Appendix C
Mine Water Management Analysis

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Technical Memorandum

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Subject: *Mine Water Management Analysis - Troy Mine*

CDM has been retained by the Montana Department of Environmental Quality (DEQ) to analyze proposed mine water management alternatives for the Troy Mine. The purpose of this memorandum is to present the results of analysis of water management alternatives to be considered in the Draft Environmental Assessment (EA) for closure of the Troy Mine. This memorandum only addresses the physical management of water; water chemistry issues are being addressed separately.

The Troy Mine is an underground copper and silver mine located south of the town of Troy in Lincoln County, MT. ASARCO began operating the mine in 1982 and halted production in 1993 due to low metals prices. The mine was sold to Revett Silver Company and production resumed under Genesis, a subsidiary of Revett, in 2005. In 2006, Genesis submitted a Revised Reclamation Plan in support of this EA. This memorandum analyzes water management alternatives presented in the EA.

It has previously been shown in the *Mine Water Balance Analysis – Troy Mine* Technical Memorandum (CDM, 2010) that the Troy Mine is expected to discharge mine water after closure. The three closure alternatives to be evaluated in the draft EA consider different water management scenarios:

- Alternative 1 is the original closure proposal from the 1978 reclamation Plan. It would close the adits with non-hydraulic plugs, which would allow the mine water to discharge from the portals. Mine water would then infiltrate to the groundwater system. The glacial till near the mill site probably is not sufficiently permeable to allow infiltration of the expected quantity of water, and there is likely a substantial risk that saturation of this material could trigger landslides and slumping of material into the creek, causing further pollution. In addition there would be a direct discharge to Stanley Creek from the adit that would not meet State water quality standards and would not be authorized. Therefore, this alternative is not being considered further in this water management analysis.

- Alternative 2 is the revised reclamation plan of March 2006 proposed by Genesis. In this alternative, the conveyor and service adits would be closed with non-hydraulic plugs, and the mine water would be carried by the existing tailings and reclaim water lines to the decant ponds. At the ponds, the water would infiltrate and evaporate, and metals would be adequately attenuated by the underlying soils to preserve ground and surface water quality in the area.

- Alternative 3 is the agency mitigated alternative. In this alternative, the both the Service and Conveyor adits would be closed with partial backfill only and the mine water would be captured inside the entrances and transported to the decant ponds for treatment and disposal. The existing tailings lines would be removed and replaced with a new, buried line with at least 6.9 cubic feet per second (cfs) capacity. If there is insufficient capacity in the new transport line or a leak or other upset, part or all of the flow would be diverted automatically to the reclaim water line that is presently in place. Sensors installed in the line would detect these conditions and Supervisory Control and Data Acquisition (SCADA) instrumentation would automatically open and close appropriate valves and alert maintenance personnel. The decant ponds would be bermed to prevent the entry of storm water. They will be constructed about 10 feet deep and lined with gravel to prevent the growth of aquatic vegetation.

The analysis of water management for a discharging mine in Alternatives 2 and 3 is the main focus of this memorandum.

Management of Mine Discharge

Mine water discharging from the service and conveyor adits at Troy Mine will be transported through a system of pipelines to the existing decant ponds in the tailings pond area under Alternatives 2 and 3. The locations of these facilities are shown in Figure 1. The question to be answered through a water balance analysis is whether the decant ponds will eventually fill and overtop or if infiltration and evaporation are sufficient to maintain the pond level below this elevation. The following information is needed to develop a water balance for the decant ponds at the tailings impoundment:

- Discharge from the mine adits
- Pond Area
- Pond volume and stage-volume relationship
- Evaporation and precipitation information near the pond

