Management of Acid Rock Drainage at Britannia Mine, BC
Part 2: Water Treatment Plant Implementation and Operations

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Abstract
The Britannia Mine, located 45 km north of Vancouver, British Columbia, Canada commenced production of copper ore over 100 years ago. Some 37 years after the mine closed, it continues to generate an average of about 300 kg/day each of copper and zinc, as well as relatively minor amounts of other metals, dissolved in some 5 million cubic metres of acid rock drainage (ARD) each year. Environmental remediation work by the Province of British Columbia commenced in 2001 with several technical studies aimed at collecting data to support a remedial concept for the mine. Several of these studies focussed on the feasibility of a water treatment plant (WTP) for the ARD and metal-contaminated groundwater, including mine hydrogeology, hydrology, geochemistry, mine workings water storage capability/reservoir management, residual handling/management, plant location selection and outfall design/location selection. These studies were used to develop a conceptual water treatment plant design used in a design-build-finance-operate (DBFO) procurement process for the WTP. Part 1 of this paper described the background and context of the water treatment plant at Britannia.

Key Words: Britannia, DBFO, ARD, PPP, Operations, Water Treatment

Procurement
The Britannia Mine Remediation Project and specifically the Water Treatment Plant (WTP) had multiple objectives by the time it was conceived as a project. It was primarily driven by the technical aspects of ensuring the mine discharge was compliant with the provincial Environmental Management Act and the Discharge Permit, and that future environmental liabilities associated with the contamination of the Britannia Mine site (the Site) would be minimized for the Province of BC. Key to these points however, was that the lifecycle costs were optimized and that taxpayers would be protected to the highest extent possible from cost over-runs. Additionally, with the development of the surrounding land, there was incentive for both the Province and the developer to ensure that there was a high degree of public confidence in the treatment of metal-contaminated water at the Site.

In 2003 the owner of the Site, then the Ministry of Sustainable Resource Management began working with Partnerships BC to select the optimum means of project delivery. The traditional engineering, procurement, and construction (EPC) model and alternative delivery options, including a Design Build Finance Operate model, were considered. As a result of the years of study that had gone into the project, it had a well-defined scope and associated risks which made it a good candidate for a competitive public private partnership (PPP). EPCOR was selected in November 2004 from a slate of six proponents through a competitive proposal process to complete the WTP and ancillary components. The primary project risks and their allocation in the Project Agreement are shown below in Table 1 (from Partnerships BC, 2005).

Table 1: Project Risk Allocation

Project Risk	Partner Accepting Risk
Construction Cost	EPCOR
Schedule	EPCOR
Operations and Maintenance Costs	EPCOR
Financing	EPCOR
Inflation	Both
Volume of Water	Province
Water Chemistry	Both
Scope/Regulatory Changes	Province
Catastrophic Failures	Province
Geotechnical Risk	Both
Environmental Liability	Both

EPCOR along with its design build partner Lockerbie Stanley Inc was able to provide a fixed price construction bid to the Province at a time when construction costs were escalating rapidly. Payments are made to EPCOR by the Province on a monthly basis for twenty years comprising a base payment amount for the construction cost as well as a variable operations payment made up of several components including chemicals, power, and residuals handling and disposal. Each of the operational components has an efficiency factor which was competitively bid, effectively transferring the operational risks to EPCOR. With the exception of a brief period during commissioning, the entire payment made to EPCOR is performance-based, with the key parameter being discharge water quality. The project schedule was driven by the WTP discharge permit issued by the BC Ministry of Environment (MoE) which came into effect January 1, 2006, with the incentive of the performance based penalties if the schedule was not met.

A Project Agreement was executed by EPCOR and the Province in January 2006. Several items were added to the scope of the construction for the WTP including the design, construction and operation of the groundwater management system (GMS), the 4100 Level adit rehabilitation/upgrades to a “civil” standard, and architectural enhancements to the WTP building that were selected through a stakeholder consultation process. EPCOR also included a Discovery Centre within the WTP with interactive educational displays where the Britannia Mine Museum conducts tours of the Site. The GMS was operational by May 2005, the main WTP groundbreaking was April 2005 and the WTP was operational by October 21 2005, more than two and a half months ahead of schedule. Utilizing a public sector comparator, the twenty year life cycle cost of the Britannia Mine WTP is $27.2 million, a savings of $12.5 million over traditional delivery (Partnerships BC, 2005).

