Water Quality Modelling of the Tailings Disposal Facility at Nyrstar Myra Falls

Rina Freed[1], Rob Marsland[2], Jean Cho[3], Ivor McWilliams[4] and Sharlene Henderson[5]

[1]Marsland Environmental Associates, Bowen Island, BC, CANADA, rina.freed@meabc.ca
[2]Marsland Environmental Associates, Nelson, BC, CANADA, rmarsland@meabc.ca
[3]Marsland Environmental Associates, Vancouver, BC, CANADA, hjeancho@gmail.com
[4]Nyrstar Myra Falls, Campbell River, BC, CANADA, Ivor.McWilliams@nyrstar.com
[5]Nyrstar Myra Falls, Campbell River, BC, CANADA, Sharlene.Henderson@nyrstar.com

Abstract
At Nyrstar Myra Falls, drainage from sub-aerial waste rock and tailings are managed with an under-drain system designed to collect the acidic, metal-laden seepage. A proposed closure cover design is considered in terms of water quality loadings to the receiving environment and the treatment system. The cover design differs for paste tailings, conventional tailings and waste rock. Priorities of the closure plan are to minimize loadings to the receiving environment and to the drainage collection system.

A groundwater model developed for the site was used to evaluate the changes in groundwater concentrations expected for the proposed cover design. A contaminant loading model is also presented for the current condition and post- closure condition. This loading model includes Myra Creek, the under-drains, waste rock sources and tailings sources. Among the cover options considered, reducing infiltration into waste rock is expected to cause the largest reduction of loadings post-closure.

Key Words: waste rock, under-drain, zinc, hydrogeology, paste tailings, covers

Introduction
The Tailings Disposal Facility (TDF) at Nyrstar Myra Falls forms part of the larger Myra Falls mine site which has been operational since 1966, producing copper, zinc and lead concentrates with silver and gold credits. The site is located within Strathcona-Westmin Provincial Park, approximately 90 km from Campbell River on Vancouver Island and is currently owned by Nyrstar, following their purchase of Breakwater Resources Limited in August 2011. Figure 1 shows an aerial image of the TDF. The TDF is a forty-four (44) hectare, oval-shaped tailings impoundment. The dashed line in Figure 1 indicates the extent of the TDF area included in the TDF closure plan. There are about 30 m of sub-aerially deposited conventional tailings with 10 m of paste tailings placed on top. The remainder of the conventional tails not covered by the paste tails is called the "strip". A Reclaim Sand Area (RSA) stores a coarser fraction of tailings, produced for backfilling underground. The entire facility is supported by a stabilizing toe-berm referred to as the Seismic Upgrade Berm. Waste rock also forms a component of the TDF as tailings were placed adjacent to and on top of the waste rock. The waste rock outline in Figure 1 shows the extent of the waste rock considered in the water quality model as a TDF source area. Other waste rock on site is not considered as a part of the TDF waste rock source area.

The waste rock and tailings at Myra Falls are considered Potentially ARD Generating (PAG). Much of the waste rock has been generating acidic drainage for decades. As such, the TDF is equipped with a number of under-drains designed to protect Myra Creek from contaminated groundwater seepage. The TP4 automatic sampling station collects daily water samples from Myra Creek.

The final paste lift of the TDF is at capacity and a cover design for closure has been proposed for the whole facility. Water quality modelling of the TDF was recently completed to enable a comparison of current conditions with expected changes resulting from the proposed tailings and waste rock cover components. Three distinct covers make up the full TDF closure design proposed: a geo-synthetic liner on the strip, RSA and the paste berm; a waste rock and till cover on the paste tailings; and a till cover on the re-contoured waste rock within the TDF footprint.

Figure 1. Aerial photo of the TDF, 2007

Current Condition

An investigation of the current conditions in Myra Creek and in on-site groundwater was conducted in 2010-2011. In Figure 1, Myra Creek can be seen along the lower portion of the TDF, flowing from left to right. Zinc is the main contaminant indicator for the mine site. In 2010, the average zinc concentration measured in Myra Creek upstream of the mine (MC-M1) was 0.0006 mg/L, while the average zinc concentration in Myra Creek downstream of the mine (TP4) was approximately 0.1 mg/L. The water quality at the downstream end of Myra Creek varies seasonally, typically with higher concentrations in the rainy season, about November to April. In the last three years, the maximum zinc concentration did not exceed 0.3 mg/L.

