USING SPREADSHEETS TO EVALUATE THE EFFECTS OF MINE WATER DISPOSAL ON SURFACE AND GROUND WATER[1]

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Abstract: Spreadsheets can be used to provide an accurate and straightforward method of modeling the effects resulting from the disposal of treated and untreated mine wastewaters using percolation and land application disposal on surface and ground water quality. Spreadsheets are more user-friendly than many ground water modeling programs. Spreadsheet models are a valuable tool that can be used to evaluate the potential effects of a new mine, proposed revisions to a mine's operating permit throughout mine life, water disposal options in preparation for closing tailings impoundments, and for disposal of adit water. As mining progresses, adjustments may be made to the formulas and input values to reflect changes in water quality and quantity, hydrogeologic data, mine wastewater treatment efficiency, method or volume requiring disposal (water balance), and other changes that may occur in the composition of the mine wastewater streams. The spreadsheet models are constructed using basic data (*e.g.*, hydrogeologic, wastewater quality and quantity, treatment, storage, and disposal system capacities, etc.), Darcy's equation, standard mixing zone calculations, and weighted-average equations. The calculations used are consistent with those of the National Pollutant Discharge Elimination System (NPDES) permitting for discharges to surface water and to ground waters that discharge to surface water. The use of spreadsheets is an innovative approach to identify water disposal requirements and the more critical elements of a water management system so that the most effective capital investment can be made during operations, and to identify operational mitigations that should be implemented to avoid costly issues during closure.

Additional Key Words: land application disposal, percolation, modeling, mine water management, mixing zone.

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Introduction

The spreadsheet models were created for a closure water management plan draft environmental impact statement (DEIS) for two underground platinum group metal mines in Montana [Montana Department of Environmental Quality (DEQ) and US Forest Service (USFS) 2010]. The DEIS evaluated and disclosed the effects of the disposal of mine adit and tailings waters on surface and ground water. Earlier analyses [Montana Department of State Lands (DSL) and USFS 1985; DSL and USFS 1989; DSL and Montana Department of Health and Environmental Services (DHES) 1992; DSL, USFS, and DHES 1992; DEQ and USFS 1998;] did not adequately address the method(s), duration, and management of all mine water streams at closure and post-closure.

The mines are operated near Nye and Big Timber, Montana. An operation at the first mine began in 1985 and ore production was approximately 777,100 tons per year. Although permitted in 1993, operations at the second mine did not begin until 1998, and is approximately 407,400 tons per year. The company mills the ore at each mine by crushing, grinding, flotation, and filtration to produce a concentrate. This concentrate is shipped by truck to a base metal refinery (BMR) in Columbus, MT for further processing. From the BMR, the product is shipped to one of two U.S. facilities for final refining (DEQ and USFS 2010).

For both mines, every 100 tons of ore fed to the mill generates 99 tons of tailings. These tailings are pumped from the mill to underground sand and paste plants where the coarse sand fraction of tailings is separated from the slimes fraction (finest-sized particle). The sand is dewatered, cement is added, and about 58 percent of the total tailings are used to backfill underground workings. The remainder of the tailings are pumped to the respective tailings impoundments at the mine and at an off-site land application disposal (LAD) facility. The tailings impoundments at both mines are used to balance water storage (DEQ and USFS 2010).

While mine operator and the agencies had considered various disposal scenarios for closure, the spreadsheet models helped to identify which disposal methods were optimal for the mine water constituents, where shortcomings lay in the water management plan, and how adjustments to the treatment system(s) would affect the quality of adit and tailings water at closure. The spreadsheet models provided the mine and the agencies a venue to better evaluate operational water management throughout mine life to develop mitigations that would minimize costly issues at closure.

For this DEIS, the spreadsheet models evaluated the disposal of treated and untreated mine waters using percolation and land application [specifically center pivots (Fig. 1), evaporators (Fig. 2), and snowmaking] during operations and at the eventual closure of two mines. The sources of water that that would need to be addressed at closure were water discharging from the adits and waters removed from three tailings impoundments prior to the placement of reclamation covers (capping).

Both mines use semi-passive, fluidized bed/fixed-film biological treatment systems (BTS) for primary treatment (denitrification) of the nitrate+nitrite nitrogen that is derived from ammonia-based blasting agents (ammonium nitrate and fuel oil—ANFO). Up to 95% of the nitrate+nitrite nitrogen is removed by the BTS (SMC 2006). The second mine has a separate biological system to treat ammonia (Anox system). The first mine uses growing

Figure 1. The off-site land application disposal (LAD) facility center pivot system. The center pivots are used to provide a polishing treatment for nitrate and dispose of excess mine waters. These center pivots use high pressure nozzles and “drops” that are oriented upward to evaporate as much water as possible, rather than deliver it to soil. This orientation evaporates an average of about 30 percent of the end-of-pipe water volume. An additional 85 to 90 percent removal of nitrate is achieved during polishing treatment by LAD (SMC 2006). DEQ photo.

