Red Dog Mine
Closure and Reclamation Plan

Supporting Document E
Water Management

Red Dog Mine
Closure and Reclamation Plan

SD E1: Red Dog Water and Load Balance

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Memo

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1 Introduction

An annual water and load balance model for the Red Dog tailings impoundment was developed to estimate future water quality and water treatment requirements in support of the development of the Red Dog Mine Closure and Reclamation Plan and to assess potential impacts to hydrology and water quality associated with mining the Aqqaluk deposit.

The specific objectives of the water and load balance were to:

- Estimate the annual water treatment discharge rates required to handle inflow to the impoundment (to closure and beyond) and to reduce the water depth to a two-foot water cover by closure;
- Estimate the amount of contaminants originating from each source contributing to the tailings impoundment and future concentrations in the pond;
- Examine the impact of increases in the surface area of the tailings impoundment and the Main Waste Stockpile, and the development of the Aqqaluk and Qanaiyaq Pits;
- Examine the effects on pond water quality of treating water directly from the Main Waste Stockpile, the Mine Sump and potentially from the dam seepage pumpback;
- Examine the effects on pond water quality of implementing progressive reclamation;
- Estimate the effects of a premature closure of the mine in 2012.

Two scenarios are presented; one assuming a premature closure in 2012 and one with closure planned for 2031. The results of the model are approximate projections only. Both the timing and the degree of changes in water quality predicted by the model may vary from those actually observed over time. The changes the model predicts may occur more slowly than the results show. In addition, secondary mineral controls such as the precipitation of gypsum in the tailings pond could result in lower concentrations in the tailings impoundment than the model predicts.

2 Model Description

2.1 Structure

The annual water and load balance was created in a Microsoft Excel workbook. The model simulates the flows and loads into and out of the tailings impoundment using average annual flow rates and chemical concentrations. The chemical constituents included in the calculations are zinc, cadmium, sulfate and TDS[1]. Other constituents can be incorporated as required. The load balance portion of the model multiplies flow rates and concentrations to estimate the loadings of each constituent and then calculates the new concentration in the pond on an annual basis.

The workbook contains several sheets of input data, including a volume-elevation curve, tailings volume information, surface areas used to determine flows, measured flow rates, precipitation and evaporation data, measured impoundment water elevations, chemistry of the various sources of water and a sub-model for WTP3 which calculates the amount of flow that can be treated given certain operating restrictions. The water balance portion of the model is located on a sheet called "Water Balance". The load balances for each chemical parameter are on separate sheets named "Loads-parameter name". The "Scenarios" sheet is used to change the variables in the water and load balance sheets. A sheet called "Figure" provides a schematic of the various flows into and out of the pond. The "Results" sheet summarizes the concentrations in the pond, water treatment flows and loads, and water discharge requirements. It also contains plots of the water level, tailings elevations and pond concentrations. Finally, the "Pit" sheet is a simplified water and load balance for the Aqqaluk Pit (or Main Pit for the 2012 closure scenario), which includes estimates of concentrations in the pit.

The model starts in 1999, to allow it to be calibrated against existing data, and runs beyond closure until 2081, by which time the model indicates that the water quality in the pond has stabilized. The model runs from May 01 to April 30 of each year. The starting month of May was used to be consistent with the water discharge season, which begins in May.

The current version of the model includes data up to April 30 2006. Therefore, 2005 is the last year that contains up-to-date measured data for the site. The model is designed to incorporate additional data when updates are required.

2.2 Water Balance

2.2.1 Basis

The model starts off using the surveyed water elevation in the impoundment on May 01, 1999. An initial impoundment volume is calculated from this measured elevation using the volume-elevation curve for the impoundment. The initial tailings volume is back-calculated from the accumulated tailings volume estimated by TCAK in 2004. The initial water volume is calculated as the difference between the total impoundment volume and the accumulated tailings. The inflows and outflows are then calculated and totalled on an annual basis. The volume in the impoundment at the end of the year is calculated as follows:

$$End\ of\ Year\,Volume = Start\ of\ Year\,Volume + \sum Annual\ Inflows - \sum Annual\ Outflows$$

[1] Sulfate and TDS inputs in the model were calculated due to the difficulties that laboratories experience in measuring sources of water with high concentrations of sulfate. Sulfate concentrations were determined from ion balances; TDS concentrations were adjusted by the difference between measured and calculated sulfate concentrations.

The end of year volume is used to predict the end of year water elevation using the volume-elevation curve. The following year starts off using the predicted end of year water elevation from the previous year, and the above process is repeated. For years with known elevations, predicted elevations were used at the beginning of each year (rather than surveyed elevations) to obtain a cumulative estimate of the inaccuracies of the model over time.

The tailings elevations are estimated from the volume-elevation curve for the impoundment using the accumulated volume of tailings and assuming flat deposition of tailings. The bathymetric survey conducted by TCAK in 2004 was used as the basis for the model.

The amount of water discharged from the Mill is calculated by adding the inflows of water to the Mill (freshwater, reclaim water and ore moisture) and subtracting the water that leaves as concentrate moisture. The tailings volume in the Mill model is the volume the tailings are expected to occupy in the impoundment based on measured in-situ densities, including trapped water. Since the water held in the tailings is included in the calculation of the water discharged from the Mill, it is accounted for twice and is subtracted from the model as an outflow to the impoundment.

2.2.2 Water Balance Inputs and Assumptions

The detailed sources of information used in the current model are listed in Appendix A, Table 7. The following sections further describe some of the key inputs to the model.

Metered Flows

Metered flows are transferred from the TCAK Proscon database to spreadsheets maintained by TCAK personnel ("YTD ddmmyy.xls"). The majority of the flow data was originally transferred from the TCAK monthly water balance and then updated routinely from the time of transfer using the YTD files. The specific Proscon sources are listed in Table 7.

Mine Sump Flows

Flows measured from the Mine Sump are higher than flows calculated using only the plan areas of the catchments contributing to the Mine Sump. The model accounts for this by adding a theoretical leakage of water from the Red Dog Creek diversion to the calculated area-based flows. This assumes that water from outside the Mine Sump catchment leaks from the Red Dog Creek diversion into the minewater collection system and reports to the Mine Sump. The leakage volume was adjusted each year such that the sum of all the flows into the Mine Sump was equal to the metered flow. In addition, flows were added to the Mine Sump inputs to simulate potential groundwater that could be derived from mining below permafrost in the Main Pit and Aqqaluk Pit in the future. A flow of 26 MGals/year was added in 2009 for the Main Pit and another 26 MGals/year was added in 2018 for Aqqaluk Pit. The estimated 26 MGals/year is based on field testing and assumptions by Geomatrix Consultants. It is a long-term estimate and initial flows could be larger.

Reclaimed Areas

For areas where covers will be applied, the flow over the cover was calculated as follows:

$$Flow\ Over\ Cover = \%\ Area\ Covered \times \%\ Cover\ Efficiency \times Area\ Based\ Flow$$

It is conservatively assumed that the cover will allow only 25% of precipitation to reach the underlying waste rock, which is equivalent to 75% cover efficiency. Seepage was calculated as the difference between the total runoff and the flow over the cover.

Flooding of Pits

For the 2031 closure scenario, Aqqaluk Pit will be used to store inflows from the Mine Sump, Main Waste Stockpile seepage collection system, Overburden Stockpile pumpback, dam seepage pumpback and contaminated runoff diverted from the tailings impoundment. It is assumed that Aqqaluk Pit will be flooded to a minimum elevation of 760-foot amsl, creating a flooded area of 54 acres, which is approximately 40% of the plan area of the pit[2]. For the 2012 closure scenario, the Main Pit will be used to store these inflows. It is estimated that the Main Pit will be flooded to a minimum elevation of 745-foot amsl, creating a flooded area of 47 acres, which is approximately 30% of the plan area of the pit. The model assumes either pit would flood within two years of closure. Water stored in the pit will be treated and released to the environment.

Flows to WTP3

WTP3 was designed to treat water collected from the Main Waste Stockpile and the Mine Sump prior to discharge to the tailings pond. The main purpose of WTP3 is to reduce the total loading (and therefore concentrations) of TDS in the tailings pond. The plant was operated for the first time in 2006.

Under the current WTP3 capacity, the plant is designed to treat water from the Main Waste Stockpile as a priority, and treat water from Mine Sump with the remaining treatment capacity.

In 2006, WTP3 treated a total of 100 Mgal of water from the Mine Sump and 11 Mgal from the Main Waste Stockpile. However, due to start-up difficulties (now resolved), the plant was not operating at its full capacity. The treatment capacity of WTP3 under the current lime slaking capacity, was therefore modeled using a separate calculation sheet (sheet “WTP3”) for use in future projections of WTP3 treatment capacity.

The WTP3 model calculates the amount of water that could be treated using the calculated sulfate concentrations of water from the Main Waste Stockpile and Mine Sump based on the following assumptions:

- Water can be treated down to 2000 mg/L SO_4;
- A maximum of 70 tonnes/day CaO is available (as per J. Weakley, TCAK);
- Ratio of moles of CaO / SO_4 = 2.89.

The ratio was determined based on the pilot plant results. The pilot plant showed that a maximum of 500 gpm of water from the Main Waste Stockpile could be treated given the current concentrations and lime slaking capacity (as per J. Weakley, TCAK). The ratio was calculated using the above assumptions such that a flow of 500 gpm was achieved for the Main Waste Stockpile.

[2] Source: Aqqaluk_Pit_Water_Quality.xls, K. Sexsmith, SRK

The WTP3 model calculates the amount of Main Waste flow on a monthly basis by multiplying the total annual Main Waste flow that can be captured (% capture efficiency x precipitation released x area) by an average monthly distribution of the flow. A 50% seepage capture rate has been assumed for current conditions. As flow data from WTP3 is collected over time, the seepage capture rate can be revised in the model to better reflect actual conditions. The seepage capture rate was increased to 95% in 2025 for the 2031 scenario. The monthly distribution is based on the average distribution of precipitation released from 1999 to 2005, assuming all accumulated snow melts in May.

The Mine Sump flow is calculated in a similar manner by multiplying the annual flow by the average monthly distribution of flows. Unlike the Main Waste Stockpile, the model assumes 100% of the flow could be captured for treatment. The monthly distribution was obtained using the average of metered flows from 1999 to 2005.

The amount of Main Waste flow that can be treated is calculated first. Next, the remaining lime is calculated and finally the amount of water from the Mine Sump that can be treated with this remaining lime is determined. An average flow per day is calculated and multiplied by the number of days that the plant would be expected to operate for any given month. The number of days of operation was estimated from the average number of days that the WTP2 operated from 1999 to 2006.

Starting in 2025, measures will be implemented to reduce tailings pond concentrations to minimal levels, thereby reducing porewater concentrations and the potential for upward diffusion of metals into the tailings pond at closure. There are several alternative methods under consideration for reducing the pond concentrations, such as direct lime addition, addition of excess lime to the tailings discharge water (from the WTP1), or increased capacity in WTP3. For the purpose of modelling the 2031 scenario, it is assumed that the capacity of WTP3 will be increased in 2025 such that it can pre-treat all the flow captured from the Main Waste Stockpile, the Mine Sump and the dam seepage pumpback. However, these other alternatives are still under consideration.

2.2.3 Constraints

The discharge from Outfall 001 and the dam crest heights were varied based on the following constraints:

1. The discharge from Outfall 001 was set at a constant rate that would allow the water cover above the tailings to reach two feet by 2025 (or 2013 for the 2012 closure scenario);
2. The discharge from Outfall 001 was reduced to a constant rate once the two-foot water cover was achieved until closure such that the water level remained constant;
3. The discharge from Outfall 001 was further reduced after closure to a constant rate such that the water level remained constant;
4. The dam crest elevation was raised such that the minimum freeboard requirements were met as the tailings and water levels increased over time. The dam raises were conservatively scheduled when the water was within 2 feet of the freeboard.