Conceptual model for Myra Creek and Pumphouse 4

A water quality model was developed in Excel to estimate the loadings to Myra Creek. The water quality model is based on the conceptual model depicted in Figure 2. Sources entering Myra Creek upstream of the TDF are considered together. A water treatment system for the site discharges into the right bank of Myra Creek, shown as “treated effluent” in Figure 2. Loadings from the TDF that enter Myra Creek via groundwater migration bypass both under-drains shown in Figure 2. In the water quality model, the paste tailings, conventional tailings and RSA tailings are considered as a combined “tailings” source area. The waste rock source in the model is assumed to be the surface exposed area, with higher infiltration rates than the buried area.

During the initial construction of the TDF in the 1980s, an Inner Drain was placed along the toe of the waste rock dump that is now buried under tailings. The full extent of the waste rock is shown by the dashed line in Figure 2. The Outer Drains are a simplification of four drains which function overall as the combined Outer Drains (MEA, 2011). Discharge from the Inner and Outer Drains is collected in Pumphouse 4 (PH4) and pumped to the site water treatment system.

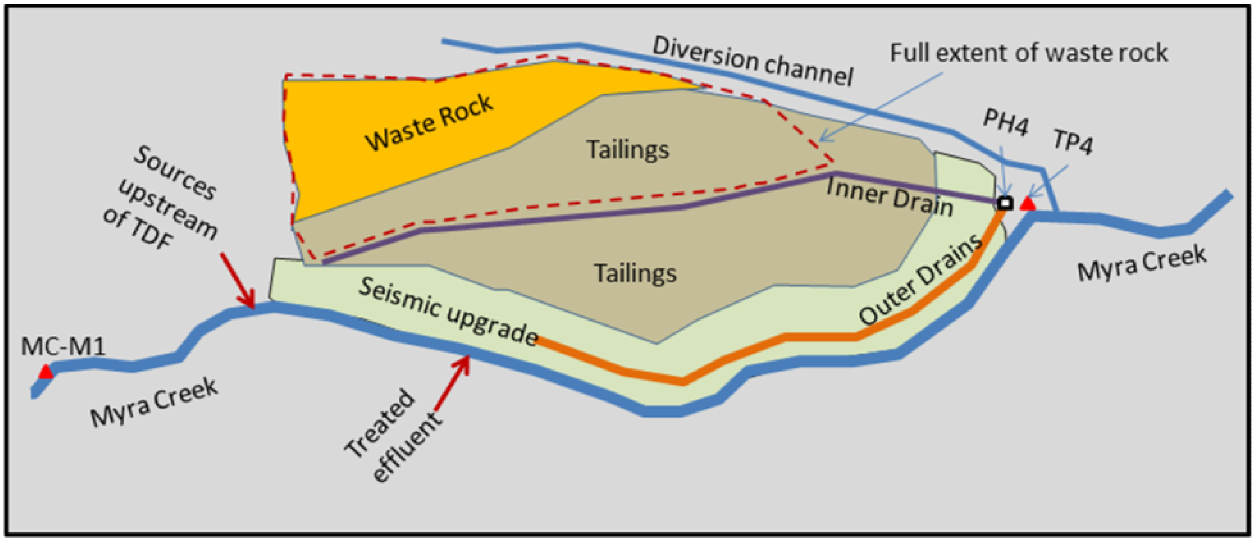

Figure 2. Conceptual model for Myra Creek load balance

Loadings at station TP4 for 2010 were estimated from observed data as shown in Table 1. The loading component at TP4 attributed to the TDF was estimated by removing the loadings from the other sources. The average treated effluent concentration of dissolved zinc (2010) is 0.059 mg/L, and the flow rate is continuously monitored. Loadings from sources upstream of the TDF were estimated from stream profile data along Myra Creek. The estimated portion of the annual Myra Creek source loadings from the portion of the creek adjacent to the TDF is about 18,800 kg/year zinc or 68% (of the dissolved load), compared with 28% for upstream sources and 3% for the treated effluent.