Water Treatment Plant Design and Construction

EPCOR considered two main options for the design of the WTP. Both the traditional high density lime sludge process (HDS) and a combined HDS – sulphide chemistry (metal extraction) process were considered in the design phase. Several key factors were important in making the final selection for proposal. The end point of the design was clear as the draft discharge permit parameters had been determined in 2003 based largely on a technical assessment (EVS, 2003). The primary contaminants of concern from the environmental impact study were copper, zinc, and cadmium. While the sulphide chemistry process would have produced a lower volume of sludge and would have essentially eliminated the contaminants of concern as they would have been captured and re-used; that process is most effective at higher concentrations of metals.

Although the Site had been well studied and the early HDS process piloting had been undertaken, the mine water chemistry changed with the construction of the 2200 Level plug in December 2001 and the samples that had been taken of the acid rock drainage (ARD) showed high variability. When the analysis was done on the specific flow ratios from the 2200 and 4100 Levels, the expected water chemistry showed lower contaminant concentrations than had been previously measured. Additionally, the very high concentrations of metals seen in the testing were associated with short duration events during flood testing of the mine reservoir. As discussed in an upcoming section, the mine reservoir was expected to largely operate under essentially flow-through conditions once the WTP was constructed. This means the water level in the mine was expected to remain relatively stable and there would only be limited periods where the metals concentrations may spike with brief high inflow periods to the mine. In these conditions, water levels in the reservoir would rise, bringing previously un-wetted mineralized rock into contact with the water held in the reservoir. With respect to the groundwater being pumped from the GMS, the overall concentrations of metals were not significantly higher than the mine workings ARD. The primary design consideration with respect to the treatment of groundwater was the chloride concentrations. A limit of 1,000 mg/L chloride was specified to limit potential complications with the lime treatment and corrosion of the WTP equipment and infrastructure. Ultimately the influent water chemistry was the primary driver of the final design selection, and with the high probability that the long-term water chemistry would be less contaminated than prior test results had shown, the high density lime sludge process was chosen. The water chemistry data that were provided in the request for proposal (RFP) are shown in Table 2 below as well as the subsequent average water quality data over the past five full years of the Britannia Mine WTP operation. In general, metals concentrations have been relatively low compared with the design parameters, with all parameters at or below the low sensitivity for the design level chemistry.

Table 2: Britannia Mine 4100 Adit Mine Workings Water Chemistry

	Dissolved metals (mg/L)						**pH**
	Al	**Cd**	**Cu**	**Fe**	**Mn**	**Zn**	
Mine Workings 2006	21	0.090	17	1.3	4.9	20	4.0
Mine Workings 2007	19	0.098	17	0.69	4.4	20	3.7
Mine Workings 2008	16	0.086	14	0.60	3.5	15	3.8
Mine Workings 2009	19	0.088	16	0.52	4.2	18	4.1
Mine Workings 2010	19	0.088	14	0.71	4.0	19	4.2
RFP 'Typical' Value	39	0.12	32	14	6.4	24	3.5
RFP 10th Percentile Value	26	0.103	25	2.6	4.6	22	3.2
RFP 90th Percentile Value	73	0.126	55	63	12	27	3.7
Groundwater 2006	27	0.1	9	16	1.5	9	4.6
Groundwater 2007	25	0.042	8.3	3.5	1.4	8.1	4.2
Groundwater 2008	20	0.038	6.9	3.7	1.1	5.6	4.0
Groundwater 2009	29	0.051	8.8	8.0	1.5	8.7	3.8
Groundwater 2010	31	0.044	8.5	10.4	1.6	8.1	3.9
Predicted Groundwater typical	50	N/A	10	50	N/A	20	4

	Dissolved metals (mg/L)						pH
	Al	Cd	Cu	Fe	Mn	Zn	
value @ RFP Stage							

The projected mine workings total acidity was 346 mg $CaCO_3$/L ranging from 10th percentile 195 mg/L to 90th percentile 686 mg/L; and the projected sulphate typical value of 1,659 mg/L ranging from 10th percentile 1,454mg/L to 90th percentile 2,330 mg/L. All chemical parameters follow the same trend as the contaminants of concern, the long-term water mine workings ARD has been less contaminated than expected. The actual long-term average total acidity in the mine workings is 198 mg $CaCO_3$/L and the sulphate is 1,289 mg/L.