It should be noted that the model does not predict peak water levels or annual variations in flow as it is based on average annual conditions.

2.3 Load Balance

The load balance sheets consist of three components: the water balance, chemical concentrations and loadings. A separate load sheet was created for each chemical parameter. The water balance portion of each sheet was converted from US gallons to metric units for ease of calculation.

Although a load balance can be achieved by simply subtracting the load out of the pond from the load into the pond, this method can not be used on an annual basis for the Red Dog tailings impoundment. When using this method, the load out of the pond is calculated by multiplying the outflows and the concentration at the beginning of the year. When large decreases in the concentrations in the pond occur during the year (such as after closure), the calculated loads removed from the pond far exceed the loads into the pond, and the resulting end-of-year concentrations are negative. As a result, the alternate method of calculation described below was used.

1. The load at the start of the year was calculated:

$$Load\ at\ Start\ of\ Year\ (L_1) = Concentration\ at\ Start\ of\ Year \times Volume\ in\ Pond\ at\ Start\ of\ Year$$

2. The Load Added to the Pond for each inflow was calculated:

$$Total\ Load\ added\ to\ Pond\ (L_2) = \sum \left[Inflows \times Concentration \right]$$

3. A new concentration in the pond was estimated assuming no flows leave the pond other than evaporation:

$$Concentration_{NEW} = \frac{Load\ at\ Start\ of\ Year\ (L_1) + Load\ Added\ to\ Pond\ (L_2)}{Volume\ in\ Pond\ at\ Start\ of\ Year\ (V_1) + \sum Inflows\ (V_2)}$$

4. The load removed from the pond was assumed to be at the newly calculated concentration:

$$Load\ \mathrm{Re}moved\ from\ Pond\ (L_3) = \sum \left[Outflows \times Concentration_{NEW} \right]$$

5. The concentration at the end of year is then the same as the above calculated concentration:

$$Concentration_{END} = \frac{Load\ at\ Start\ of\ Year\ (L_1) + Load\ Added\ (L_2) - Load\ \mathrm{Re}moved\ (L_3)}{Volume\ in\ Pond\ at\ Start\ of\ Year\ (V_1) + \sum Inflows\ (V_2) - \sum Outflows\ (V_3)}$$

Where the units are:

$$Load \cdots tonnes / year$$
$$Inflows, Outflows\ and\ Pond\ Volume \cdots million\ m^3 / year$$
$$Concentration \cdots mg / L$$

2.3.1 Load Balance Inputs and Assumptions

The water quality inputs are provided in Appendix B, Table 8. The inputs were obtained from routine monitoring data provided by the site. In cases where the chemistry did not appear to be changing over time, the median was derived from long-term data and/or years with the best quality data. Where annual trends were observed, (tailings discharge water, mine sump and reclaim water), median values were calculated for each year the data was available. The annual values were based on the period from May 01 to April 30 for consistency with the water balance portion of the model.

Although concentrations in the tailings discharge and reclaim water have been increasing over time, data from the waste rock stockpiles and pit sump suggest that concentrations in these areas are starting to stabilize. For this reason, future concentrations from waste rock and pit wall sources are assumed to remain at current levels. However, the chemistry of individual seeps suggests that higher concentrations are possible. Therefore, one set of model scenarios was also completed using higher concentrations for seepage from the Main Waste Stockpile. This latter scenario is not considered to be a true worst case or upper bound. It is within the range that could reasonably be expected at this site.

As mentioned in Section 2.1, Sulfate and TDS inputs were calculated from measured values for most of the sources. Sulfate concentrations were determined from ion balances; measured TDS concentrations were adjusted by the difference between measured and calculated sulfate concentrations.

3 Model Calibration

The model was initiated in 1999 to provide several years of comparison between water elevations and chemistry predicted from the model and those measured on site.

As of April 30, 2006, the model shows an under-prediction in the tailings impoundment water elevation of 1.46 feet when compared to measured water elevations. This error is cumulative over six years as the predicted water elevations from one year are carried forward to the following year. This level of error is small given the total flux of water through this system, and indicates that the model is a sufficiently accurate representation of average flow conditions for use in developing the load balance.

The predicted and measured concentrations in the pond are plotted on the Results sheet of each scenario. Figures 1 through 4 (Appendix C), which plot the concentrations in the pond from 1999 to closure for the 2031 scenario, show that the model calibrates well with measured data. The measured beginning of year chemistry appears to drop significantly for TDS and sulfate in 2004 and 2005 and for cadmium in 2005, which is inconsistent with the mean concentrations measured in the pond throughout the year. The concentrations at the beginning of the year are based on only one or two measured values and are highly dependent on when they are taken. SRK believes there is seasonal stratification that leaves a cleaner upper layer in the pond. Later in the year, mixing occurs, removing the stratification. The samples collected in May 2004 and/or 2005 could reflect this cleaner upper layer.

4 Results

4.1 Scenarios

Table 1 describes the scenarios that were run through the model. The results are discussed in detail in the following sections.

Table 1: Model Scenarios

Closure Scenario	Source Concentrations	Progressive Reclamation	WTP3 Operations	Other Measures to Improve Pond Water Quality (2025-2031)	Closure Measures	Purpose
2012	Current levels	None	Operating at current capacity	n/a	75% cover efficiency, 5% seepage escape, contaminated flows directed to *Main Pit*	***2012 Closure***: Aqqaluk Pit not developed, Main Pit used for storage of contaminated water
2031	Current levels	Cover Oxide Stockpile in 2007, start covering Main Waste in 2016 and waste in Main Pit in 2027	Current capacity until 2025, then expanded from 2025 to 2031 to treat all of Main Waste Seepage captured Mine Sump and dam seepage	Seepage escape rate decreased from 50% to 5% in 2025	75% cover efficiency; 5% seepage escape; contaminated flows directed to *Aqqaluk Pit*	***2031 Closure:*** Aqqaluk Pit fully developed, WTP3 expanded in 2025, implementation of progressive reclamation, Aqqaluk Pit used for storage of contaminated water
*	Increase in 2010	Where an asterisk is shown next to a scenario, the assumed concentrations of the Main Waste Stockpile seepage were increased in 2010				

4.2 Flow Amounts and Distribution

The distribution of flows to and from the tailings pond and other key locations on site are shown for three separate time intervals for the 2031 scenario on the following figures (Appendix C):

- Figure 5 – 2009 (prior to Aqqaluk development);
- Figure 6 – 2019 (after Aqqaluk development);
- Figure 7 – 2037 (post-closure).

During operations (Figures 5 and 6), the largest inflows to the pond are (in decreasing order):

- Mill discharge,
- return from WTP2,
- Mine Sump,
- dam seepage,
- runoff from background areas and
- precipitation on pond.

The largest outflows from the pond are (in decreasing order):

- inflow to WTP1,
- inflow to WTP2 and
- dam seepage.

Treated water is discharged from the system at Outfall001.

After closure, the largest inflows to the pond are (in decreasing order):

- precipitation on the pond,
- runoff from background areas,
- return from water treatment and
- a combination of runoff from the covers on the Main Waste Stockpile and escaped seepage.

The only outflows from the pond after closure are:

- seepage,
- inflow to the treatment plant and
- evaporation.

After closure, contaminated flows from the following sources are diverted from the tailings pond and pumped to Aqqaluk Pit: Mine Sump, Main Waste Stockpile seepage (captured), Overburden Stockpile pumpback, dam seepage pumpback and contaminated runoff. The total inflow to the Aqqaluk Pit is approximately 1060 MGals/year after closure. Excess water from the Aqqaluk Pit and the tailings pond will be treated prior to discharge at Outfall001. The total amount of discharge will be comparable to the amount discharged during operations.

The impact of the development of Aqqaluk can be seen in the Mine Sump flows, as shown on Table 2. The volume of water that the Aqqaluk deposit catchment contributes to the Mine Sump increases from 54 MGals/year to 166 MGals/year from 2009 to 2019 due to the development of the pit, the collection of water from the potential disturbance buffer zone and a flow of 26 MGals/year added in 2018 to account for potential groundwater as the Pit is mined below permafrost. This, along with some other changes in area, results in a 20% increase to the Mine Sump flow from 517 MGals/year in 2009 to 644 MGals/year in 2019. However, the Mine Sump contribution to the total inflows to the pond is only 8% (prior to Aqqaluk development) and 10% (after Aqqaluk development). In addition, a portion of the increased catchment for the Mine Sump was previously included in the Main Waste Stockpile catchment (area 6). As a result, the overall increase to the pond inflow is approximately 1%.

Table 2: Flows Before and After Aqqaluk Development for 2031 Closure Scenario

Inflow Component	**2009**	**2019**	**Change**	**% Change**	**Comments**
	MGals/year				
Precipitation on Pond	310	334	24	7%	Increased surface area with rise in pond level
Runoff from "Background" Areas	364	320	-44	-14%	Decreased runoff area with rise in pond level and continuing development
Overburden Stockpile	54	52	-2	-3%	Decreased runoff area with rise in pond level
Main Waste Stockpile	181	161	-20	-12%	Change mainly due to Upper Main Waste Catchment area now reporting to Mine Sump
Mine Sump:					Aqqaluk Deposit includes buffer zone around Pit and groundwater; overall increase includes Upper Main Waste Catchment area now reporting through Qanaiyaq Pit
Aqqaluk Deposit	54	166	112	67%	
Other Mine Sump Flows	463	479	16	3%	
Overall Mine Sump Flow	517	644	128	20%	
Mill Discharge to Pond	3,386	3,386	0	0%	No change
Grey Water	35	35	0	0%	No change
Return from Water Treatment	1242	1242	0	0%	No change
Dam Seepage Pumpback	501	501	0	0%	No change
Total Inflows to Pond	6,589	6,676	87	1%	

Notes:
1. The volumes shown for the Main Waste Stockpile and Mine Sump include the flows diverted to WTP3 for treatment. Water treated through WTP3 is discharged to the tailings pond after treatment.
2. The Mill Discharge to Pond flow is the volume occupied by the tailings solids and includes water held in tailings. The water held in tailings is a loss to the impoundment and is subtracted with the outflows.

4.3 Flows Requiring Treatment

Figure 8 shows the operation of the tailings impoundment for the 2031 scenario, including the water discharge requirements. The water treatment plant inflows during operations and after closure for both scenarios are provided in Table 3. The inflows to WTP2 (tailings pond water) during operations were calculated using the average return ratio for WTP2 from 1999 to 2006 (approximately 1.8, ratio of inflow to discharge). The inflows to water treatment after closure were calculated assuming a return ratio of 1.1. Return water is added to the tailings impoundment.

For the 2031 closure scenario, WTP2 needs to treat an average 2769 MGals/year until 2025, when the minimal water cover of two feet is achieved, and 2449 MGals/yr until closure in 2031. After closure, the total water treatment plant inflow is 1567 MGals/yr (tailings pond and Aqqaluk Pit water). The reduction in inflows to the water treatment plants after closure is due to the reduction in the return ratio.

For the 2012 closure scenario, the amount of water reporting to WTP2 is the same as for the 2031 closure scenario until 2011. The inflow to the treatment plant is reduced after 2011 due to the reduced return ratio assumed after closure. This reduces the water cover in the pond to approximately 2 feet by 2013. Once the desired water cover is achieved, the total water treatment requirement would be 1493 MGals/year, with 366 MGals/year from the tailings impoundment and 1127 MGals/year from the Main Pit.

