawdown in the lake below the invert elevation of 21.5 m during the winter. The probabilistic results for the predicted Doris Lake elevations are shown on Figure 6-7. The predicted drawdown below the Doris Creek invert elevation of 21.5 m is shown on Figure 6-8, where the drawdown (in m) is calculated as shown below:

$$Drawdown = Minimum\ [(Elevation\ in\ Doris\ Lake - Doris\ Creek\ Invert\ Elevation), 0]$$

As shown in Figure 6-8, the predicted drawdown during operations is less than 0.20 m. The maximum withdrawal is expected to occur in 2019 (Year 3) when the groundwater recharge and freshwater demand peak.

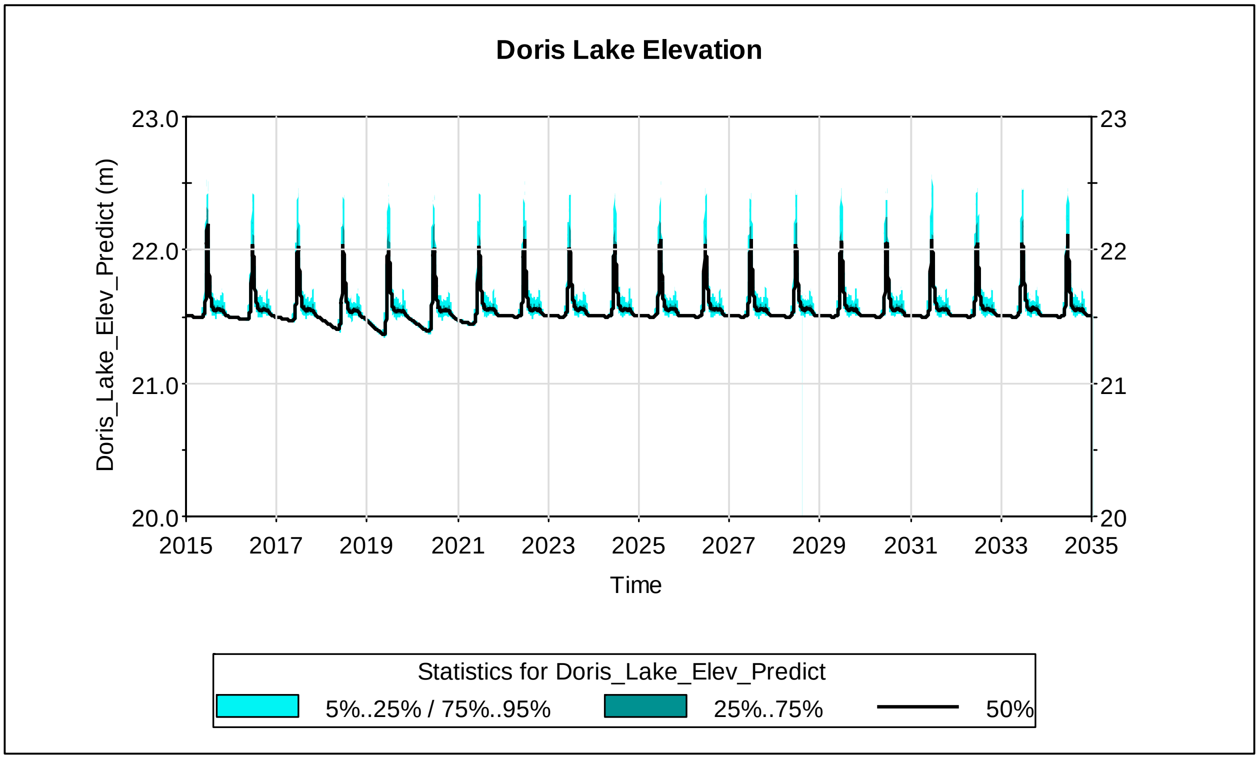

Figure 6-7: Predicted Doris Lake Elevation – Probabilistic Results

Source: \\Van-svr0\projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\HopeBay_WLBalance_TypeA_Rev19_SPB_KPW.gsm