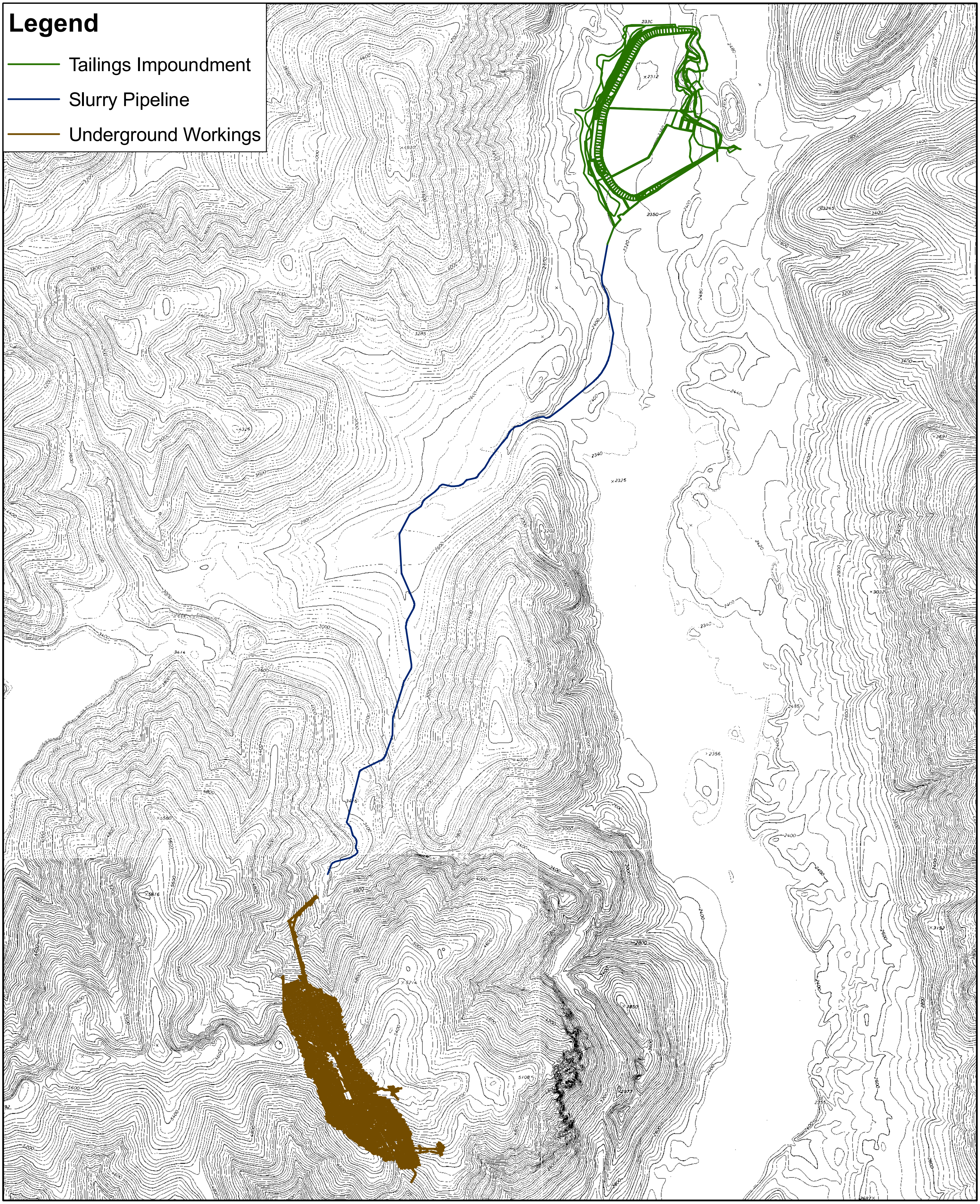

Figure 1: Location of Underground Workings, Pipeline, and Tailings Impoundment

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- Infiltration rate below the pond

For a detailed water balance analysis, a ten-year period with monthly time steps was selected to provide sufficient time to allow a general balance of inputs and outputs and to capture extreme conditions that would correspond roughly to a ten-year recurrence interval. The selected time period was the period of record for the Poorman Creek SNOTEL site, where the available record runs from 1999 through 2008. The Poorman Creek period of record is important to this analysis because the estimated mine discharges are tied to precipitation records at Poorman Creek in the mine water balance memorandum (CDM 2010). Monthly values for the mine discharge and climatic data were developed for the period 1999 -2009 as input to the pond water balance model.