Table 3: Water Treatment Plant Inflows

	Water Treatment Plant Inflows (MGals/year)				
2031 Closure	**To 2025**	**2026-2031**	**Post-Closure**		
			Pond Water	**Pit Water**	**Total**
	2769	2449	518	1050	1567
2012 Closure	**To 2011**	**2012-2013**	**Post-Closure**		
			Pond Water	**Pit Water**	**Total**
	2769	1679	366	1127	1493

Table 4 shows the amount of water that would be required to be discharged on an annual basis during operations and after closure. This is the net volume of water obtained by subtracting the return flow from the water treatment plant inflow.

For the 2031 closure scenario, the amount of water to be discharged from Outfall 001 was determined to be 1527 MGals/year in order to achieve the two-foot water cover in 2025 and 1350 MGals/year until closure. After closure, the discharge requirement is 1425 MGals/year. The volume of water to be treated and discharged to the environment increases slightly after closure due to the fact that the operation of the Mill creates an annual loss to the pond of approximately 85 MGals/year. This loss is attributed to storage of water in the tailings voids and concentrate water, less water contributed by freshwater and water present in the ore. The 2012 closure scenario shows a water discharge requirement of 1527 MGals/year until 2013, followed by a discharge requirement of 1357 MGals/year after closure.

The impact of the development of Aqqaluk can be shown by comparing the post-closure water discharge requirements for the 2012 and 2031 closure scenarios. As shown in Table 4, the projected discharge requirements are 1425 MGals/year and 1357 MGals/year for the 2031 and 2012 scenarios, respectively. As previously shown in Table 2 above, the development of Aqqaluk leads to an additional 112 MGals/year of inflow to the impoundment. However, increased pond evaporation due to the larger pond surface area in the 2031 scenario partially offsets this, leading to a net increased treatment requirement of only 68 MGals/year.

Table 4: Treated Water Discharge Requirements

	Treated Water Discharge (MGals/year)				
2031 Closure	**To 2025**	**2026-2031**	**Post-Closure**		
			Pond Water	**Pit Water**	**Total**
	1527	1350	471	954	1425
2012 Closure	**To 2011**	**2012-2013**	**Post-Closure**		
			Pond Water	**Pit Water**	**Total**
	1527	1527	333	1024	1357

4.3.1 WTP3 Operation

Figure 9 shows the flows to WTP3 for the two closure scenarios. At its current capacity, WTP3 is expected to treat roughly 250 MGals/yr initially (combination of Main Waste Stockpile seepage and Mine Sump flows). A slightly lower capacity can be seen in the 2012 closure scenario due to the lack of reclamation of the Oxide Stockpile. This capacity drops to roughly 220 MGals/year when Aqqaluk is developed in the 2031 closure scenario. This is due to the increase in concentrations of the Mine Sump flows which limits lime slaking capacity. The capacity drops to zero for the 2012 closure scenario in 2012 due to shut down of the Mine and WTP3.

WTP3 is able to treat more flow after progressive reclamation begins due to a reduction in the amount of seepage pumped from the Main Waste Stockpile. This reduction frees up lime capacity for the Mine Sump water, which has a lower lime demand than the Main Waste Stockpile, allowing a higher volume of water to be treated in WTP3.

4.4 Pond Water Chemistry

4.4.1 Operations

Figures 10 through 13 show the concentrations of TDS, sulfate, cadmium and zinc in the tailings pond over time during operations for the 2012 and 2031 closure scenarios with both current and increased Main Waste Stockpile concentrations. Concentrations of contaminants in the pond predicted by the model show an increase from 1999 to 2006, which is consistent with measured concentrations.

The 2031 closure scenario shows a decrease in concentration in 2007 due to the start-up of WTP3 in 2006. The concentrations increase in 2011 when the chemistry of the Aqqaluk Pit walls is changed from storm water quality to a pit wall source term. In addition, a steeper increase occurs for the scenario where higher Main Waste seepage concentrations are assumed starting in 2011. A gradual decrease in pond concentrations can be seen starting in 2016 due to the implementation of progressive reclamation of the Main Waste Stockpile. This is followed by a sharp decrease in concentrations in 2025 due to an increase in the capacity of WTP3 (both flow and lime slaking capacity) to treat all the seepage captured from the Main Waste Stockpile (95% capture efficiency), all the Mine Sump flow and Main Dam seepage. This scenario also assumes that water that can not be treated immediately in WTP3 will be stored in the Main Pit (within the voids in the waste rock). The improvement in pond water quality in 2025 would help to reduce the potential for diffusion from the tailings porewater to the pond during the post-closure period.

In the 2012 closure scenario, WTP3 is operational, but there is no progressive reclamation. The concentrations decrease after 2006 due to the implementation of WTP3. However, the concentration drop is slightly lower than for the 2031 scenarios due to the lack of reclamation of the Oxide Stockpile in the 2012 scenarios. The concentrations increase in 2011 for the scenario where the higher Main Waste Stockpile seepage concentrations are assumed starting in 2011. After closure, concentrations drop as inflows are pumped to the Main Pit.

4.4.2 Post-Closure

Table 5 shows the post-closure concentrations in the pond for both scenarios once the pond has reached a steady state. The 2012 closure scenario has slightly higher zinc and cadmium concentrations than the 2031 closure scenario, however, SO_4 and TDS concentrations are lower. The variations in concentrations are due to the following differences between the two scenarios:

- The 2012 closure scenario has a lower pond elevation, and therefore less submerged areas, resulting in more runoff from background areas and the north side of the Overburden Stockpile;
- In the 2031 scenario, part of the Upper Main Waste Catchment area becomes part of Qanaiyaq Pit, which is diverted away from the pond, whereas the full catchment area and resulting loads flow to the tailings impoundment in the 2012 closure scenario;
- The seepage rate for the 2012 scenario is kept at the current rate throughout the model, whereas it is lowered after closure in the 2031 scenario to the rate that was estimated for this closure scenario assuming a 600-foot wide tailings beach.

- The 2031 scenario requires a slightly higher volume of water to be treated than the 2012 scenario, resulting in slightly higher volumes of return water to the pond for the 2031 scenario.

Table 5: Post-Closure Pond Concentrations

Option	Brief Description	Zinc	SO_4	TDS	Cadmium
		mg/L			
2012 Closure	WTP3 operating at current capacity; Aqqaluk Pit not developed	18	627	978	0.15
2031 Closure	WTP3 capacity increased in 2025; progressive reclamation; 75% cover efficiency; 5% seepage escape	16	633	983	0.14

4.4.3 Treatment Requirements

Table 6 presents the sulfate loads reporting to water treatment after closure. These loads are equivalent to the post-closure water treatment requirements. The results of the model indicate that the sulfate load for the 2012 scenario is slightly lower than the load associated with the 2031 closure scenario. This is a result of the lower concentration and volume of water requiring treatment for the 2012 scenario.

Table 6: Post-Closure Sulfate Loads

Option	Brief Description	Pit Water	Pond Water	Total
		Tonnes/year		
2012 Closure	WTP3 operating at current capacity; Aqqaluk Pit not developed	13,556	869	14,425
2031 Closure	WTP3 capacity increased in 2025; progressive reclamation; 75% cover efficiency; 5% seepage escape	14,473	1,240	15,713

References

Geomatrix 2003. “Final Calculations, Red Dog Tailings Dam, Freeboard Analysis”, Geomatrix Consultants, June 18, 2003.

Geomatrix 2006. Memorandum to Mark Thompson, TCAK, “Red Dog Water Balance Considerations”, Jeff Weaver, Geomatrix Consultants, March 23, 2006.

URS 2005. Memorandum to Gary Coulter, TCAK, “Conceptual Design of Spillway at Tailings Main Dam for Closure”, URS Project No. 33757098, URS Corporation, April 08, 2005.

URS 2006. “Seepage Analysis Report, Red Dog Tailings Main Dam, Future Raises To Closure, Red Dog Mine, Alaska”, URS Job No. 33757098, URS Corporation, September 29, 2006.

APPENDIX A
Sources of Flow Data

Table 7: Sources of Flow Data

Component	Source of Information or Assumption Used
Dam Crest Elevation	Measured elevations from 1999 to present; calculated for future years to maintain adequate freeboard
Minimum Freeboard Elevation	Distance from maximum (normal) operating water level to dam crest = 5 feet (5.8 feet for final dam crest)[1]
Precipitation	Adjusted Bons Creek weather station data to 2005; 20.7 inches/year for future years[2]
Evaporation	Adjusted Bons Creek weather station data to 2005; average of site data (1992 to present) for future years[3]
Discharge to Outfall 001	Metered flow to 2006[4]; calculated for future years to achieve two-foot water cover by 2025 (by 2011 for 2012 closure) and maintain constant level after closure
Sand Filter Dilution	Metered flow of water pumped from Bons Creek to sand filters for 2005 and 2006; zero for future years [5]
Bons Creek Consumption	Metered flow to 2005[6]; 2005 data for future years
Water Elevations[7]	Surveyed levels[8] used to start model (05/01/99) and for calibration; estimated from volume-elevation curve elsewhere
Impoundment Volume	Calculated from measured water level and volume-elevation curve at start of model (05/01/99) and from inflows and outflows elsewhere
Tailings Elevations	Estimated from calculated volume and volume-elevation curve[9]
Accumulated Tailings Volume	Volume determined from site surveys in May 2004 (21,400,000 tonnes)[10]; subtracted annual volume prior to 2004 and added annual volume after 2004
Beginning Free Water Volume	Difference between water and tailings elevations
Plan Areas	Current surveyed areas and projected areas from Mine Plan; Pond areas estimated from area-elevation curve[11]
Volume-Elevation Data	Provided by TCAK (bathymetric surveys) for elevations 908 to 945 feet; data extrapolated below and above these elevations by SRK
Precipitation on Pond	Pond area (less tailings beach area) x adjusted precipitation
Runoff from Tailings Beaches	Plan area x adjusted precipitation (assumed zero)[12]
Runoff from Background Areas	Plan area x adjusted precipitation[13]
Overburden Stockpile	Plan area x adjusted precipitation[14]
Main Waste Stockpile Runoff	Plan area x adjusted precipitation
Mine Sump to Pond	Metered flow to 2005[15]; area-based flow + leakage from Red Dog Creek Diversion + groundwater elsewhere
Discharge from WTP3	Assumed all flows to WTP3 are discharged to tailings impoundment
Mill Discharge Model:	
• Freshwater	Bons Creek consumption less grey water to closure; zero at closure[16]
• Water in Ore	Based on actual production to 2005 (or projected ore production for future years) with 2.3% moisture content; zero at closure [17]
• Flow to WTP1	Metered flow to 2005[18]; average of metered flows (1999-2005) for future years; zero at closure
• Tailings Volume (solids & entrained water)	Based on actual production to 2005 and 2,163,889 tonnes/year for future years with in-situ dry bulk density of 1.51 t/m^3; zero at closure[19]
• Water in Concentrate	Based on actual production to 2005[20]; average from 1999-2005 from 2006 to closure; zero at closure