Along with the influent water chemistry, the WTP flow was a key design factor. There were three key flows that required consideration. The first was the design flow of the WTP at 1,050 m^3/hr (25 MLD) for which the chemical feed systems bulk storage as well the mix tanks, reactors, and blowers had to be sized. This was the flow that the WTP was to be designed to achieve the water quality targets. The hydraulic capacity of the WTP of 1,400 m^3/hr (34 MLD) drove the main infrastructure design, including the sizing of the piping feeding the clarifier, through the reactors and from the clarifier launders to the new outfall. The intent was that during high mine inflow events, even if the WTP flow could not achieve the permitted water quality limits, the water would at least be partially treated, with the key being dissolved copper and zinc removal. Finally the WTP and bypass hydraulic capacity of 3,600 m^3/hr (86 MLD) was taken into account for the plant outfall and associated piping design as well as the piping configuration from the plug in the 4100 Level through the micro-hydro turbine building. In the event of extremely high snowpack events (1 in 50 year event) where there was a rapid onset of freshet, there was consideration that only a portion of the flow coming from the mine could be treated and the remainder of the flow would need to be safely conveyed to the discharge point in Howe Sound. Any flow past 1,400 m^3/hr would bypass the WTP, be pH adjusted with lime and then blended with the treated WTP effluent prior to discharging into the deep water outfall.

Water from the mine can be conveyed to the micro-hydro turbine building either through the high pressure penstock, or alternatively through a low pressure line which follows an energy dissipation chamber located underground at the 4100 Level plug. All flow up to the hydraulic capacity of the WTP then moves into the first reactor where it is combined with the GMS water and the overflow from the lime sludge mix tank. Air is also introduced into the reactor to oxidize the iron and manganese to their highest oxidation state, removing the acid-generating potential and allowing them and other metal sulphates to be precipitated with lime. A mechanical mixer mounted on the top of the baffled reactor provides efficient mixing prior to the flow entering the second reactor. Air continues to be introduced in the second reactor and a high molecular weight anionic polymer is introduced at the reactor effluent, prior to the water entering the 33m diameter clarifier. The solids content within the reactors ranges from 3 to 5% (w/v).

Approximately 70 tons of quicklime (CaO) is stored in a silo at the WTP and the lime is slaked and fed to the lime sludge mix tank as a slurry. The pH of the process is tightly controlled between 9.2 and 9.3 and approximately 20% of the incoming flow is re-circulated into the lime sludge mix tank where it overflows into the first reactor tank. The remainder of the sludge is drawn from the bottom of the clarifier and temporarily stored in an onsite storage tank before being dewatered in a plate and frame press. Each filter press produces approximately 3.3 m^3 of dewatered sludge cake that ranges from 40 to 50% solids (w/w). The dewatered sludge is stored on site year round utilizing legacy concrete infrastructure as an impoundment basin. Runoff management and cover have been added to the temporary storage site with storm flows from the sludge management area contained and treated at the WTP. Depending on annual flow and sludge generation, the sludge is transported to the permitted disposal facility in Jane Basin approximately 11.5 km from the WTP site either once or twice per year. Access to Jane Basin is limited seasonally due to the high elevation. Jane Basin was selected as the disposal site for the mine residuals as the WTP functions as the ultimate treatment of any runoff/leachate water from the disposal site as the water entering Jane Basin flows into the mine workings and reports back to the WTP.

The complete flow and process schematic for the WTP is shown in Figure 1 below.