Table 1. Myra Creek zinc loading sources

Component	Zn (Kg/yr)	% of Total
MC-M1 Load (background)	150	0.55
Sources upstream of TDF	6,700	24
Treated Effluent	1,800	6.6
TDF groundwater into Myra Creek (by difference)	18,800	68
TP4 load	27,000	100

Note: all values rounded to 2 significant figures

Loadings to Pumphouse #4 (PH4) were also estimated from measured data. The flow rate from PH4 to the water treatment system is continuously monitored, and the annual average flow rate is 3200 US GPM. The annual average concentration of the PH4 flow was estimated from measured data and data from the five individual collection drains. The annual PH4 zinc load collected, 74,000 Kg/yr, is far greater than the load reaching Myra Creek (about 19,000 Kg/yr). The Inner Drain collects about 60% of the load at PH4, while the Outer Drains collect the remainder. The loadings balance for Myra Creek and PH4 shows that the TDF drains are important for maintaining, in the long term, Myra Creek water quality at current concentrations.

Groundwater Model of TDF

In order to evaluate the major groundwater flow processes in and around the tailings facility, a three-dimensional groundwater flow model was constructed using MODFLOW. The model incorporates data and conclusions from previous hydrogeological assessments of the TDF (Simco Groundwater Research 1983; Knight-Piesold 1989; Northwest Geochem 1990, 1992; Klohn-Crippen 1999, 2004a). As concluded by these previous analyses, a large proportion of the groundwater which flows through the TDF originates as recharge on the valley slope north of the TDF. This mountain-derived groundwater flow combines with precipitation that directly recharges the TDF. The TDF sits on highly permeable sand and gravel deposits which act as the major conduit for groundwater flow beneath the TDF.

The 2010 model shown in Figure 3 was built after calibrating a groundwater model for 1982 conditions, again building and calibrating for 1990 conditions, and finally calibrating to 2003-2010 conditions. The cross-section represents approximately the middle of the TDF, and the extent of the groundwater model domain is shown conceptually in Figure 2. The cross-section shows the waste rock extending underneath the paste tailings, with the valley wall rising steeply beside the waste rock. Conventional (strip area) tailings are also shown within the model on top of the gravel aquifer. The dark green and dark blue layers in Figure 3 represent the Myra Creek alluvial aquifer underlying the TDF. The seismic dam materials, paste berm and conventional dam materials are shown but do not represent a key part of the model. Myra Creek is situated in the lowest topography shown in Figure 3.

