APPENDIX N-3: Prediction of Groundwater Quality below UIG

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7 July 2017

To: Tintina Montana

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RE: **Prediction of Groundwater Quality below Underground Infiltration Galleries
       Tintina Black Butte Copper Project**

Introduction

In response to questions regarding the potential for mobilization of constituents following discharge of reverse osmosis treated water into the underground infiltration galleries (UIG), Enviromin has predicted the chemistry of infiltrated water below the UIG where it encounters groundwater.

Tintina proposes to collect mine-affected water for treatment by reverse osmosis (RO) during operations and at closure. The RO permeate will be run though a limestone trickling filter to add alkalinity and some dissolved solids back into the extremely clean and solute-depleted RO permeate, which is highly corrosive with a large potential to scavenge solutes. Buffered permeate will then be discharged intermittently, via perforated pipe, at an average rate of approximately 0.44 gpm per lineal meter into inert, washed river gravel within a 2 meter deep and 1 meter wide infiltration gallery.   The lines in Figure 1 show the proposed location of the UIG system (Tintina Montana MOP, July 2017). The blue lines represent the unperforated pipes and the black-dotted lines represent the perforated pipes where the water will be released.

The purpose of this model is to predict the quality of the discharged water after it exits the UIG pipes and then reacts with the shallow rock above the water table.   Solutes acquired within an oxidized and flushed zone immediately beneath the UIG will be transported through the unsaturated bedrock along fractures, where some attenuation will occur. Water quality is predicted below the reactive zone within the bedrock, and above the mounded groundwater where compliance with non-degradation standards will be assessed. To this end, water quality predictions were compared to calculated non-degradation standards for groundwater in bedrock, and surface water in alluvium receiving discharge from bedrock (Hydrometrics, Mar 2017).
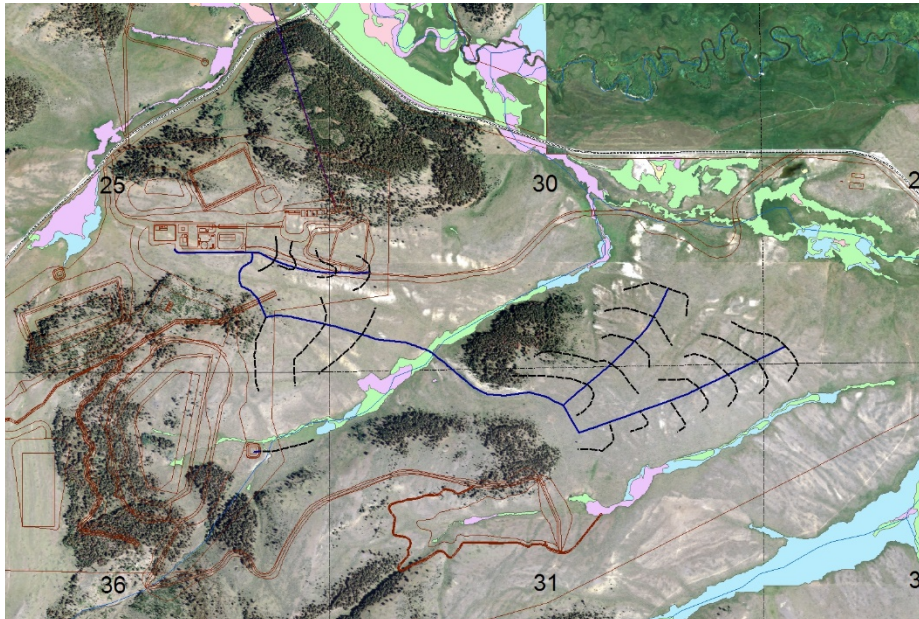
Figure 1. The dotted black lines show the proposed distribution of perforated pipes for the underground infiltration gallery. The section lines in gray represent 1 mile.