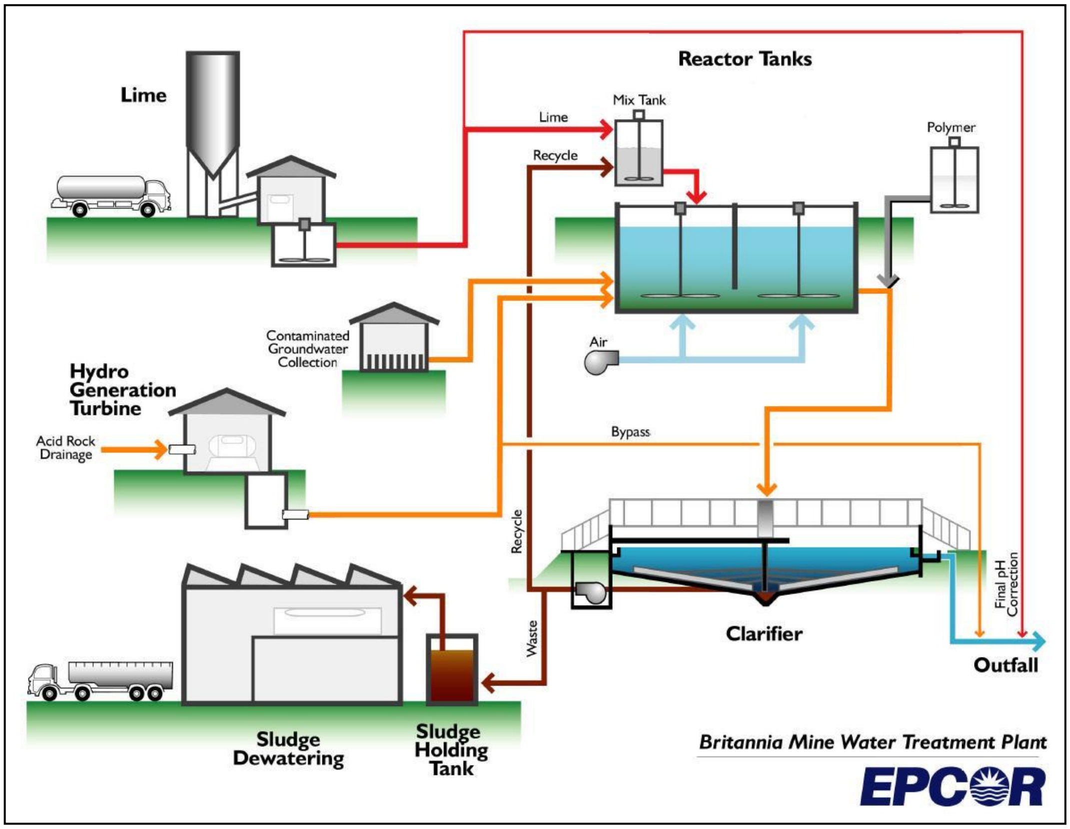

Figure 1: Britannia Mine WTP Schematic.

EPCOR undertook several design initiatives with a view to adapt LEED (Leadership in Energy and Environmental Design) concepts where possible. Although the LEED rating system is restricted to commercial and residential facilities, the framework was used to assess the plant design through the process to provide the most balanced project possible with respect to environmental, social, and economic responsibilities. Water efficiency at the site was a key issue through the design and construction due to the remote location of the WTP and the majority of the process water used at the WTP is treated effluent. Although the WTP was connected to the municipal water system in 2008, that water is typically only used for limited domestic use, with WTP effluent still meeting the process water needs.

Another of the innovations within the design is the micro-hydro turbines which feed the WTP. The discharge from the mine reservoir is through a plug that was installed in 1978 at the 4100 Level of the mine. The installation of the plug created a large reservoir within the workings of the mine with an estimated volume of 430,000 m^3 and capable of reaching water levels within the mine of over 266 m. In order to take advantage of this potential energy, two 110 kW impeller style turbines were installed just outside of the 4100 Level adit and fed through a 12” stainless steel penstock. During periods of high inflow to the mine, the electrical load of the WTP can be partially offset by the on-site generation of power. The configuration of the generators is one duty and one standby, and the flow through the mine plug can be diverted through the penstock or bypass it completely or partially and then flow by gravity into the WTP. Power usage at the WTP varies seasonally, with electric fan heaters driving power costs up in the cold months when mine inflows are lowest; however, the average on-site generation when the turbines are operating is 40% of the WTP running load.