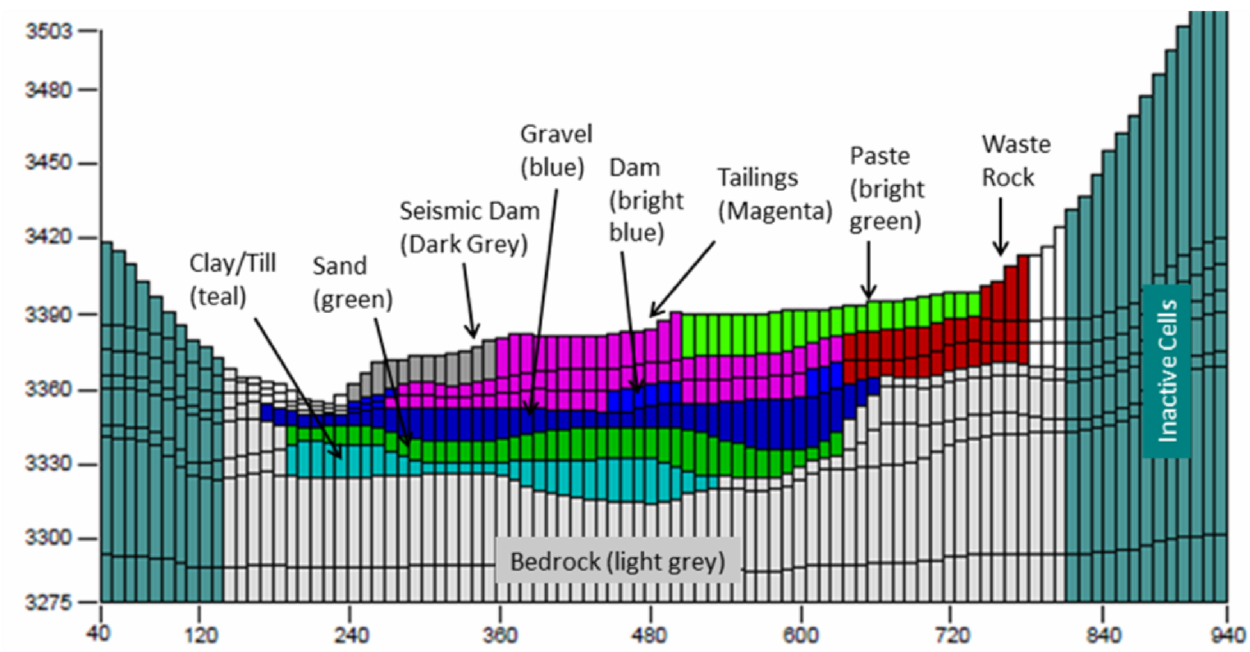

Figure 3. Groundwater model in cross-section for the current condition

A summary of the water balance estimated by the calibrated groundwater model is shown in Table 2. The largest component of groundwater flow is the mountain recharge, travelling laterally down the hillside and through the gravel aquifer. The total groundwater flow derived from direct recharge onto the TDF is small in comparison. Discharge from the groundwater model is to the Inner Drain, the Outer Drains and Myra Creek.

Table 2. Key components of groundwater balance

Component	Flux (L/s)
Indirect Recharge from Mountain	290
Direct Recharge to TDF	5
Outflow to Inner Drain	53
Outflow to Outer Drain	63
Outflow to Myra Creek (by difference)	179

Figure 4 shows the predicted groundwater pathlines for the waste rock (in red) and the tailings (in green). The model predicts that the majority of the pathlines from the tailings are captured by the drain system. Groundwater flows parallel to Myra Creek rather than directly down slope because of the hydraulic conductivity of the gravel aquifer. The locations where groundwater escapes the Outer Drains generally mimic seepage areas as measured along the stream profile and within the groundwater monitoring wells.