Component	Source of Information or Assumption Used
Grey Water	Metered flow 1999-2002 and 2005; 25% of Bons Creek consumption elsewhere [21]
Return from WTP2	Flow to WTP2 - [Discharge to Outfall 001 - Sand Filter Dilution][22]
Seepage Pumpback (from tailings impoundment)	Metered flow to 2003; 2003 values for future years; post-closure (2031closure only), 550 gpm + flow from Main Dam face (as per URS 2006)[23]
Evaporation from Pond	Pond area x adjusted evaporation[24]
Water Held in Tailings	*Water (tonnes) = (Dry Tailings in tonnes / 0.76) – Dry Tailings in tonnes* to closure; zero at closure [25]
Flow to WTP1	See above
Flow to WTP2	Metered flow to 2006[26]; 1.81 x Outfall 001 Discharge (average ratio from 1999 to 2006)
Seepage (from tailings impoundment)	Pumpback less flow from Main Dam face; 550 gpm post-closure for 2031 closure, assuming a 600-foot tailings beach (URS 2006)

[1] Source: Geomatrix 2003
[2] Precipitation data provided by TCAK Environmental Department. Precipitation is increased by factor of 1.4 during winter months (Jan-Apr, Oct-Dec) due to biases in measurements that occur due to the methodology used to measure precipitation and the spatial location of the recording station (Geomatrix, 2006). Value of 20.7 inches is the long-term average generated by the Geomatrix weather generating model.
[3] Evaporation data provided by TCAK Environmental Department. Evaporation reduced by factor of 0.5 to account for over-predictions obtained from pan evaporation measurements (Geomatrix, 2006).
[4] Source: Proscon, PLC5#24, "Treated/Filtered Water Discharged to Red Dog Creek".
[5] Source: Proscon, PLC5#24, "Bons Creek Total Flow to Sand Filters". Dilution carried out for first time in 2005. Dilution not used for future years as projected 001 discharge rates are net rates, assuming dilution has already been subtracted.
[6] Source: Proscon, PLC5#24, "Bons Creek Water to Fresh Water Tank".
[7] Surveyed water elevations in impoundment were adjusted in January 2005 due to discovery of survey error, which increased elevation by approximately 0.5 feet. According to TCAK Survey Department, error goes back to before 1999, but site data has not been adjusted prior to 2005. Measured water elevations in model increased by 0.5 feet back to start of model in 1999.
[8] Source: TDAM-H2O.xls from TCAK Mine Department.
[9] Assumes struck level tailings elevations.
[10] Source: Tailings_Alternatives.dh_jp.v7.Nov_2004.xls by Daryl Hockley.
[11] Pond area-elevation curve from URS memorandum on conceptual spillway design (URS 2005).
[12] The flow associated with the tailings beach areas is included within the precipitation inflow.
[13] Diverted area to West of impoundment (catchment for DD-4 diversion ditch) assumed to have no diversion until 2003, the year the ditch was constructed. Based on measured flow rates in 2003, diversion set to 75% efficiency from 2003 (as per George Thornton, TCAK).
[14] Used area-based flows rather than metered flows from Overburden Stockpile pumpback as area-based are higher.
[15] Source: Proscon, PLC5#20, "Red Dog Div. Water to Tailings Pond".
[16] Assumes all freshwater that is not used as potable water reports through the mill (reagent mixing, cooling, etc.) to the tailings impoundment.
[17] Source: “Red Dog production history.xls” from Brigitte Lacouture (TCAK); moisture in ore provided by Jason Weakley (TCAK). Projected ore tonnage = 1.6 x projected annual tailings production, based on historical production data.
[18] Source: Proscon, PCL5#24 - "Total Flow to WTP#1".
[19] Source: “Red Dog production history.xls” from Brigitte Lacouture (TCAK); dry bulk density obtained from Norman Paley (TCAK) based on in-situ testing. Future tailings production provided by TCAK (Source: Tailings_Alternatives.dh_jp.v7.Nov_2004.xls by Daryl Hockley).
[20] Source: “Red Dog production history.xls” from Brigitte Lacouture
[21] Source: Proscon, PCL5#05 - "Potable Water Effluent". Freshwater was not decreased at closure; in reality it will decrease due to a reduction in staffing. Estimate of 25% obtained from “*fresh and potable use.xls”* from Jason Weakley.
[22] Source: Proscon, PCL5#24 - "Total Flow to WTP#2". Sand filter dilution must be removed from the measured discharge at Outfall 001 as the water is pumped directly from the reservoir to the sand filters and bypasses the tailings impoundment.
[23] Source of metered flow: Proscon, PLC5#24, "Seepage Pond Water to Tailings Pond". Post-closure seepage based on estimated seepage at 986-ft dam crest (URS 2006).
[24] Evaporation subtracted in the inflows section for ease of chemical load calculations (it carries no load).
[25] Source: “Red Dog production history.xls” from Brigitte Lacouture (TCAK).
[26] Source: Proscon, PCL5#24 - "Total Flow to WTP#2".

APPENDIX B
Sources of Water Quality Data

Table 8: Sources of Water Quality Data

Component	Description	TDS mg/L	Calc TDS mg/L	SO_4 mg/L	Calc SO_4 mg/L	Cd mg/L	Zn mg/L
Discharge from Outfall 001 (used for WTP3 discharge and Return from WTP2)	Median of data from 1998 to 2004 (Jan-Dec) from Outfall 001	3,350	3,350	2,165	2,165	0.0008	0.05
Inflow to Tailings Impoundment:							
Precipitation on Pond	Zero concentrations (i.e. no load)	0	0	0	0	0	0
Runoff from Tailings Beaches	Same as Precipitation on Pond (i.e. no load)[1]	0	0	0	0	0	0
Runoff from Background Areas	Median of data from 1998 to 2004 (Jan-Dec) from Station 140	175	175	85	85	0.02	2.7
Overburden Stockpile	Median of data from 2004 (May-Oct) from East and West Sump	1,666	1,648	1,078	1,061	0.01	7.5
Main Waste Stockpile Runoff:							
Runoff over Cover	Same as Overburden Stockpile	1,666	1,648	1,078	1,061	0.01	7.5
Seepage – water quality remains constant	MWD data (excluding MWD#24) from 2003 (Jan-Dec), flow weighted averages for TDS, SO4 and acidity, median values for others	25,787	21,963	21,050	17,226	52	5,576
Seepage – water quality deteriorating	MWD #22 from 2003 (Jan-Dec), flow weighted averages for TDS, SO4 and acidity, median values for others	36,113	34,682	27,811	26,380	60	7,245
Mine Sump to Pond:							
1999	Median of 1999 data (May 01-Apr 30)	4,530	4,349	3,200	3,019	6	625
2000	Median of 2000 data (May 01-Apr 30)	5,570	4,149	4,900	3,479	27	930
2001	Median of 2001 data (May 01-Apr 30)	6,400	6,185	4,160	3,945	18	1,090
2002	Median of 2002 data (May 01-Apr 30)	8,565	8,475	5,480	5,390	18	1,250
2003	Median of 2003 data (May 01-Apr 30)	7,880	7,264	5,330	4,714	24	1,340
2004	Median of 2004 data (May 01-Apr 30)	7,620	5,887	6,915	5,182	26	1,675
Future Years:	Sum of loads divided by total flow to mine sump, where each component contributing to the sump is assigned its own concentration						
Disturbed Areas (Main Pit & Low Grade NE, SE & NE Pit Walls)	Pit wall chemistry – back-calculated from Main Pit sump chemistry assuming that the pit walls were the only input contributing loading	31,233	28,649	20,637	18,719	115	5,263
Undisturbed Areas (Main Pit & Low Grade NE, SE & NE Pit Walls)	Same as Runoff from Background Areas	175	175	84.85	84.85	0.0211	2.655
Flow over Cover on Waste in Pit	Same as Overburden Stockpile	1,666	1,648	1,078	1,061	0.01	7.5
Seepage from Waste in Pit	Same as Seepage from Main Waste Stockpile[2]	25,787	21,963	21,050	17,226	52	5,576

[1] It is assumed that the tailings beaches will be covered, therefore, no load was applied to these areas.

Component	Description	TDS mg/L	Calc TDS mg/L	SO_4 mg/L	Calc SO_4 mg/L	Cd mg/L	Zn mg/L
Slope to N of Camp & Mill	Same as Runoff from Background Areas	175	175	84.85	84.85	0.0211	2.655
Hilltop Creek and S Pit Wall	Same as Runoff from Background Areas	175	175	84.85	84.85	0.0211	2.655
Aqqaluk Pit prior to development	Aqqaluk stormwater runoff from two samples collected in 2005	210	210	133	133	0.3	21
Aqqaluk Pit after development	Pit wall chemistry (same as Disturbed Areas)	31,233	28,649	20,637	18,719	115	5,263
Aqqaluk Pit Buffer Zone	Aqqaluk stormwater (same as Aqqaluk Pit prior to development)	209.5	209.5	132.5	132.5	0.3075	21.3
Qanaiyaq Pit	Pit wall chemistry (same as Disturbed Areas)	31,233	28,649	20,637	18,719	115	5,263
Flooded Pit Area	Same as Precipitation on Pond (i.e. no load)	0	0	0	0	0	0
Leakage from Red Dog Creek Diversion	Same as Runoff from Background Areas	175	175	84.85	84.85	0.0211	2.655
Groundwater	From Aqqaluk Drill Site #2, sample taken 09/08/2005	5800	5800	3590	3,590	90	694
Discharge from WTP3	Same as Discharge from Outfall 001 (no data currently available)	3,350	3,350	2,165	2,165	0.0008	0.05
Mill Discharge to Pond:							
1999	2000 data due to lack of data for 1999	3,575	3,271	2,610	2,306	1.4	107
2000	Median of 2000 data (May 01-Apr 30)	3,575	3,271	2,610	2,306	1.4	107
2001	Median of 2001 data (May 01-Apr 30)	3,770	3,772	2,460	2,462	1.0	103
2002	Median of 2002 data (May 01-Apr 30)	3,960	3,714	2,630	2,384	2.1	122
2003	Median of 2003 data (May 01-Apr 30)	3,975	3,899	2,665	2,589	2.2	126
2004	Median of 2004 data (May 01-Apr 30)	4,070	4,085	2,570	2,585	1.8	122
Grey Water	Same as runoff from background areas (no data available)	175	175	84.85	84.85	0.0211	2.655
Return from WTP2	Same as discharge from Outfall 001 (no data available)	3,350	3,350	2,165	2,165	0.0008	0.05
Seepage Pumpback (from tailings impoundment)	Median of data from 2003 (Jan-Dec)	3,235	3,207	2,245	2,217	0.34	159
Outflow from Tailings Impoundment:							
Evaporation from Pond	Zero concentrations (i.e. no load)	0	0	0	0	0	0
Water Held in Tailings	Calculated pond concentration						
Flow to WTP1	Calculated pond concentration						
Flow to WTP2	Calculated pond concentration						
Seepage (from tailings impoundment)	Calculated pond concentration						
Reclaim Water Chemistry:							
Beginning of Year - 1999	Median of data from April/May 1999	3,300	3,300	1,640	2,525	1.8	240

[2] For the scenarios where Main Waste Stockpile seepage concentrations were increased in 2011, the concentrations from the waste in the Pit were not increased.