A geothermal heating and cooling system was also designed for the WTP, although ultimately the small size of the WTP meant reduced payback for the construction of the system. Considering the competitive nature of the project and the prescribed evaluation criteria which were largely capital and life cycle cost driven, the system was not able to be justified and was not constructed.

Britannia Mine Reservoir Operations Plan

The available storage volume in the mine reservoir is comprised of the 4100 Level tunnel behind the plug, a raise located a short distance upstream of the 4100 Level plug, referred to as the '2700 Raise', that connects the 4100 Level tunnel to the 3250 Level tunnel, and the mine workings east of the 2700 Level Raise that constitute most of the available storage volume. The mine water overtops at the 3250 Level at 266 m static water level. The primary goal of the mine reservoir operations plan (ROP) is to meet the requirements of the Ministry of Energy and Mines (MEM) Mines Act Permit M-214 as well as the MoE *Environmental Management Act* Permit PE-17469 and to minimize the possibility of mine water overtopping and discharging uncontrolled at the 3250 Level portal, and then to Mineral Creek, a tributary of Britannia Creek, which discharges into Howe Sound; and to treat the maximum amount of water to a high standard. Thus, the specific goals of the ROP are to mitigate the potential environmental impact of extreme events when the short-term mine inflow exceeds the WTP capacity and mine reservoir storage capacity.

Development of the ROP was an iterative process with WTP and reservoir operational experience and hydrology modelling driving each version. The current version has been simplified over previous models and has been in practice since 2007. Flow into the mine reservoir is not consistent through the year; the vast majority of flow (80%) comes from the snow melt water infiltrating the mine workings through the Jane Basin/Fairwest open pit/glory hole complex, with the remainder from regional groundwater flow and other mine entry points. Over 50% of the annual WTP flow is treated in May through August and this period represents the highest risk time when the capability of the WTP infrastructure and mine storage capacity to handle mine inflows may be challenged. To mitigate the risk of overtopping or the requirement to bypass the WTP with excess flow above the WTP hydraulic capacity, the mine reservoir level is brought down to the lowest operational level possible, typically around 30-40 m. The mine reservoir cannot safely be brought below 20 m as this volume is considered dead storage which is maintained to mitigate the potential for floating debris within the mine workings to enter the WTP infrastructure or compromise the ability of the piping through the plug to convey water into the WTP.

As the flow into the mine increases, the WTP influent flow is increased up to the design capacity of 1,050 m^3/hr. Once the design flow capacity of the WTP is reached, notification requirements to MoE as well as additional sampling and testing requirements are triggered. As the inflow to the mine increases further, the WTP flow is matched up to its hydraulic capacity. Operational experience through commissioning of the WTP including hydraulic flow tests, operational acceptance tests, and the past six years of freshet flows, has proven that the WTP is capable of meeting permit limits for metals, Total Suspended Solids (TSS), pH and toxicity up to the maximum flowrate of 1,400 m^3/hr. If the mine inflow continues to increase, the water level in the mine reservoir rises while the WTP continues to treat water at the hydraulic capacity. If the mine level increases to 230 m, the WTP bypass is initiated at a flow matching the inflow to the mine reservoir minus the hydraulic capacity of the WTP up to total combined bypass and WTP flow of 3,600 m^3/hr (the maximum flow capacity of the pipework through the plug in the 4100 Level). The bypass flow is pH-adjusted with lime and blended with the treated water from the WTP prior to entering the outfall. Water quality testing during a hydraulic flow test showed that the blended bypass and WTP discharge water is capable of passing a 96 hour LC50 toxicity test with juvenile rainbow trout. The test result of LC50 $\geq$ 100% was not only achieved, but all of the rainbow trout survived in the combined bypass-effluent water for the 4 day test.