Conceptual Model

We have based our analysis on the conceptual model described in Figure 2, which defines the geometry of the physical system, the profile of oxygen, the release zone and the attenuation zone. The near-trench zone of disturbance, where freshly-exposed surfaces will oxidize and release solutes during flushing by discharged buffered RO water, is the source of potential solutes entering the groundwater. This trench will be 2 meters deep, as shown in Figure 2, but the upper 0.7 meters will be backfilled with soil, with bedrock exposed over the lower 1.3 meters of depth. This models assumes that all of the bedrock in the 1.3 meter portion of the trench sees groundwater, which is conservative; no exposure to soil is expected or included in the model. The total reactive surface area is thus estimated to be 8 m^2 per lineal meter, accounting for radial flow in all directions out of the trench up to 1.3 meters of height from the discharge point.

Enviromin estimates that the fracture density of the disturbed zone will be 10%, which is the same as the fracture density estimated for the blast-induced zone of the underground workings. This zone is calculated to be 0.34 meters in thickness, based on a sulfide oxidation rate of 6 kg SO$_4$/m2/yr, for an average *Ynl Ex* sulfide content of 0.006 weight percent.   In the model, fracture density is used to directly scale the surface area from the unconsolidated material in the humidity cell test (HCT, Enviromin, 2017a) to the expected surface area in the shallow rock gallery, using the methods discussed in detail in Appendix N of Tintina's MOP (Enviromin, 2017b).
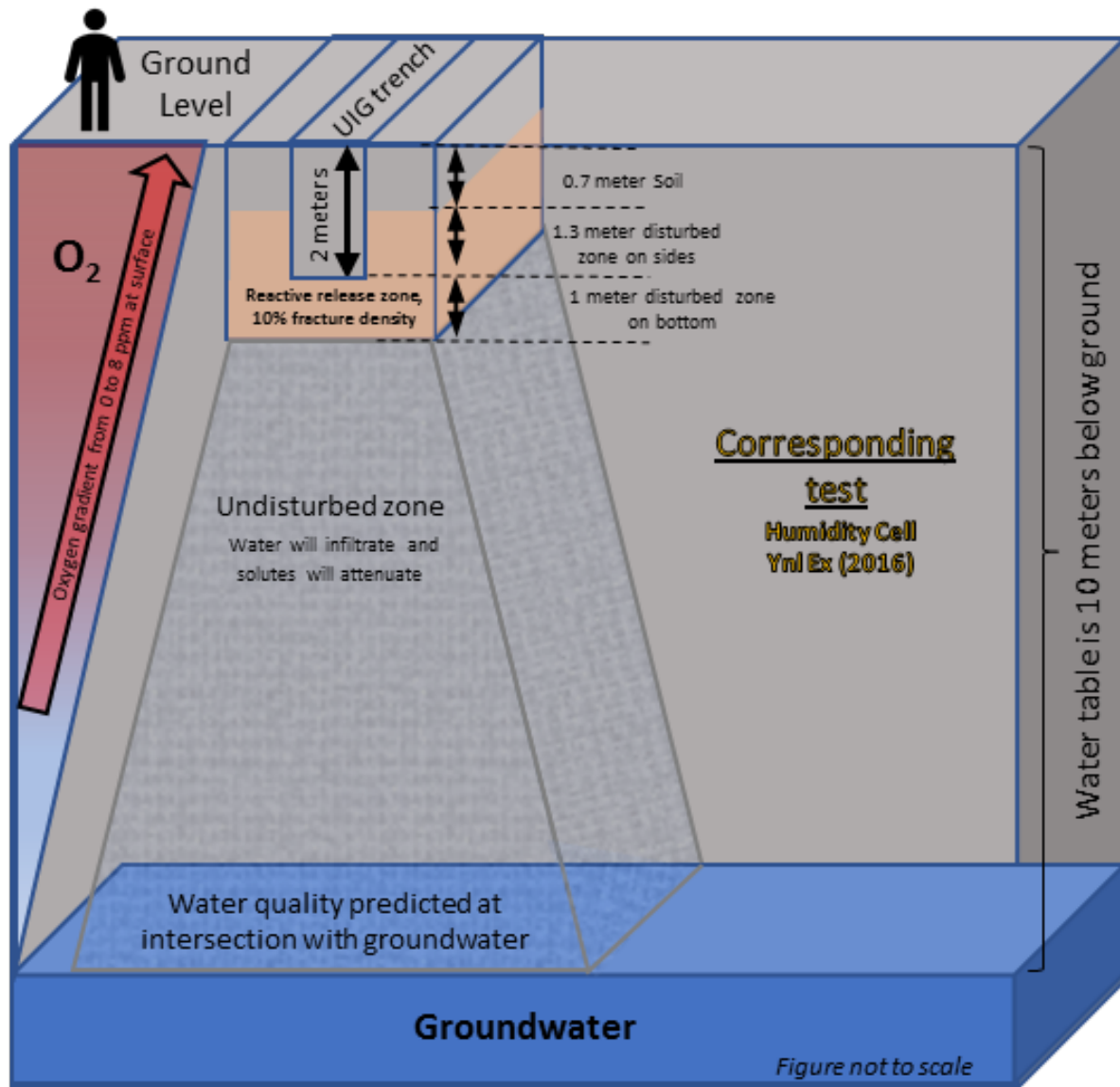
Figure 2. Conceptual model of underground infiltration gallery groundwater hydrology/ geochemistry. The upper (i.e. disturbed) zone will describe the release of solutes according to HCT data from Ynl Ex material. The undisturbed zone will provide rock surfaces for the released solutes to attenuate as water flows towards the compliance point just above the water table.