Mine Discharge Data

In the *Mine Water Balance Analysis – Troy Mine* Technical Memorandum, CDM developed an annual relationship between rain plus snowmelt and mine discharge. This relationship demonstrated that the mine would generally discharge water after closure and quantified the annual amount of discharge. Although no robust predictive model of monthly discharge could be developed, evaluation of mine inflows on a monthly basis during a period of high mine water level resulted in an approximate distribution of expected mine discharge through a typical year. To produce the monthly data set, the predictive model was used to calculate estimated annual mine discharge based on precipitation records at the Poorman Creek SNOTEL. The average monthly distribution of mine discharge was then estimated by adding the typical distribution to the difference between the annual distribution for a particular year and the average annual discharge:

$$Q_{Myrx} = Q_{Ayrx} - Q_{Aave} + Q_{Mave}$$

Where: Q_{Myrx} is the calculated monthly discharge for year x

Q_{Ayrx} is the predicted annual flow for year x

Q_{Aave} is the predicted average annual flow

Q_{Mave} is the typical monthly discharge.

Table 1 shows the calculation of the predicted annual discharge based on precipitation at the Poorman Creek SNOTEL site and Table 2 shows the estimated monthly mine discharges for the period of record 1999-2008. The equation used to calculate the monthly discharges occasionally results in negative discharges; these discharges are set to zero.

Table 1. Predicted Annual Inflow and Discharge (Q_{Ayrx}) Based on Inflow Analysis Relations

Year	Rain+ Snowmelt (in)	Predicted Inflow (ac-ft)	Predicted Inflow (cfs)	Adjusted Inflow (cfs)*	Estimated Discharge (cfs)
1999	76.0	1118	1.54	1.54	1.14
2000	84.4	1837	2.54	2.54	1.87
2001	45.4	-1499	-2.07	0.76	0.56
2002	104.1	3522	4.86	4.86	3.59
2003	69.4	554	0.76	0.76	0.56
2004	89.1	2239	3.09	3.09	2.28
2005	74.3	973	1.34	1.34	0.99
2006	78.1	1298	1.79	1.79	1.32
2007	79.0	1375	1.90	1.90	1.40
2008	87.9	2136	2.95	2.95	2.18

*Because the inflow prediction equation results in a negative mine inflow for 2001, the mine inflow is conservatively set to the next lowest inflow (2003).

Table 2. Estimated Monthly Discharges at Mine Adit Elevation 4225 ft.

	Estimated Monthly Discharge (cfs)									
Month	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Oct	0.17	0.90	0.00	2.62	0.00	1.31	0.02	0.35	0.43	1.21
Nov	0.64	1.37	0.06	3.09	0.06	1.78	0.49	0.82	0.90	1.68
Dec	0.33	1.07	0.00	2.79	0.00	1.48	0.19	0.52	0.60	1.37
Jan	1.09	1.82	0.51	3.54	0.51	2.23	0.94	1.27	1.35	2.13
Feb	0.85	1.58	0.28	3.30	0.28	1.99	0.70	1.03	1.11	1.89
Mar	0.72	1.46	0.15	3.17	0.15	1.87	0.58	0.91	0.99	1.76
Apr	1.51	2.24	0.94	3.96	0.94	2.65	1.36	1.69	1.77	2.55
May	2.85	3.58	2.27	5.30	2.27	3.99	2.70	3.03	3.11	3.89
Jun	3.70	4.44	3.13	6.16	3.13	4.85	3.56	3.89	3.97	4.74
Jul	1.73	2.46	1.15	4.18	1.15	2.87	1.58	1.91	1.99	2.77
Aug	0.52	1.25	0.00	2.97	0.00	1.66	0.37	0.70	0.78	1.56
Sep	0.00	0.36	0.00	2.07	0.00	0.77	0.00	0.00	0.00	0.66

The estimated monthly discharges presented in Table 2 do not account for the water that originates in that portion of the service adit below the high point of 4,225 ft. or a corresponding high point in the conveyor adit. These adit discharges have been measured semi-annually by the mine operator from July 2005 to February 2008 using weirs. The flows vary relatively little with the average February flow of the two adits being 0.67 cfs and the average July flow being 0.74 cfs. The 0.67 cfs flow was applied to the months of August through March, and the

0.74 cfs flow was applied to the months of April through July, resulting in the total estimated mine discharges shown in Table 3.