In the event that the mine reservoir level continues to increase and is projected to surpass 266 m and overtop at the 3250 Level, emergency procedures would be initiated with co-ordination of MoE, MEM, MFLNRO, and EPCOR resources. The consultants SRK Consulting (Canada) Inc. and Golder have undertaken extensive modelling of the flows through the mine reservoir and by applying the above strategy to the historical mine inflows dating back to 1978, showed that an overtopping event at the 3250 Level would not occur. However, modelling indicated that there would be two bypass events in this modelled period (SRK, 2008). The historical modelling data includes a one in fifty year return period snowpack (1999) where inflow to the mine exceeded 3,600 m^3/hr for one day. In the event that a snowpack that exceeds the one in fifty year return period were to occur, the hydrology model would be reviewed and bypass could be initiated sooner than the 230 m trigger point to mitigate the possibility of overtopping at the 3250 Level. Table 3 shows the key decision points and associated WTP and infrastructure design flows.

Table 3: Britannia Mine Reservoir Operations Plan

	Target Mine Level (m)	**Mine Core Level (m)**	**Flow Through 4100 Level Plug**		
			Design Capacity < 1,050 m^3/hr	**Hydraulic Capacity < 1,400 m^3/hr**	**pH Adjusted WTP By-Pass < 3,600 m^3/hr**
Prior to Freshet	40	<40	✓		
High Inflow Potential Period Apr 15 to Aug 1	(30-60)	40-230	✓	**	
		>230	✓	**	**
Low Inflow Potential Period Aug 1 to Apr 15	90 (80-100)	<90	✓		
		>200	✓	**	
		>230	✓	**	**

*** WTP flow exceeding the WTP design capacity triggers water quality monitoring and reporting requirement for WTP effluent and/or combined WTP effluent/bypass streams*

Other than during the freshet flows, there is very little risk of the WTP bypassing. Although the Britannia Mine is situated along the Pacific Northwest coast and receives significant fall rains, the volume entering the mine has not historically been high enough to overtop the 3250 Level following the strategy of matching the WTP flow to mine inflows. Once the freshet flow has been treated and the snowpack is gone, there is little risk of having to bring the WTP past the design capacity and the mine level is deliberately raised in order to generate hydro electric power. As can be seen in the decision matrix in Table 3, the same strategy would apply as during the high inflow potential period if the inflow to the mine rises past the capacity to treat the flow up to the design capacity. Information on the mine reservoir level as well as weather stations at the WTP and Jane Basin are continuously monitored and the information from this instrumentation is used in the decision making process.

Britannia Mine Water Treatment Plant Operations

Flow

Once construction was completed, two key performance tests were required by the Province. First was the test of the WTP and associated infrastructure up to the required maximum flow of 3,600 m^3/hr. This was a relatively short duration test with the maximum bypass and WTP flow maintained for just over one hour to collect the required water quality data, prove the infrastructure, and minimize the environmental impact of discharging partially treated ARD to the marine environment. The second test was the operational acceptance test where the WTP was run at the design capacity of 1,050 m^3/hr for thirty consecutive days with daily water quality tests for dissolved metals. Table 4 summarizes the annual flows through the WTP and the bypass flow in 2006 is from the outfall and commissioning work required by the Province and authorized by the MoE to prove performance. The bypasses in subsequent years represent the flow from the GMS that are diverted to the deep water outfall during the annual WTP maintenance shut downs. These bypasses were authorized by the Province under the Approved Operations and Maintenance plan. During the scheduled WTP shutdowns, the water level in the mine reservoir is allowed to rise and no untreated water is discharged.

Table 4: Britannia Mine Water Treatment Plant Annual Flow

Month	Mine Workings Flow (m^3)	Groundwater Flow (m^3)	WTP Flow (m^3)	Bypass Flow (m^3)
2006	3,819,400	103,600	3,907,700	38,800
2007	5,136,900	119,500	5,258,400	2,140
2008	3,761,800	74,400	3,836,200	1,260
2009	3,269,000	101,700	3,370,700	640
2010	4,313,100	111,300	4,427,600	400
Average	**4,060,040**	**102,100**	**4,160,120**	