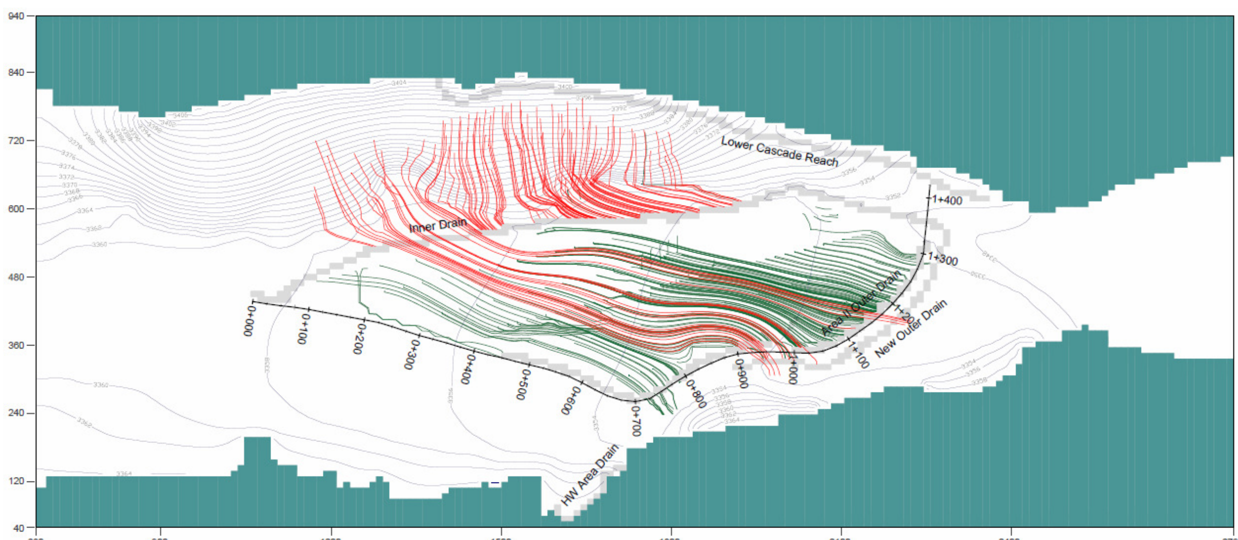

Figure 4. Predicted groundwater pathlines

Tailings and waste rock loadings

Loadings to the under-drain system and to Myra Creek are primarily the result of loadings from the tailings and the waste rock dumps (Table 3). Loadings from the tailings results from infiltration through the tailings as saturated groundwater flow. Evidence suggests that the tailings mechanism is not contributing significant loadings to the system at present. For example, a recent water quality monitoring well installed just beneath the tailings showed 3 mg/L zinc (July and October, 2011). This is lower than almost all groundwater and drain concentrations measured. Groundwater concentrations typically range from about 5 to 20 mg/L zinc along the Outer Drains and associated monitoring wells, and 25-35 mg/L in the Inner Drain.

Table 3. TDF loadings from waste rock and tailings

Source	Zn (Kg/yr)	Flow (L/s)
Waste Rock – Direct Infiltration	59,000	3.8
Waste Rock - Water Table Fluctuation	30,500	127
Waste Rock - PAG in seismic berm	2,300	1.8
Tailings - Infiltration	900	2.5

Loadings from the waste rock are considerably higher. Based on past evidence (Northwest Geochem 1992) of *saturated* pore water, with concentrations as high as 470 mg/L zinc within waste rock, it was concluded that 500 mg/L zinc was a reasonable approximation of the *unsaturated* pore water quality contributing loadings from the waste rock. This assumption was required for the water quality model as numerous monitoring wells have been covered up in the waste rock, and current conditions are uncertain.

The TDF conceptual model for loadings from waste rock includes three mechanisms. One mechanism is infiltration through unsaturated waste rock into the saturated system from above as a result of rain on the surface of the dump.

A second mechanism is mass loading as a result of water table fluctuations in waste rock. With a stable water table, groundwater from mountain recharge that enters the waste rock laterally is expected to contribute lower loadings than with a fluctuating water table. The reason for this is that the fluctuating water table exposes a larger volume of subsurface material to oxygen, thereby increasing the rate of metals release. Based on the findings of Northwest Geochem (1992), water table fluctuations in waste rock are attributed to seasonally variable groundwater flow from the hill slope (mountain recharge). Figure 5 depicts the two mechanisms that contribute metals loadings from waste rock to groundwater that discharges to Myra Creek. These mechanisms are also itemized in Table 3.

A third mechanism is loadings associated with waste rock included in the construction of the seismic berm (Klohn-Crippen 2004b). The assumption is that precipitation infiltrates freely through an area of coarse PAG waste rock. Waste rock that is potentially acid generating was used in the part of the seismic berm that has seepage collection from the Outer Drains (see Figure 2). Clean fill was used for the portion of the seismic berm with no Outer Drain collection.

From a geochemical perspective, the infiltration through unsaturated waste has the potential to act as a larger source of loadings than saturated flow from recharge on the mountain. Oxygen is, of course, more available in unsaturated waste rock than in saturated waste rock. Furthermore, the volume of waste rock influenced by direct recharge of precipitation is likely greater than the volume of rock affected by water table fluctuations. As a result, the infiltration mechanism is thought to contribute a significant load to the system. However, if infiltration were to be reduced with a low permeability cover, source loadings from the waste rock would still be significant because of the water table fluctuation mechanism.