Table 3. Estimated Monthly Total Mine Discharges (QM_{yrx})

	Estimated Total Mine Discharge (cfs)									
Month	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Oct	0.84	1.57	0.67	3.29	0.67	1.98	0.69	1.02	1.10	1.88
Nov	1.31	2.04	0.73	3.76	0.73	2.45	1.16	1.49	1.57	2.35
Dec	1.00	1.74	0.67	3.46	0.67	2.15	0.86	1.19	1.27	2.04
Jan	1.76	2.49	1.18	4.21	1.18	2.90	1.61	1.94	2.02	2.80
Feb	1.52	2.25	0.95	3.97	0.95	2.66	1.37	1.70	1.78	2.56
Mar	1.39	2.13	0.82	3.84	0.82	2.54	1.25	1.58	1.66	2.43
Apr	2.25	2.98	1.68	4.70	1.68	3.39	2.10	2.43	2.51	3.29
May	3.59	4.32	3.01	6.04	3.01	4.73	3.44	3.77	3.85	4.63
Jun	4.44	5.18	3.87	6.90	3.87	5.59	4.30	4.63	4.71	5.48
Jul	2.47	3.20	1.89	4.92	1.89	3.61	2.32	2.65	2.73	3.51
Aug	1.19	1.92	0.67	3.64	0.67	2.33	1.04	1.37	1.45	2.23
Sep	0.67	1.03	0.67	2.74	0.67	1.44	0.67	0.67	0.67	1.33

Climatic Data at the Tailings Pond

Precipitation data were taken from the Troy, MT weather station 248390 (Western Regional Climate Center 2009). This station is located 9.5 miles north of the tailings facility at an elevation of 1929 ft. It has 48 years of record. The elevation of the tailings ponds is about 2,400 feet, somewhat higher than Troy, so increased precipitation might be expected at this site. However, without local information, the Troy weather station data cannot be reliably adjusted to the site.

Five years of pan evaporation data, 1963-1967, are available from the tailings facility (Genesis, Inc. 2008). To estimate the evaporation amounts for the period 1999-2008, the record was extended using data from Station 4328 at Hungry Horse Dam near Columbia Falls, MT. This station is located at an elevation of 3,160 feet. Fifty-eight years of pan evaporation data, 1948 to 2007, are available from the National Climatic Data Center. The data from the tailings facility were compared to the evaporation values at Hungry Horse Dam and a correction factor was created. Before using the corrected data, a coefficient of 0.75 was applied to the data to adjust for the increased energy and therefore increased evaporation experienced in an evaporation pan as opposed to a lake or pond (Haan et al, 1994).

Average annual precipitation at the Troy, MT weather station is 24.5 inches for the period 1960-2009. November and December are the wettest months and July and August are the driest. Average annual adjusted evaporation is 15.7 inches. The greatest evaporation is generally experienced in August.

In most years, precipitation will exceed evaporation. Therefore, if the area of disposal ponds is increased, any accelerated loss of water due to evaporation will more than be compensated for by increased precipitation, and larger pond areas would not equate to greater disposal of water.

Estimation of Infiltration Rate

There are several sources of information on infiltration rates in the vicinity of the tailings ponds including estimates of seepage from the ponds as well as measurements of the hydraulic conductivity of the underlying materials in the vicinity of the ponds. Seepage was estimated in the Operating Plan (Asarco, 1976) to range between 292 and 803 gallons per minute (gpm), whereas the Draft Environmental Impact Statement (USFS-DSL, 1978) estimated 1,170 gpm. The Tailing Impoundment Design and Operation report (Pfahl, 1989) estimated seepage at 845 gpm based on a simplified water balance. Unfortunately, insufficient information is provided to determine the area over which seepage calculations occurred. Without this information, it is not possible to calculate infiltration on a unit area basis. In Alternatives 2 and 3, the current decant pond would be used to dispose of the mine discharge. This may be a reasonable solution if the bottom of the decant pond is not sealed by slimes. Alternatively, a new pond could be excavated directly in native materials and used to dispose of the discharge water. An estimate of infiltration rate based on hydraulic properties of the native materials is appropriate in the analysis of long-term water disposal options.