It is worth noting that the flow through the WTP along with the water chemistry differs from the expectations at the RFP stage of the project. At that time, the typical or average flow to the WTP was projected to be just under five million m^3 annually, with additional groundwater flow up to half a million m^3 annually. The difference in flow seen at the WTP can be accounted for by several factors. At the same time the WTP was being constructed, the Province was also installing surface water diversions to reduce the amount of runoff entering the numerous glory holes around the Site. Three main locations were identified to divert flow from entering the mine: East Bluff diversion, Upper Jane Creek diversion, and the Victoria diversion. The purpose of the surface water diversions is to minimize treatment costs to the Province and is an important part of the high inflow mitigation strategy to reduce the number and volume of potential bypass events and reduce the risk that overtopping at the 3250 Level could occur. As the diversions primarily function during the freshet, they act to reduce the impact of the high inflow events and thus also reduce the chance of debris movement within the mine workings that may potentially modify or restrict the flow through the mine reservoir. The annual impact of the diversions is summarized in Table 5 (from SRK, 2011).

Table 5: Britannia Mine Surface Water Diversion Flow Summary

Water Year	East Bluff Diversion Flow Volume (m^3)	Upper Jane Creek Diversion Flow volume (m^3)	Victoria Diversion Flow volume (m^3)	Est. Total Diversion Flow Volume (m^3)
2005	58,500			58,500
2006	109,000	218,000		327,000
2007	111,000	236,000	>38,000	>385,000
2008	76,500	154,500	>23,000	>254,000
2009	52,000	103,500	17,000	172,500
2010	70,200	191,200	15,400	276,800
Total	**477,200**	**903,200**	**>93,400**	**>1,473,800**

Although there have been some maintenance issues with the diversions due to their remote location, their performance has been excellent overall. At the onset of the project, the impact of the diversions could not be estimated, however, at this point, the reduction in flow to the WTP is on average, approximately 7%, with the largest benefit being their effect on peak flows.

Along with the surface water diversions, the total flow of contaminated groundwater to the WTP is less than the maximum volume that was specified at the proposal stage. To date, the actual annual volumes of groundwater treated have only been 20% of the specified maximum. Although the capture of the contaminated groundwater is limited by the maximum chloride content of the groundwater, the lack of quantitative contaminated groundwater flow data at the project development stage is the main reason for the flow discrepancy. Two additional pumping wells were added in 2009, and as the GMS is optimized further it is likely that more groundwater will be fed to the WTP. In additional, treatment of some metal contaminated surface water run-off may be undertaken in the future, again with potential increased inflow to the WTP.

The final factor accounting for the flow discrepancy between the projected and actual flows is similarly attributable to the data available at the project definition stage with respect to the impact of plugging the 2200 Level portal. During the time period when the flow data from the 2200 Level was collected (1997-1999), the flows were significantly higher than average, however, this data was used as representative of the typical flow coming from the 2200 Level portal. Once this portal was plugged in 2001, the water that was discharging at this point was diverted internally within the mine workings to the 4100 Level. Ultimately, however, the end result of these three factors was the design and construction of a WTP that is suitably conservative to meet the range of flow conditions that can be expected to require treatment and include a contingency factor for potential additional sources of water such as metal contaminated storm water runoff. Updating the historical inflow model, the projected long term flow to the WTP is expected to be similar to the average flows shown in Table 4.

Treatment Performance
The overall performance of the WTP has been consistent across the inflow and chemistry conditions experienced to date. The pH in the reactors is kept at 9.2 to 9.3, which although low for a conventional HDS plant, is adequate to achieve the permit limits at the Site. A summary of the chemical usage at the WTP is shown in Table 6.

Table 6: Average Annual Chemical Usage

Year	Average Lime Dose (mg/L)	Average Polymer Dose (mg/L)
2006	266	2.0
2007	236	1.9
2008	232	2.1
2009	219	2.0
2010	228	1.8
Average	**236**	**2.0**

These values are annual mass basis averages; however, they are representative of the treatment conditions at the WTP. The polymer dose is identical to the required dose that was predicted at the design stage. Lime usage directly correlates to the mine workings total acidity and pH and follows the identical pattern as the influent water chemistry, with usage at the lower sensitivity of the range of initial conditions provided.