Component	Description	TDS mg/L	Calc TDS mg/L	SO_4 mg/L	Calc SO_4 mg/L	Cd mg/L	Zn mg/L
Beginning of Year - 2000	Median of data from April/May 2000	3,300	3,300	1,640	2,525	1.8	240
Beginning of Year - 2001	Median of data from April/May 2001	3,610	3,610	5,040	2,503	2.8	269
Beginning of Year - 2002	Median of data from April/May 2002	3,760	3,744	2,360	2,344	3.1	238
Beginning of Year - 2003	Median of data from April/May 2003	3,950	3,843	2,630	2,523	3.6	288
Beginning of Year - 2004	Median of data from April/May 2004	3,570	3,503	2,245	2,178	4.5	279
Beginning of Year - 2005	Median of data from April/May 2005	3,420	3,306	2,290	2,176	3.9	345
Median - 1999	Median of 1999 data (May 01-Apr 30)	3,390	3,318	2,385	2,313	2.5	258
Median - 2000	Median of 2000 data (May 01-Apr 30)	3,470	3,214	2,625	2,369	3.1	249
Median - 2001	Median of 2001 data (May 01-Apr 30)	3,760	3,434	2,720	2,394	4.3	294
Median - 2002	Median of 2002 data (May 01-Apr 30)	3,930	3,684	2,590	2,344	4.1	310
Median - 2003	Median of 2003 data (May 01-Apr 30)	4,085	3,822	2,755	2,492	4.7	300
Median - 2004	Median of 2004 data (May 01-Apr 30)	4,360	4,061	2,930	2,631	5.0	386