The Interim Report of Findings Hydrologic and Hydrogeologic Assessment prepared by Summit et al (1996) offers the most comprehensive data for the materials underlying the tailings pond area. This report includes logs from ten test borings, seven monitoring wells and seven sandpoints in the vicinity of the tailings ponds. Data from a hydraulic conductivity test and other information related to infiltration rates are presented. The Summit report measured a hydraulic conductivity of 8.4 feet per day using a well in the middle of the tailings pond and one just below the pond berm. The boring logs from these wells and other wells in the area indicated the unit measured was primarily fine sand. This hydraulic conductivity value is within the expected range for sandy materials.

In November of 1995, ASARCO personnel decreased the flow rate to the decant pond for seven days. During this time, Summit reported a 4.5 foot drop in water levels in the decant pond. The report does not state the amount that the flow rate was decreased or whether flow ceased altogether, so it is not possible to calculate an exact infiltration rate from this information. However, a 4.5 foot drop in water level over the area of the decant pond for a seven-day period equates to a rate of infiltration of 0.64 feet per day and provides a potential pond infiltration rate.

Further data on the infiltration rate at the decant ponds was obtained in 2001 during a tracer test conducted by Hydrometrics (2001). During a period of low mine water discharge, all discharge to the decant ponds was suspended and a 24-day salt tracer test was conducted.

During this period, the ponds dropped at a typical rate of about 0.4 feet per day, somewhat lower than the rate determined in the 1995 study. The infiltration rates used in our analyses vary from 8.4 feet per day for good infiltration conditions to a minimum of 0.4 feet per day.

Water Balance at the Tailings Pond

Precipitation on the surface of the tailings and mine water delivered to the decant ponds are the major input values for a water balance calculation at the tailings facility. The primary outputs are seepage and evaporation from the decant ponds. The general equation used to determine the change (Δ) in storage of water at the decant ponds or tailings impoundment is as follows:

$$\Delta Storage = Precipitation + Mine\ Discharge - (Evaporation + Seepage)$$

Because information on the size of the proposed disposal facilities is not included in the proposed Alternatives, the procedure followed in this analysis was to set the size of the proposed disposal facility based on the other inputs to the model. For simplicity, it was assumed that an infiltration pond of a certain area had a capacity of 10 feet of water and vertical sides. This approximate design would need to be revised based on site conditions and other factors during implementation of the pond disposal alternative. In the model input, the pond area was varied to determine at what size the pond would overflow at some time under the 10-year climatic record.

An initial model run was undertaken with the assumption that the hydraulic conductivity of the underlying materials at the site was 8.4 feet/day, a value derived from aquifer tests by Summit et al (1996). A review of the well logs in the vicinity of the east edge of the tailings pond indicates that ground water would be located about 50 feet below the pond bottom. This information was inserted into Darcy's equation to translate the hydraulic conductivity into an infiltration rate:

$$v = k\,i$$

where v = the Darcy velocity
k = hydraulic conductivity (ft/day) and
i = the gradient.

To calculate the gradient, the following terms are defined:

h_A = the height of the pond bottom above the aquifer in feet, and
h_W = the depth of water in the pond in feet.