WTP effluent quality has proven to be stable and consistently below the discharge permit limits. At the time the project was being defined additional discharge permit criteria were provided to the various proponents clarifying the expectations of what the WTP discharge should be technically capable of achieving. These values are guidelines only and exceeding them does not trigger any adverse reaction to the operator. Both the discharge permit limits and Provincial guideline limits for dissolved metals are shown in Table 7. The parameter of manganese is a monitoring requirement only and is not included in the discharge limits. Along with the dissolved metals concentrations, the WTP effluent must also remain between pH 6.5 to 9.5, discharge total suspended solids less than 30 mg/L and must pass a monthly acute toxicity test (96 hour LC50 with rainbow trout). Over the past five full years of operation, the WTP has consistently surpassed the discharge permit limits as well as meeting the Provincial guideline limits most of the time. With monthly toxicity testing, there have been over sixty 96 hour tests, and through all of the tests not a single fish has died in diluted or undiluted plant effluent. The WTP discharge water pH is consistently 9.2 and the total suspended solids less than 2 mg/L.

Table 7: Average Annual Britannia Mine WTP Effluent Water Quality

Month	WTP Effluent Dissolved Metals (mg/L)					
	Al	**Cd**	**Cu**	**Fe**	**Mn**	**Zn**
2006 Average	0.5	0.002	0.01	0.01	0.3	0.02
2007 Average	0.5	0.001	0.01	0.05	0.1	0.03
2008 Average	0.5	0.001	0.02	0.01	0.3	0.04
2009 Average	0.4	0.001	<0.01	0.01	0.4	0.03
2010 Average	0.5	0.001	<0.01	<0.01	0.4	0.03
Discharge Permit Limit	< 1	< 0.01	< 0.1	< 0.1	N/A	<0.2
Provincial Guideline Limit	< 0.5	< 0.001	< 0.02	< 0.01	0.2	<0.03

Originally manganese was included within the permit limits for the WTP at a value of 0.4 mg/L even though the metal was not assessed during the Environmental Impact Study conducted by EVS Environmental Consultants in 2003 (EVS, 2003) and was not included in the proposed permit limits. The inclusion of manganese in the permit application was determined to be an administrative rather than technical issue with the value of 0.4 mg/L selected as twice the design value from the original HDS piloting. A thorough literature review was conducted by Golder (Golder 2007) on manganese toxicity and discharge limits in other jurisdictions, including potential impacts on the receiving environment, and recommended removing manganese from the discharge permit limits. The same study, finding a gap in the literature of toxicity of manganese to marine fish, conducted a 7 day survival and growth test with marine larval fish. The no observed effect concentration (NOEC) and the lowest observed effect concentration (LOEC) for survival were 10 mg/L and 20 mg/L respectively; the NOEC and the LOEC for growth were 2.5 mg/L and 5 mg/L respectively. Ultimately, it was determined that the treatment for manganese, which included the addition of potassium permanganate, had a more potentially detrimental impact to the environment when considering the production, transport, and application of the chemical than any tangible environmental benefit to reducing WTP effluent manganese consistently to below the permit levels and the recommendation of changing manganese to a monitored parameter only was implemented by the MoE.

Since the WTP commissioning was completed in 2006, there have been two instances where the WTP effluent discharge criteria were not met for one day. The first incident in February 2010 resulted from a complete WTP programmable logic controller (PLC) failure. The second, in May 2011 was the result of a failure of the WTP alarm dialler at the same time that the lime system became plugged with a foreign object. With the Project Agreement between the Province and EPCOR, strict daily performance penalties ensured that incidents were quickly and thoroughly investigated and the WTP effluent was quickly brought back into compliance. Each day of non-compliance can result in a deduction of not only the operational, but the capital costs of the construction of the WTP. With the robust design and construction of the WTP along with well developed operational processes, the WTP has been in compliance with the discharge permit 99.9% of the time over its approximately 6 years of operation.

References

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Acronyms

DBFO	design-build-finance-operate
EPC	engineering, procurement, and construction
GMS	groundwater management system
HDS	high density lime sludge process
LEED	Leadership in Energy and Environmental Design
LOEC	lowest observed effect concentration
MEM	Ministry of Energy and Mines
MoE	BC Ministry of Environment
NOEC	no observed effect concentration
PLC	programmable logic controller
PPP	public private partnership
RFP	request for proposal
ROP	reservoir operations plan
TSS	Total Suspended Solids
WTP	water treatment plant