The total load to the treatment system and Myra Creek (93,000 Kg/yr) was used as an upper limit on the current loadings from waste rock and tailings combined. After estimating the infiltration loading from waste rock (from the assumptions described previously), the remaining load was attributed to the mountain recharge via the water table fluctuation mechanism. The portion of loadings attributed to each of the loading mechanism is largely uncertain. Monitoring wells in waste rock will be needed to reduce this uncertainty.

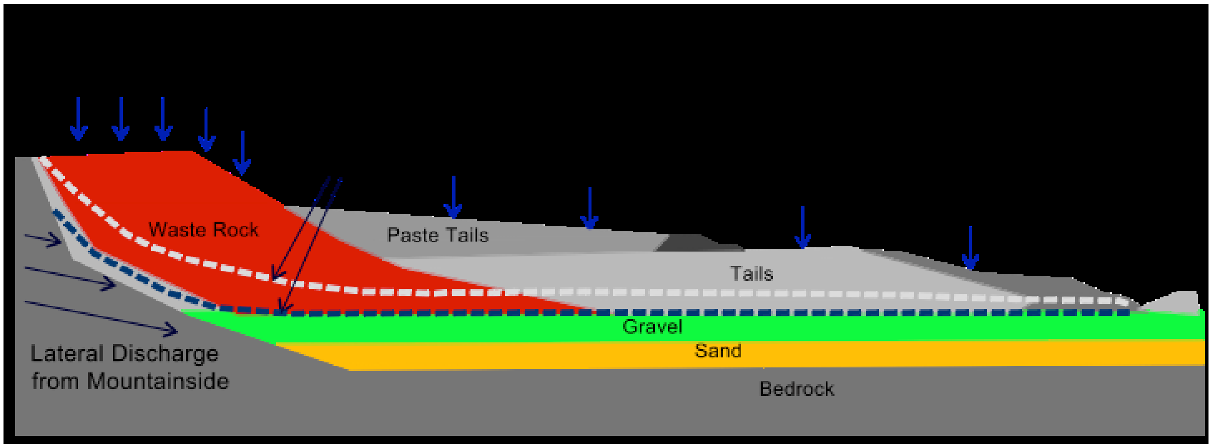

Figure 5. Loading mechanism from TDF waste rock

The total current condition

The total loadings to PH4 and Myra Creek are summarized in Table 4 by the source of the loads. This way of looking at the loadings considers the PH4 and Myra Creek loadings together, as though the treatment system were not in place. The Inner Drain accounts for 41%, the Outer Drains accounts for 32%, groundwater bypassing the creek accounts for 19%, and sources upstream of the TDF account for 7% of the total load. The treated effluent accounts for less than 2% of the loading. This breakdown of loadings shows the critical importance of the Inner Drain and Outer Drains in protecting Myra Creek water quality at present.

Table 4. PH4 and Myra Creek loadings, 2010

Component	Zn (Kg/yr)	% of Total
Inner Drain	42,000	41
Outer Drains	32,000	32
Groundwater bypassing TDF drain to Myra Creek	19,000	19
Sources Upstream of TDF	6,700	6.6
Treated Effluent	1,800	1.8
Background	150	0.15
PH4 and Myra Creek Total Load	100,000	100%

Note: all values rounded to 2 significant figures

Closure Plan Predictions

A closure plan for the TDF was submitted for review in 2011. The proposed closure plan design features are summarized here, along with expected changes in infiltration rates. The entire TDF will be covered with a till layer and revegetated. Within specific areas, certain supplemental modifications will be implemented.

For the paste tailings area, a waste rock working platform will be implemented to support the till cover. This cover design is expected to slightly increase infiltration from 225 mm to 305 mm per annum, based on SEEP/W modelling conducted by O'Kane Consulting. Seepage modelling also showed that because of the slope on the paste tailings surface, water table mounding is not a concern.

For the strip, RSA and paste berm, a geosynthetic liner is proposed over the waste rock working platform. This cover is expected to decrease infiltration from 225 mm to 50 mm. The intent of this cover is to prevent water table mounding and associated loadings from the oxidized surface of these tailings areas. Seepage modelling by O'Kane Consultants (unpublished) indicated the need for this proposed cover design.