The average total flow rate through the infiltration gallery will be 398 gpm. The minimum length of pipe needed for the average discharge rate is ~904 meters, which equates to a discharge rate of ~0.44 gpm/meter of trench.

After equilibration, the water will pass through the undisturbed zone where solutes may potentially sorb to surfaces, but those attenuation calculations have not been addressed here.

Humidity cell test data

The disturbed zone, extending 0.34 meters from the walls of the infiltration Trench, will be scaled to the HCT of the *Ynl Ex* material. Accordingly, the model will assume that new surfaces will be created from the construction of the Trench, and the surfaces will oxidize and release solutes. To scale the amount of release, we will assume a reactive mass based on an assumed fracture density of 10% - meaning that the surface area of the near-Trench material is 10% of the surface area of the unconsolidated material in the humidity cell test, using the calculated reactive mass for the rind thickness of 0.34 m. Recognizing the influence of the carbonate mineralization in the trickling filter, the effluent chemistry was calculated by adding the predicted solute released from the *Ynl Ex* HCT to the buffered RO permeate chemistry predicted by AMEC (2017). The average HCT data from weeks 1-4 was used as a basis for predicting solute release.

Sensitivity Scenarios

Recognizing that over time, any oxidation products will be flushed from the gallery surface, Enviromin has recalculated model predictions using the average HCT chemistry including all weeks of testing. Further, to evaluate the effect of uncertainty in reactive mass (e.g., rind thickness), we have also predicted water quality for scenarios using twice (and half) the reactive mass.

Results

Due to the significantly higher volume of water, relative to exposed reactive mass in the UIG, the solute contribution predicted based on the scaled HCT data is quite low. As shown in Table 1, the water quality predicted using the average of weeks 1 to 4 HCT data meets non-degradation criteria for both bedrock and surface water settings. The same is true when an average of all weeks of humidity cell test data are used. Criteria for both settings is also met when the reactive mass is halved, and when it is doubled. An apparent exceedance is observed for Cd and Pb, due to the detection limit reported by AMEC for the treated RO discharge water (AMEC, 2017; column 171 of Table V-2, Tintina MOP Appendix V). These are artifacts of analytical methods and do not truly reflect exceedances of the non-degradation standards. Due to the very low rate of predicted release, no attenuation modeling was considered here.

Conclusion

Much like rainwater, with its low solute content, the buffered RO permeate will equilibrate with bedrock, acquiring a small mass of solutes as it transits the disturbed and oxidized infiltration gallery. Given the relatively low reactive mass, and the larger volume of discharged water, the predicted solute concentrations are low and, not surprisingly, meet both surface and groundwater non-degradation standards under all cases and in all sensitivity scenarios.