APPENDIX C
Figures

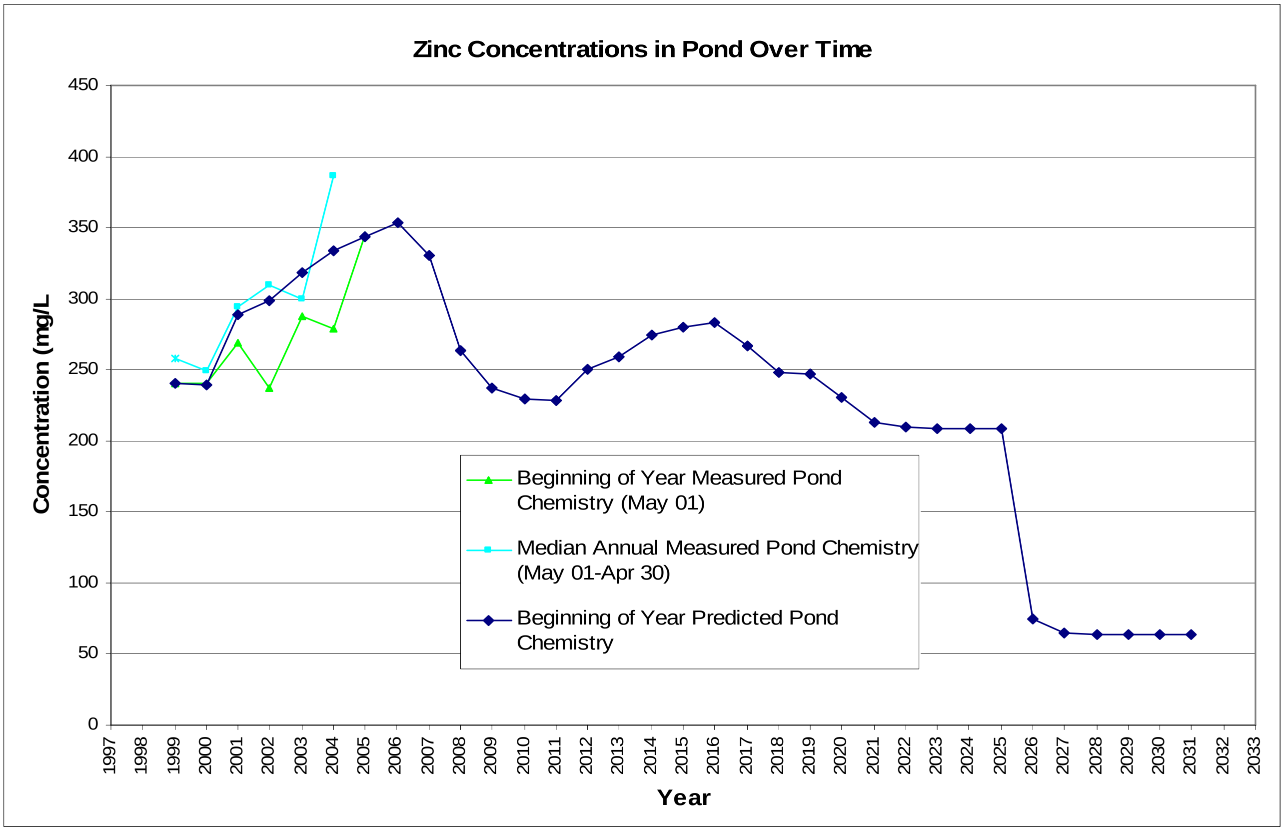

Figure 1: Zinc Concentrations in Pond for 2031 Closure Scenario

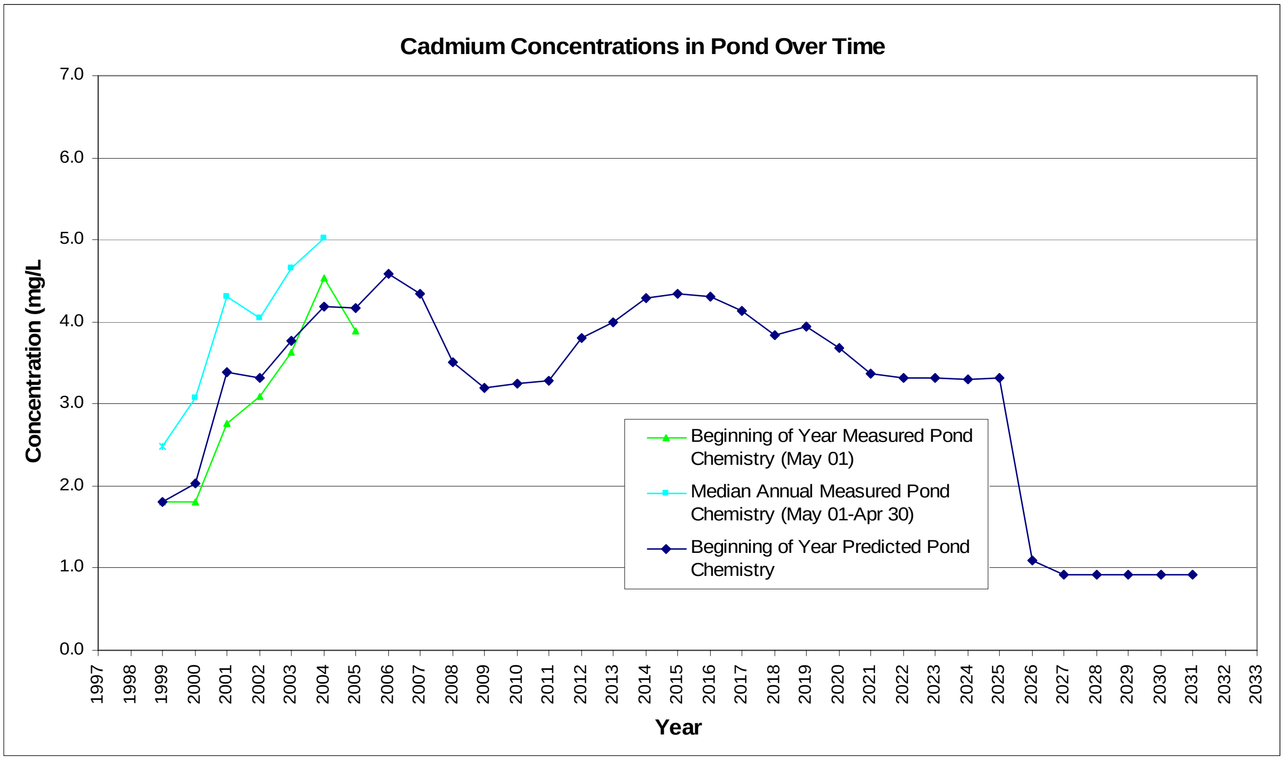

Figure 2: Cadmium Concentrations in Pond for 2031 Closure Scenario

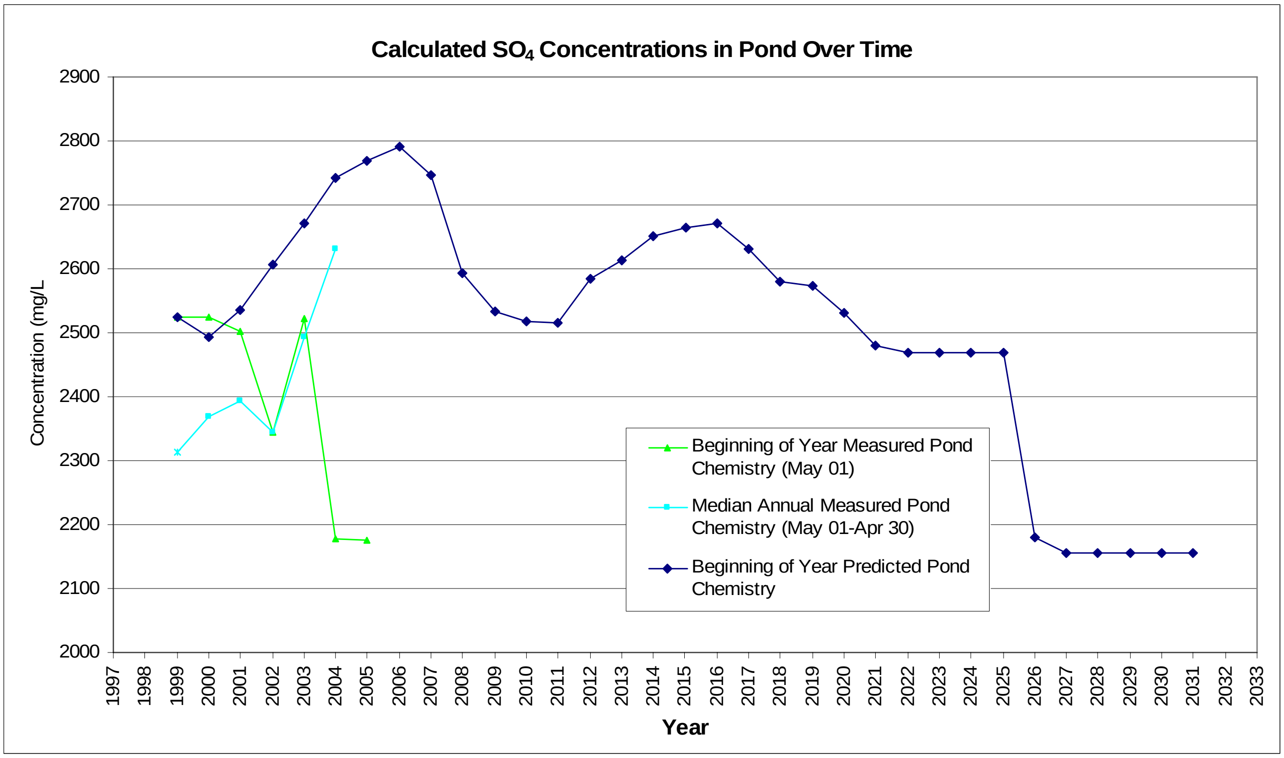

Figure 3: Calculated SO_4 Concentrations in Pond for 2031 Closure Scenario

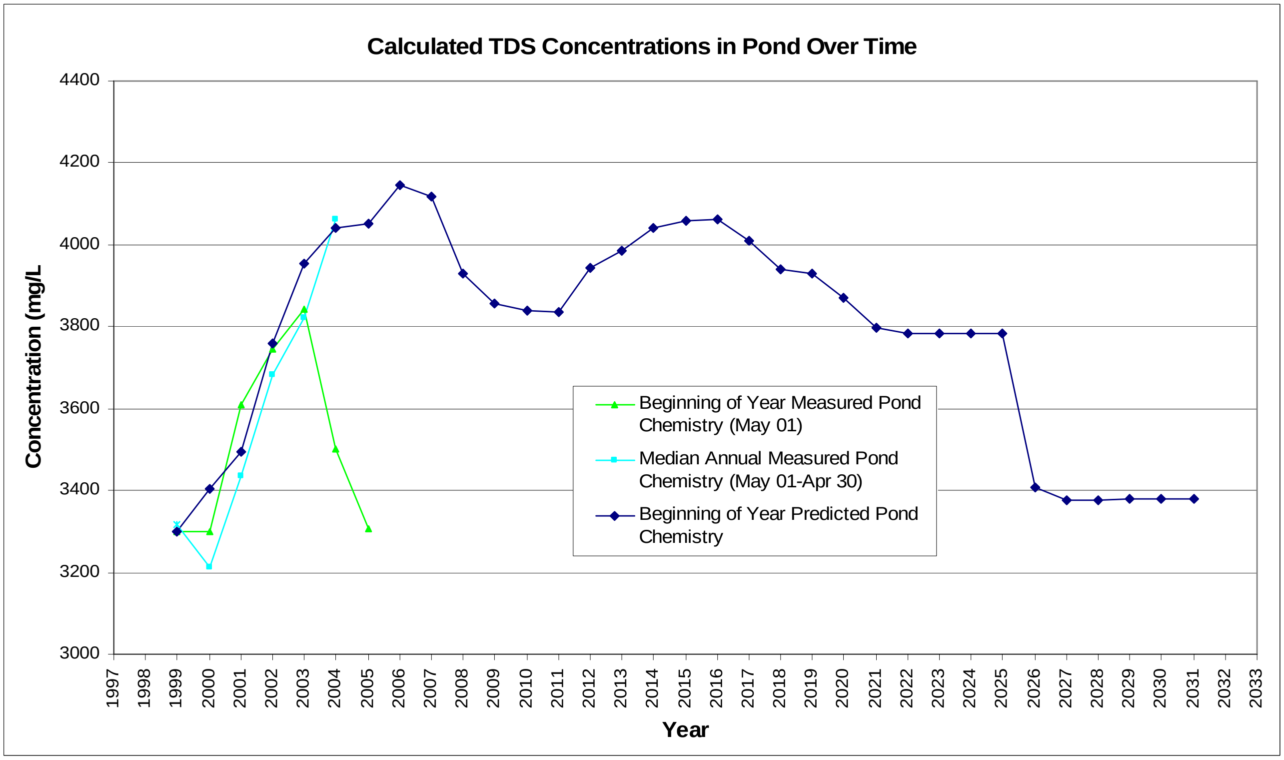

Figure 4: Calculated TDS Concentrations in Pond for 2031 Closure Scenario

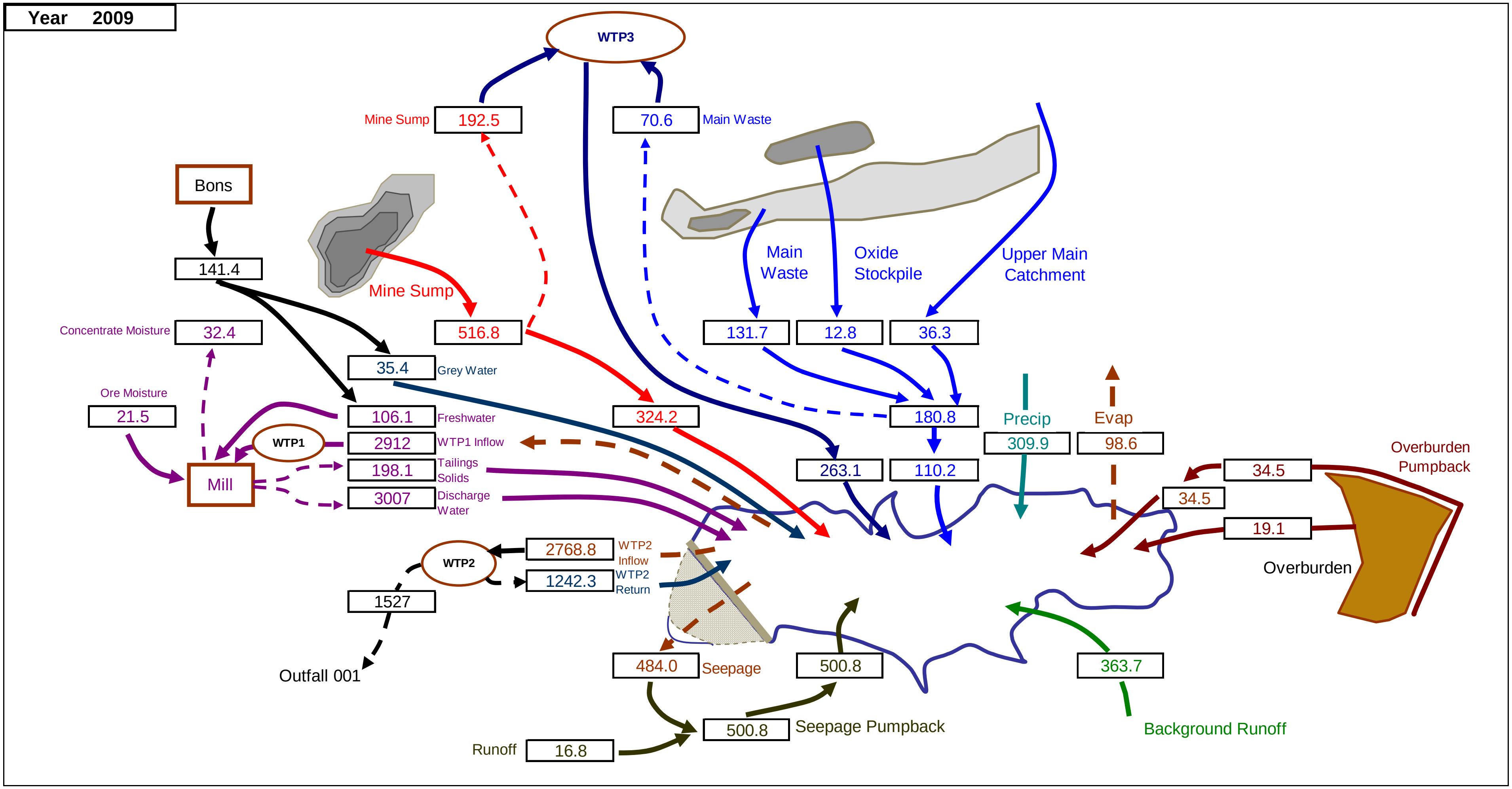

Figure 5: 2009 Annual Tailings Impoundment Flows (MGals/year) for 2031 Closure Scenario

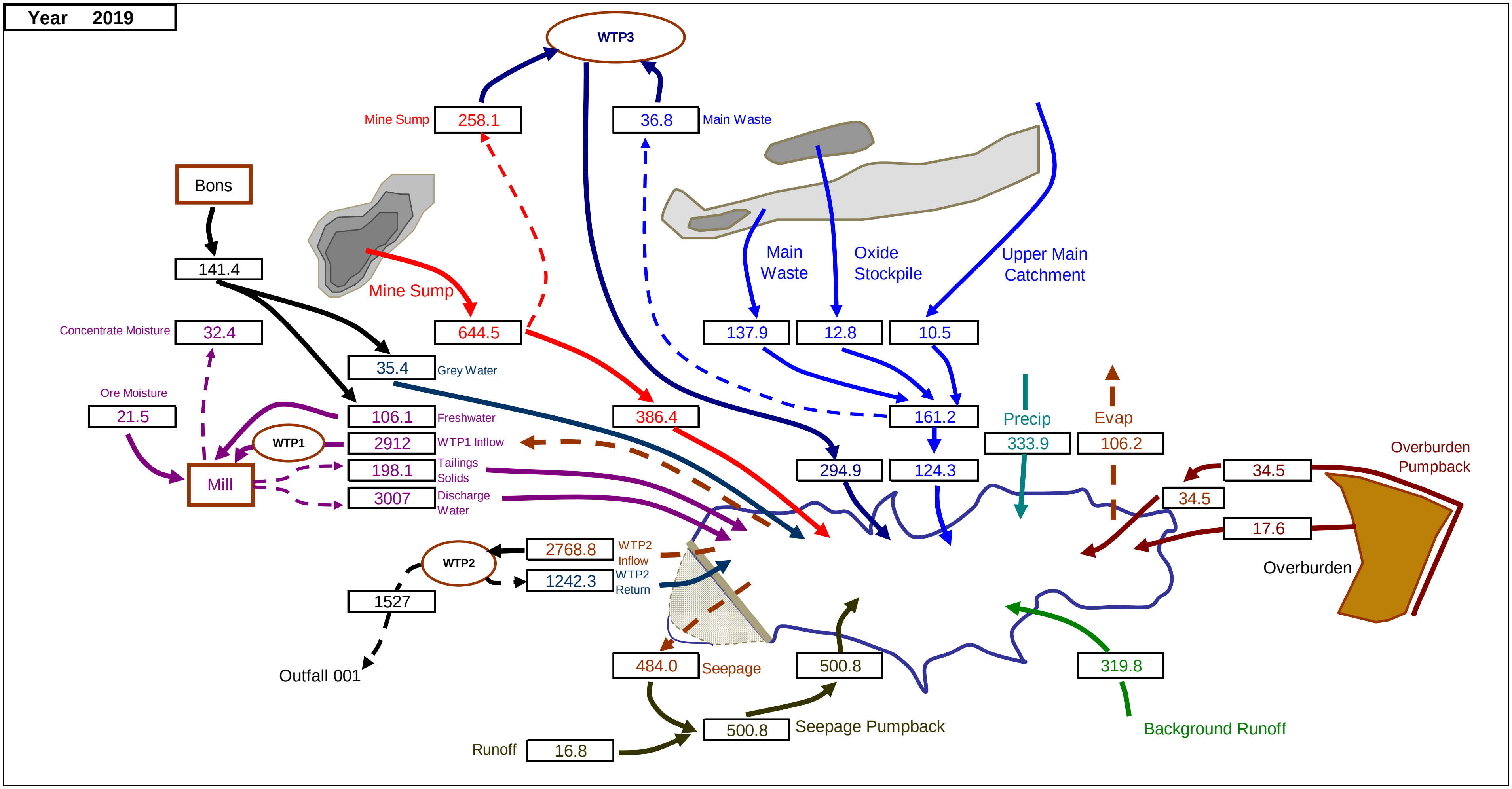

Figure 6: 2019 Annual Tailings Impoundment Flows (MGals/year) for 2031 Closure Scenario