For the waste rock area included within the TDF boundary (Figure 1), a till cover is proposed along with re-contouring. This cover is expected to reduce infiltration from 1350 mm to 600 mm. The area of waste rock covered is about 40% of the total waste rock area included in the groundwater model (Figure 1). The remainder of the waste rock will be re-contoured, and covered when site activities allow (i.e., potentially not until the time of site-wide closure).

Post-Closure loading balance model
Tailings and waste rock loadings for the current condition are compared with the predicted loadings resulting from the proposed closure design (Table 5). The proposed cover design is expected to reduce loadings in the short-term to approximately 80% of the current condition.

Table 5. Zinc loadings for closure scenario from tailings and waste rock

Scenario	Zn (Kg/yr)	% of Total
Current Condition	93,000	100
Proposed Closure Plan (post-closure)	76,000	81

The key changes to the loadings result from the partial till cover on the waste rock. When a site-wide closure plan is implemented, further reductions in the waste rock source term are expected.

Groundwater model concentrations
The groundwater concentrations predicted at the Inner Drain and Outer Drains for the current condition and the proposed closure design are shown in Figure 6. Groundwater concentrations were predicted in MODLFOW. Post- closure groundwater concentrations are lower because of reduced infiltration through the till cover on waste rock.

Summary
Water quality in Myra Creek is being influenced by the Nyrstar Myra Falls Mine. Treated effluent is a relatively small source of the loadings reaching Myra Creek. Groundwater flowing under the TDF is the largest source of loadings to Myra Creek, and waste rock is the primary cause of these loadings. The model shows the critical importance of the under-drains and treatment system in protecting Myra Creek water quality.

For this site, the conceptual model for loadings from waste rock differentiates direct infiltration and mountain recharge. Water table fluctuations within waste rock are caused by seasonal variations in mountain recharge. Both the groundwater model and the loading balance concluded that covering waste rock is expected to improve water quality. While reducing infiltration into waste rock may remove part of the loadings, a waste rock cover will not remove all loadings because of the water table fluctuations caused by mountain recharge.

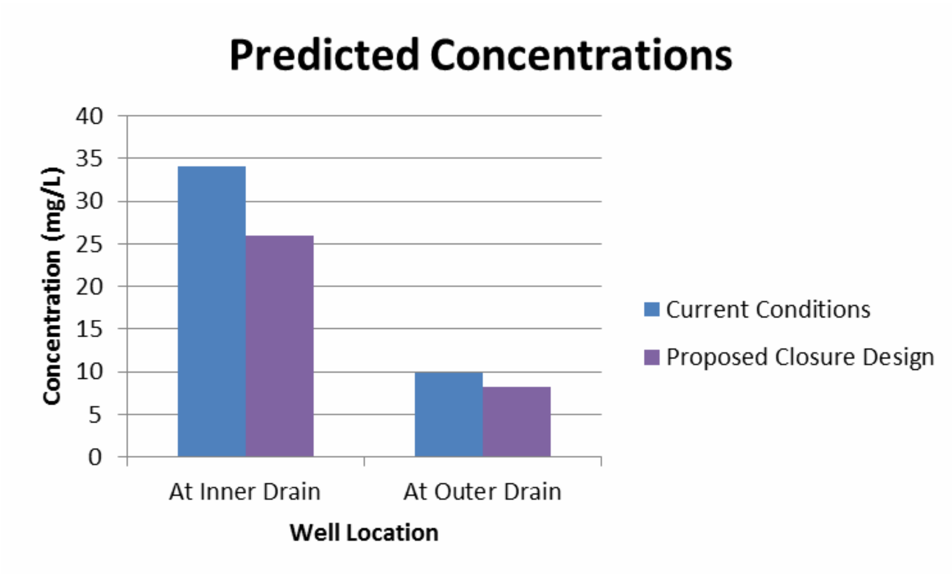

Figure 6. Effect of the cover design on water quality

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