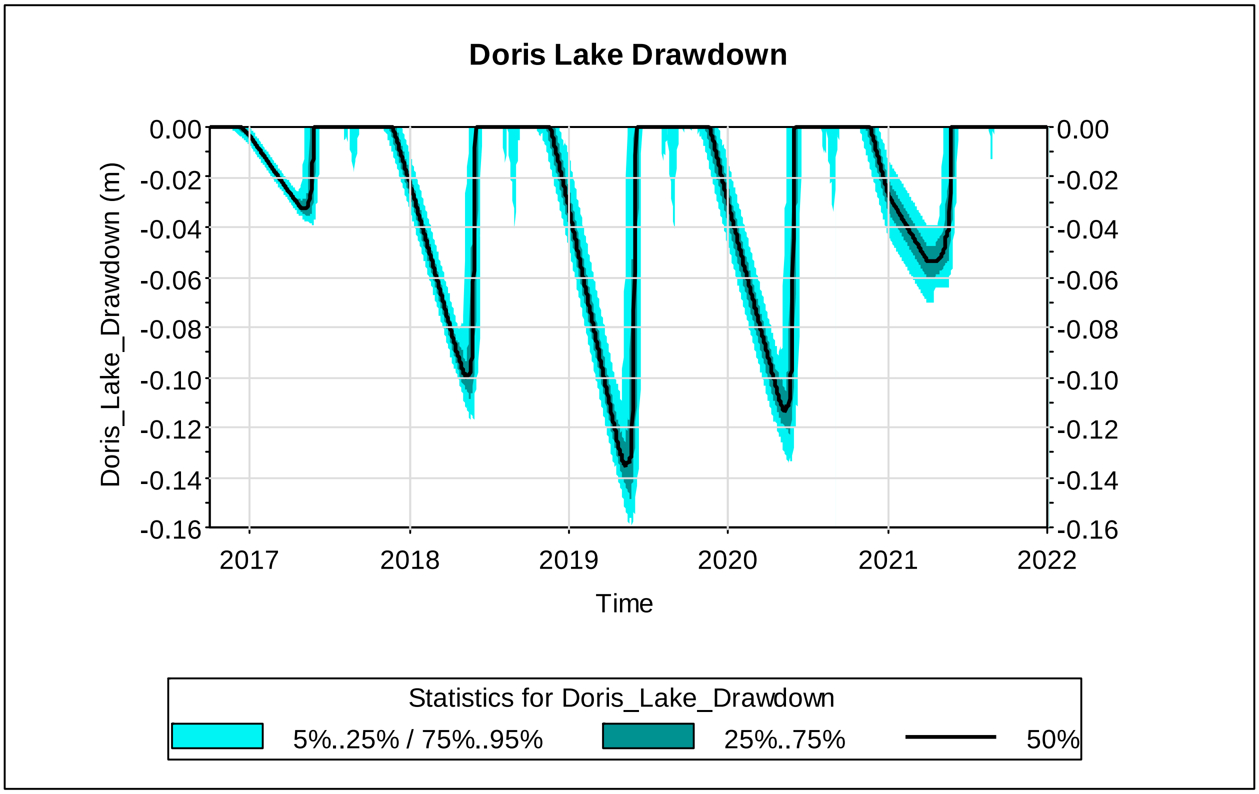

Figure 6-8: Predicted Drawdown Doris Lake – Probabilistic Results

Source: \\Van-svr0\projects\01_SITES\Hope.Bay\1CT022.002_2015_Hope Bay Ongoing Support\200_Type_A_Water_License\700_Site_Wide_WQ_Model\Model\HopeBay_WLBalance_TypeA_Rev19_SPB_KPW.gsm

6.2.3 Roberts Bay Outfall

Once milling begins, water from the TIA and groundwater collected in underground sumps will be pumped to the Marine Outfall Mixing Box, where the flows will be combined and discharged to Roberts Bay. Groundwater will be pumped to the Mixing Box at a rate of 3,000 m^3/day when sump capacities have been met. Water will be pumped from the TIA to the Mixing Box at a rate of 4,000 m^3/day during the open water season.

Consequently, discharge from the Mixing Box to Roberts Bay during operations is expected to range from 3,000 m^3/day when only groundwater is pumped to 7,000 m^3/day when both groundwater and TIA water are pumped simultaneously.

At closure, as noted previously, if TIA water quality does not meet the applicable criteria for discharge to Doris Creek, it will be dewatered. Dewatering flows will be pumped year-round from the TIA to the Mixing Box at a rate of 4,000 m^3/day until the target elevation is reached. Groundwater collection will cease at closure and will no longer be pumped to the Mixing Box.