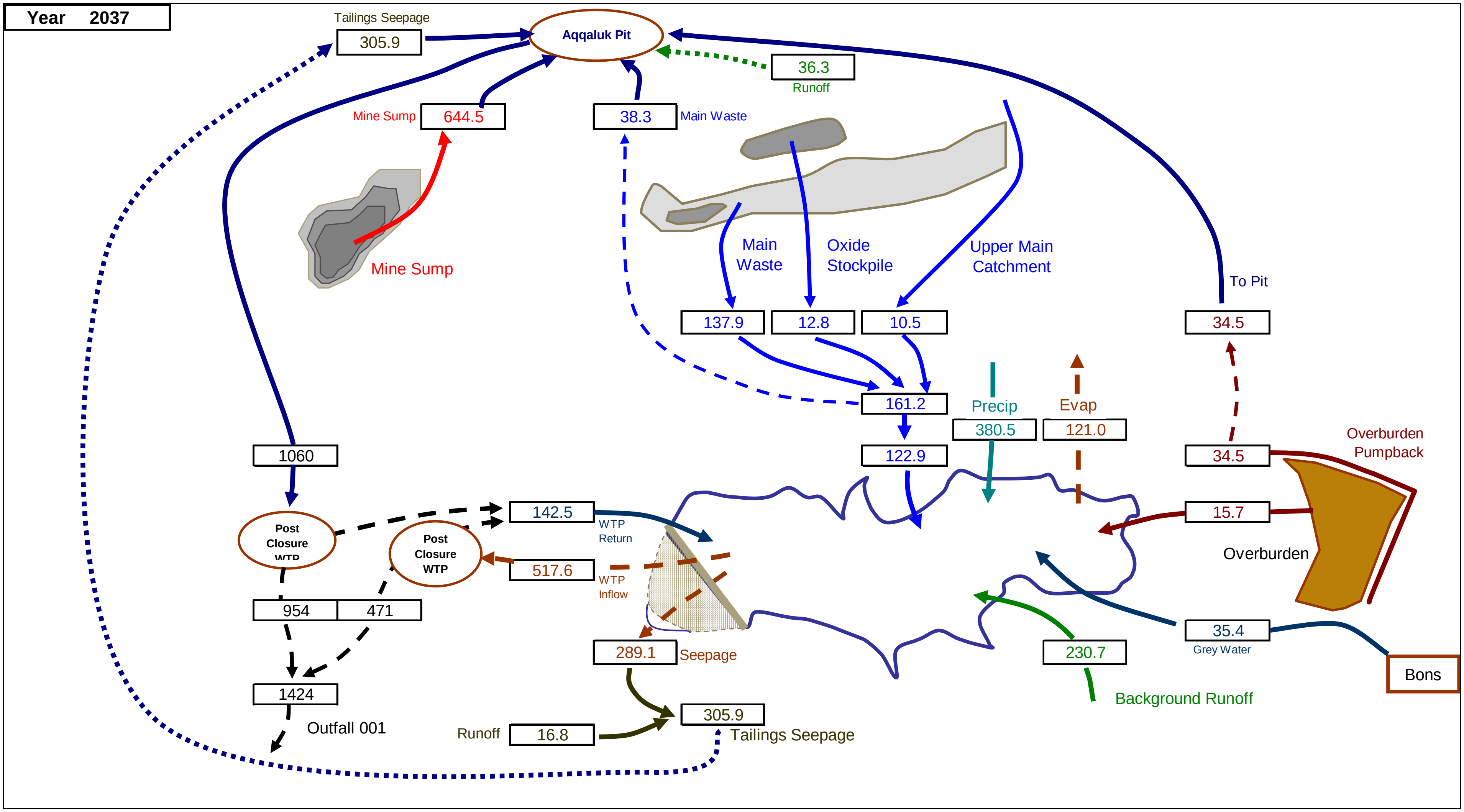

Figure 7: 2037 Annual Tailings Impoundment Flows (MGals/year) for 2031 Closure Scenario