For vertical flow, the gradient, i, is the total head ($h_A + h_w$) divided by the length of the media through which it passes (h_A) or, for 50 foot separation from the aquifer:

$i = (h_A + h_w)/ h_A$

$i = (50 + h_w)/50$

Referring to the spreadsheet model "Water Management" and work sheet "1.6-acre Pond" on the attached compact disc, for a pond with a maximum depth of 10 feet, the infiltration rate will vary from 8.4 to 10.1 ft/ft^2 – day. Because of the depth to the aquifer is large, the amount of water in a pond with a maximum 10-foot depth does not have a great effect on the magnitude of the infiltration rate. Running the model with various-sized ponds and the precipitation rates for the period of record shows that a 1.6-acre pond that is 10 feet deep would not overtop. Note that the model indicates the pond only fills with water during the wettest portion of 2002, which was the wettest year in the period of record. In part, this is because the infiltration rate modeled (at least 403 acre-feet for a 30-day month) is sufficiently high to accommodate the mine discharge rate, which only averaged 292 acre-feet. Neither precipitation nor evaporation exceed one acre-foot per month, and are almost inconsequential in this calculation. Only when mine inflows exceed those of June 2002 does the model predict the 1.6-acre pond would fill.

It is likely that the high infiltration rate used in the preceding calculation will not be realistic, at least in the long term, due to siltation or vegetation accumulating in the pond. Although pond maintenance should minimize these effects, it is still probable that some decrease in performance will be experienced over time. Therefore, a spreadsheet calculation was also developed to size a pond for the minimum infiltration rate of 0.4 ft per day reported in 2001 by Hydrometrics. Referring to the spreadsheet model "Water Management" and worksheet "23-acre Pond" on the attached compact disc, at this lower infiltration rate, a 23-acre pond is required to prevent overtopping a 10-foot deep pond. For this pond configuration, the model indicates the pond would hold water during early summer in four of the wet years, 2000, 2002, 2004 and 2008. Although the effects of precipitation and evaporation are somewhat more important with a larger surface area pond, they are still generally less than 10 acre-feet per month with minor effects on the calculation.

Implementation

The calculations presented in the previous section suggest that disposal of water through use of a pond is feasible given the transmissive quality of the underlying soils. Even a 23-acre pond would be quite feasible to construct, although it would have significant maintenance requirements. Because the existing 4-acre decant pond system has successfully infiltrated excess mine water during operations, it is expected that this same facility can continue to handle mine discharge water after mine closure. Normally these ponds infiltrate about 2,500 gpm (5.6 cfs) and have infiltrated 3,000 gpm (6.7 cfs), which is nearly the maximum design flow assumed in this memorandum (6.9 cfs) (personal communication, Doug Parker, Hydrometrics, June 16, 2010). If the existing ponds are maintained with a depth of about 10 feet, are gravel lined to increase infiltration, and vegetation growth is controlled, the infiltration rate should be maintained. The infiltration ponds would need a berm constructed around them to prevent storm water from flowing into them.

Summary

This memorandum presents an analysis of the expected feasibility of mine water disposal in the vicinity of the tailings ponds. Based on previous work, the mine will discharge an average of 2.1 cfs from its adits after pumping ceases and water reaches the overflow elevation of the adits. Flows are expected to range from 0.67 cfs to 6.90 cfs with the largest discharges generally expected in the months of May and June in relatively wet years.

A spreadsheet water balance model was developed for the water disposal pond and used to evaluate 10 years of discharge and climatic data including precipitation, evaporation, and infiltration. The infiltration rates modeled were based on an aquifer test performed at the tailings pond and an observation of infiltration rates at the decant pond. It is not known how representative these data are of the soil conditions in the area. A range of pond sizes, depths, and infiltration rates was modeled using actual discharge plus precipitation rates. The various pond designs were sufficient to contain all expected inflows during the 10-year evaluation period. An important conclusion of this analysis is that the pond size is almost entirely dependent on the magnitude of the mine water discharge and infiltration rate of the subsurface, and relatively unaffected by precipitation and evaporation.

Water disposal ponds sized from 1.6 to 23 acres are feasible to build and maintain. The current decant ponds, which are about 4 acres in size fall within the modeled range of sizes. These ponds have successfully infiltrated the mine discharge for the period of operation of the mine and, with proper maintenance, should continue to infiltrate the discharges expected post closure. To prevent plugging of the ponds and ensure they are not overwhelmed with storm water runoff, berms should be constructed around the ponds to exclude entry of storm water runoff from the surrounding area.

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