Table 1. Results of Base Case model, Sensitivities, and Estimated Non-Degradation Standards

Parameter	Base Case Weeks 1-4	Sensitivity Analyses			Non Degradation Standards*	
		All weeks	1/2 Reactive Mass (weeks 1-4)	2x Reactive Mass (weeks 1-4)	Receiving Waters: Bedrock	Receiving Waters: Bedrock>>Alluvium>>Surface Water
pH	8.099	8.099	8.099	8.097	6.5-8.5	6.5-8.5
Activity of hydrogen	7.97E-09	7.97E-09	7.96E-09	7.99E-09	--	--
Specific Conductance	NA	NA	NA	NA	639	910
Total Dissolved Solids	163	163	163	163	367	532
Temperature	NA	NA	NA	NA	--	--
Total Alkalinity	100.3	100.3	100.3	100.5	598	--
Aluminum	0.001081	0.001054	0.001040	0.001161	0.013	0.466
Antimony	0.000005	0.000003	0.000002	0.000009	0.0009	0.0031
Arsenic	0.0010	0.0010	0.0010	0.0010	0.003	0.001
Barium	0.001093	0.001087	0.001047	0.001186	0.153	0.395
Beryllium	0.000002	0.000002	0.000001	0.000003	0.001	0.001
Cadmium**	0.00100006	0.00100006	0.00100003	0.00100012	0.00008	0.00013
Calcium	40.2	40.3	40.2	40.3	--	--
Chloride	0.87208	0.87246	0.87104	0.87416	30	194
Chromium	0.001	0.001	0.001	0.001	0.015	0.048
Copper	0.001	0.001	0.001	0.001	0.203	0.006
Fluoride	0.005	0.003	0.003	0.008	0.61	3.91
Iron	0.001	0.001	0.001	0.001	0.11	0.76
Lead**	0.001001	0.001004	0.001001	0.001002	0.002	0.001
Magnesium	0.072623	0.088840	0.056311	0.105245	--	--
Manganese	0.001014	0.001012	0.001007	0.001028	--	--
Mercury	0.00000001	0.00000001	0.00000001	0.00000002	0.000005	0.000007
Nickel	0.001	0.001	0.001	0.001	0.016	0.053
Nitrate + Nitrite	0.220	0.220	0.220	0.220	7.80	11.35
Phosphorus	0.00001	0.00001	0.00001	0.00002	--	0.035
Potassium	0.10221	0.09514	0.09111	0.12442	--	--
Selenium	0.000014	0.000008	0.000007	0.000028	0.0078	0.0044
Silicon	0.0078	0.0067	0.0039	0.0155	--	--
Silver	0.0000004	0.0000021	0.0000002	0.0000008	0.0156	0.0027
Sodium	0.084	0.085	0.082	0.088	--	--
Strontium	0.0012	0.0013	0.0011	0.0015	0.62	3.75
Sulfate	0.1673	0.3360	0.0836	0.3346	88	193
Thallium	0.000000	0.000000	0.000000	0.000001	0.0003	0.0025
Uranium	0.000002	0.000003	0.000001	0.000004	0.008	0.008
Zinc	0.001	0.001	0.001	0.001	0.31	0.11

* Hydrometrics, 2017

**Exceedances/proximal for cadmium and lead are an artifact of the predicted RO discharge water chemistry, which assumes a non-detect value of 0.001. Additional significant figures are included here to highlight the contribution from the scaled HCT data

References

Amec Foster Wheeler, 2017. Water Quality Modeling Memorandum. Dated May 2, 2017. 36 p. In Appendix V of MOP Application document. 36p.

Enviromin, Inc., 2017a. *Baseline Environmental Geochemistry Evaluation of Near-Surface Materials: Black Butte Copper Project Revised Mine Operating Permit Application,* April 24, 2017, 18p. With Appendices A and B. Report prepared for Tintina Resources. In Appendix D-1 of MOP application document.

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Hydrometrics, Inc., 2017. Black Butte Copper - Non-degradation Analysis for MPDES Outfalls. Evaluation Memorandum (Black Butte Project) to Tintina Montana. From J. Lloyd. And G. Bryce and March 21, 2017. 8 p. In Appendix V-1 of this MOP Application document.

Tintina Montana, Inc., 2016. *Mine Operating Permit Application, Black Butte Copper Project, Meagher County, MT., Tintina Montana Inc*., Black Butte Copper Project, White Sulphur Springs, MT,   Document submitted to Montana Department of Environmental Quality. September 13, 2016, 625 pp., appendices, and MT DEQ comment responses.