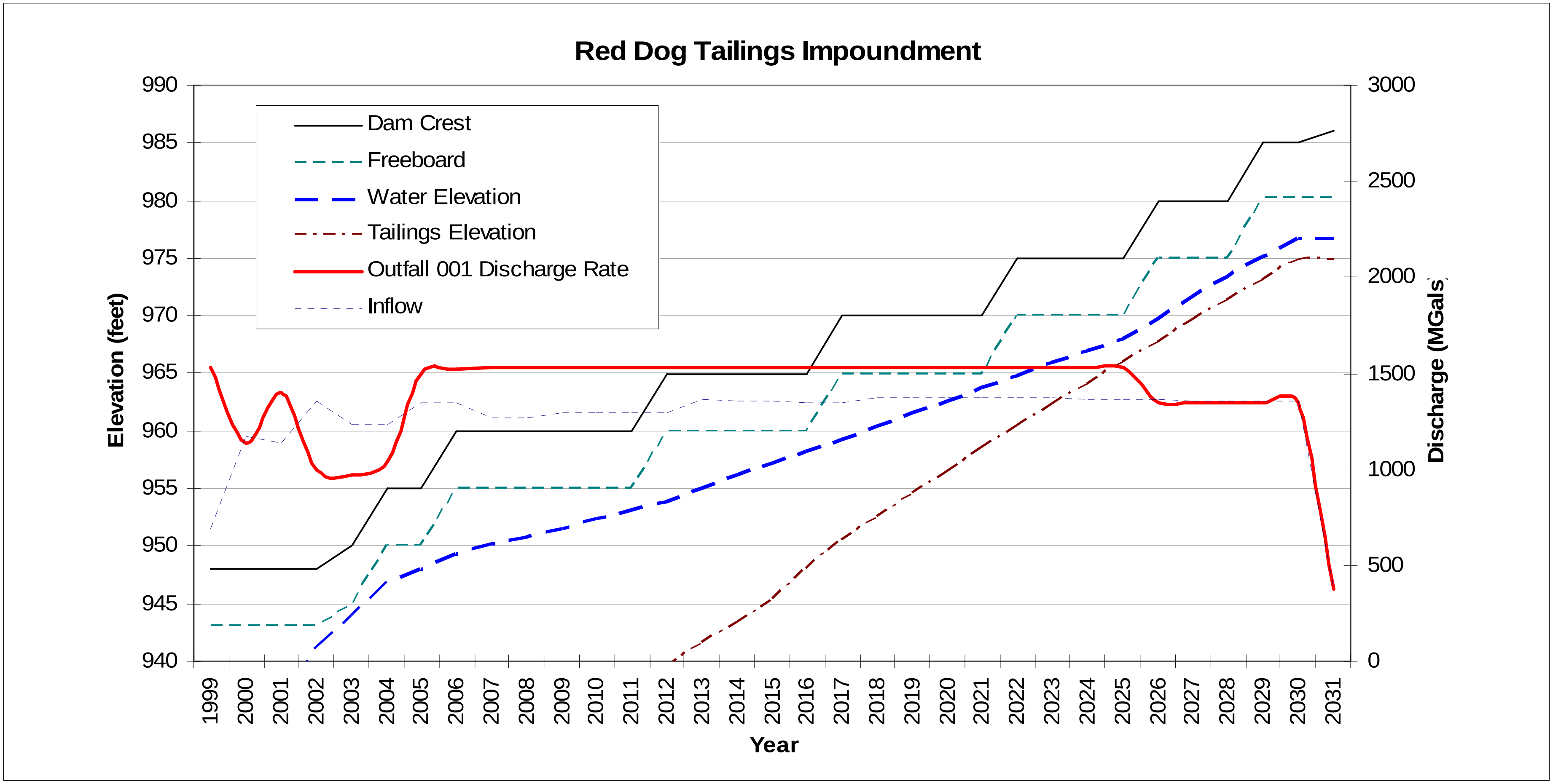

Figure 8: Operation of Tailings Impoundment for 2031 Closure Scenario

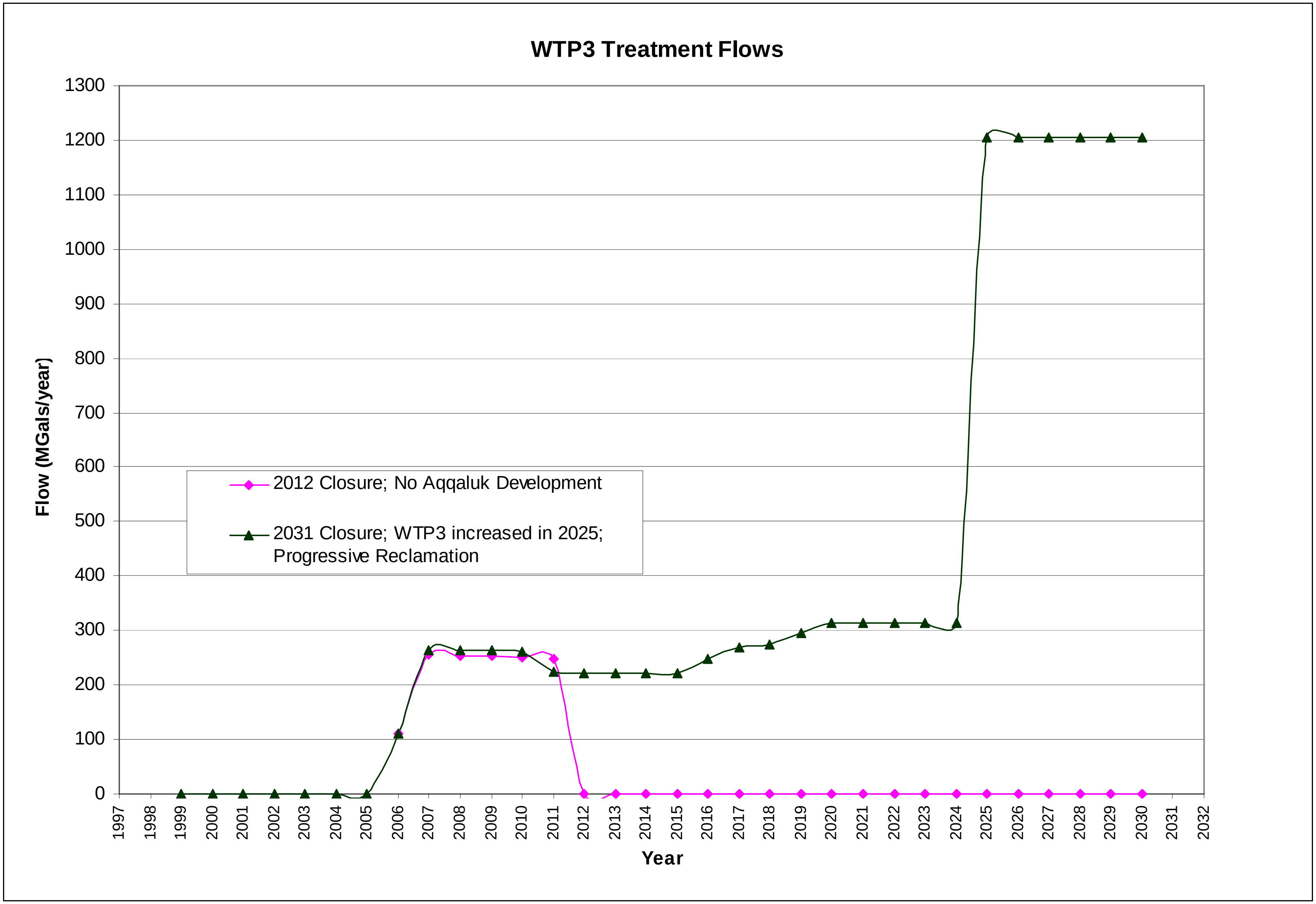

Figure 9: WTP3 Treatment Flows

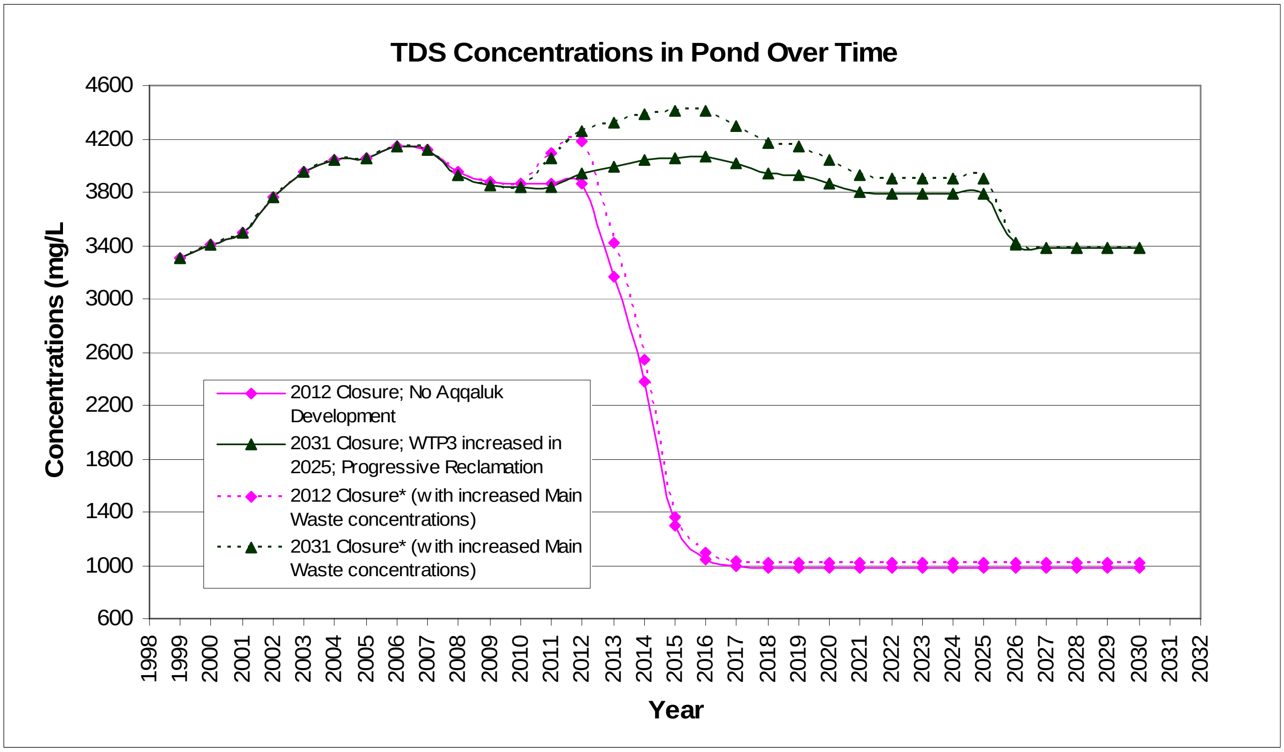

Figure 10: TDS Concentrations in Pond during Operations

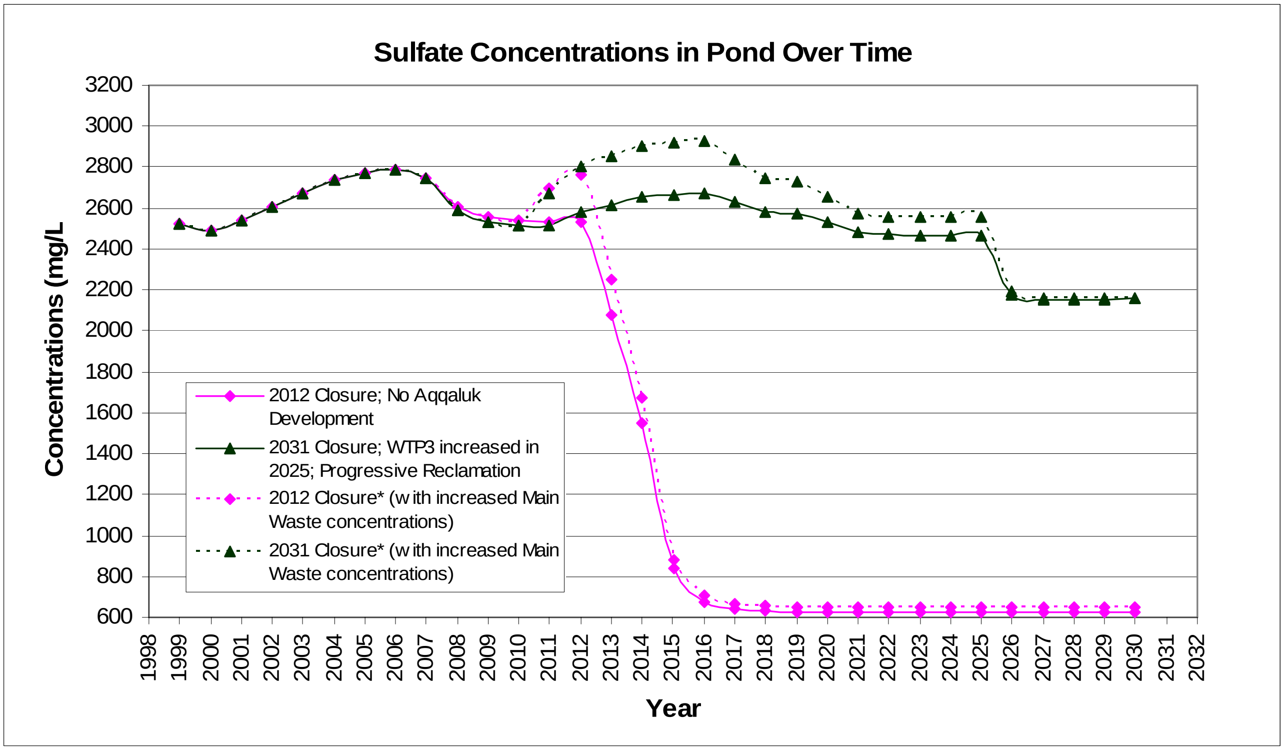

Figure 11: Sulfate Concentrations in Pond during Operations

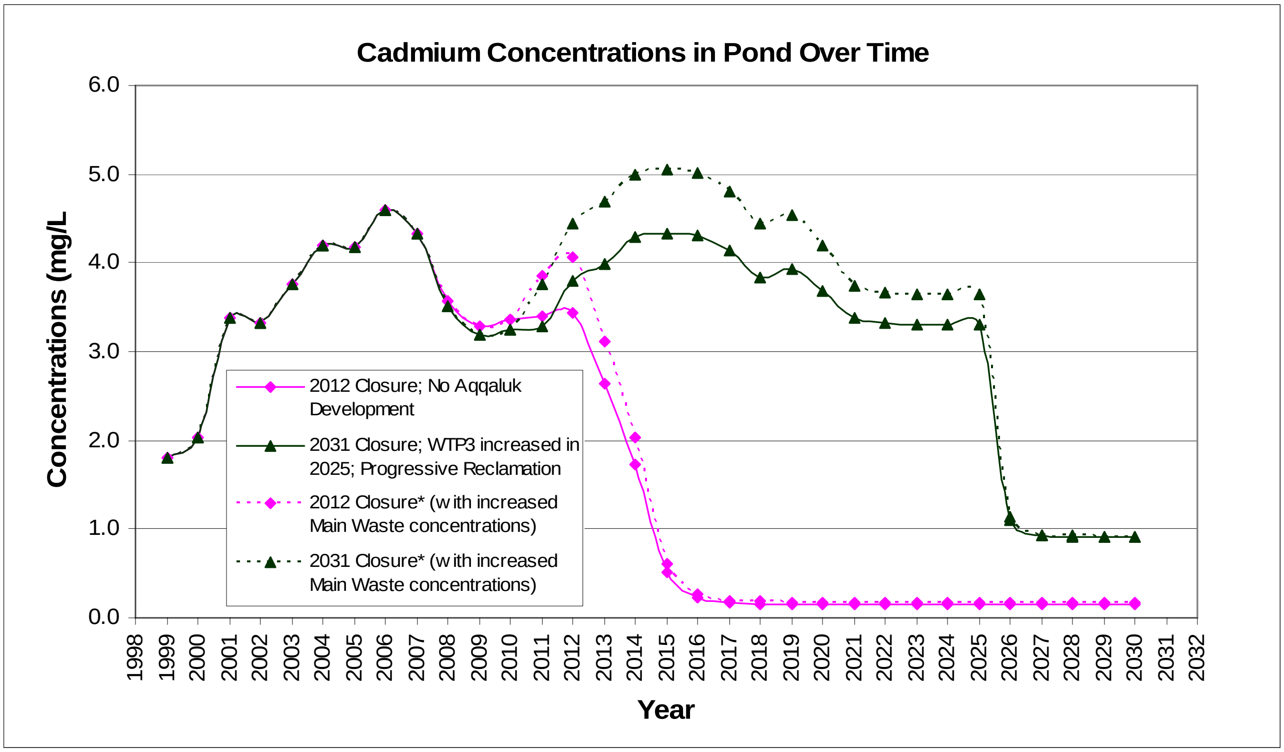

Figure 12: Cadmium Concentrations in Pond during Operations

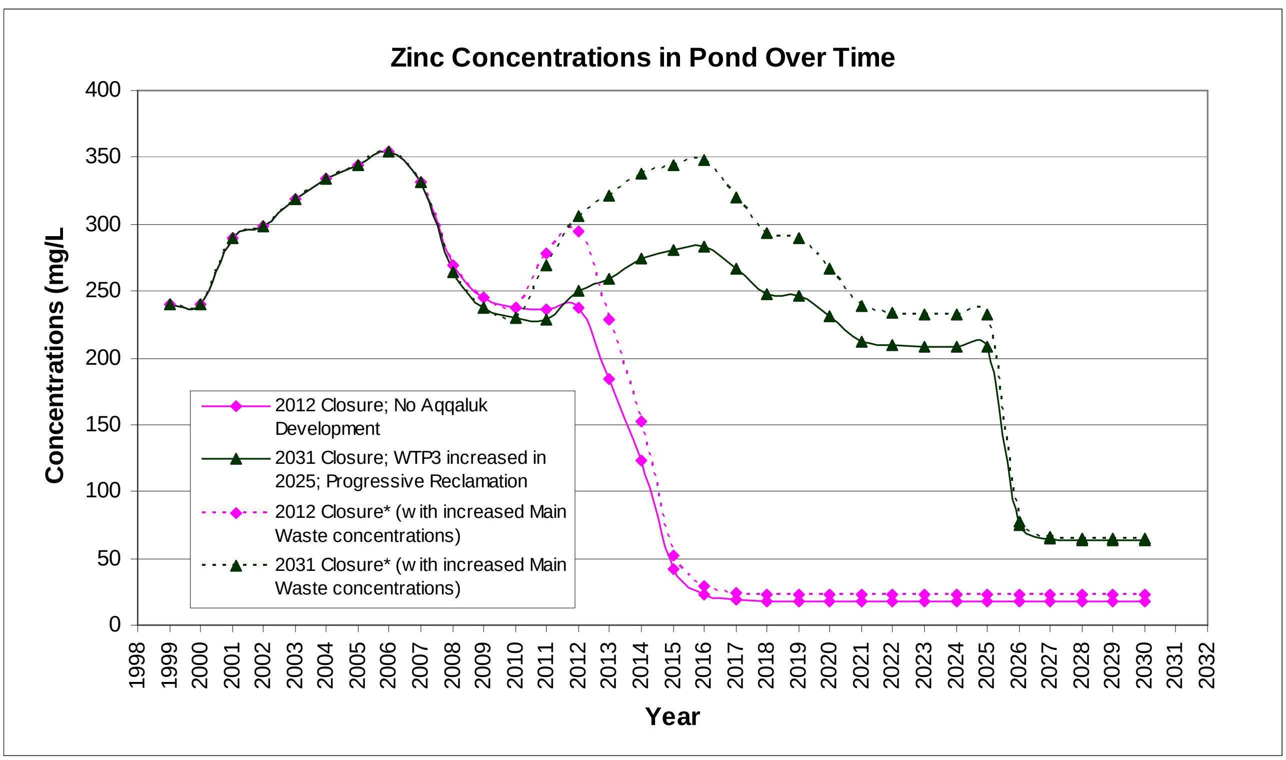

Figure 13: Zinc Concentrations in Pond during Operations