Figure 2. Evaporators/snowmakers can be used to provide a polishing treatment for nitrates and dispose of excess mine waters in the on-site LAD area. The evaporators can be used on uneven terrain to dispose of water by land application in summer and continue to provide disposal and nitrogen polishing treatment by snowmaking in winter (SMC, HKM Engineering Inc., and Knight-Piésold 2004). DEQ photo.

season LAD as a polishing treatment for nitrogen. Both mines can employ percolation for water disposal (Fig. 3).

The mine water contains salts (*i.e.,* sulfate and chloride derived from reagents added during the milling process) that are not treated in the BTS, by LAD, or percolation. Due to the nature of the ore body, the metals Cd, Cr, Cu, Pb, and Zn are present in the mine water at non-detectable concentrations or at concentrations less than human health standards (the mines' water quality database). Metals are not treated in the BTS, by LAD, or percolation.

For the past 10 years, one of the mines has been using a 265-acre (107.2 hectares) LAD system for the operational disposal of up to 225 million gallons (851,720 m^3) during one LAD season. The DEIS analyzed a new LAD system that is proposed for use at the other mine. Both mines use percolation to ground water as a disposal method for treated mine water. The spreadsheets also modeled the direct discharge of untreated adit water to surface water at post-closure.

Figure 3. Percolation pond used for disposal of treated mine water. Treated water is discharged to the percolation pond where it infiltrates to the subsurface to ground water and eventually flows to surface water. The percolation ponds at both mines are NPDES-permitted outfalls. DEQ photo.

Although the parameters evaluated in this DEIS were nitrogen and salts, other parameters (*e.g.*, metals) could also be evaluated using attenuation factors. The approach used by the agencies is unique in that the DEIS analyses were not prescriptive, but considered a range of adit discharge flow rates using different disposal options, thereby permitting the mine to retain water management flexibility during operations and closure. These spreadsheet models are a valuable tool that can be used throughout life-of-mine to assess the elements of a water management plan, evaluate changes in water treatment methods or efficiencies, appraise potential improvements or additions to the primary treatment system(s), and include refinements in hydrologic data.

Methods

The Microsoft Office Professional Excel spreadsheet program was used to construct the models. The spreadsheet models consisted of several sections that included the following:

- a list of the assumptions used when evaluating the alternative;

- the option analyzed (*i.e.*, specifics of water routing);
- a list of the input parameters including citations for the data that were used in the analyses;
- an evaluation of the hydraulic capacity of the treatment system(s) and disposal method(s) considered in that option (*e.g.,* whether the percolation pond capacity was sufficient to manage the volume of water to be disposed of);
- calculation of surface and ground waters available for mixing;
- projected constituent loading in surface and ground water;
- projected constituent concentration in ground water; and,
- projected constituent concentration in surface water.

Assumptions and Equations

The spreadsheets list the assumptions for each analysis that dictate how certain parameters were handled in the equations. For example, primary treatment of nitrogen (nitrate+nitrite) occurs in the fixed-film BTS in use at both mines where up to 95 percent of the influent nitrate+nitrite is removed (SMC 2006). The waste streams that were evaluated consisted of adit water (*i.e.*, ground water inflow to the mine mixed with water used in the underground operations such as muck pile washdown water and excess drilling water) and treated and untreated tailings waters (*i.e.*, the volume of supernatant plus tailings mass waters that would be removed from the impoundment so that the reclamation cover could be emplaced). The analyses considered a range of adit water flow rates from the current operational rate to the maximum anticipated rate. The BTS efficiency data were available for the current operational rate. Assumptions were made to address questions raised regarding the treatment system capacities and efficiencies if the maximum anticipated adit flow rates were reached. The assumptions also described how water would be routed for each mine and each alternative considered (Fig. 4).

BTS-Treated Adit Water Nitrogen Concentration. To determine the concentration of nitrogen in adit water at closure, the agencies assumed that, regardless of adit water flow rate, the BTS would achieve nitrogen removal equivalent to at least the historic maximum nitrogen load discharged at the mines. A standard loading equation (1) was solved for concentration (mg/L), using both the current operational and anticipated maximum adit water flow rates

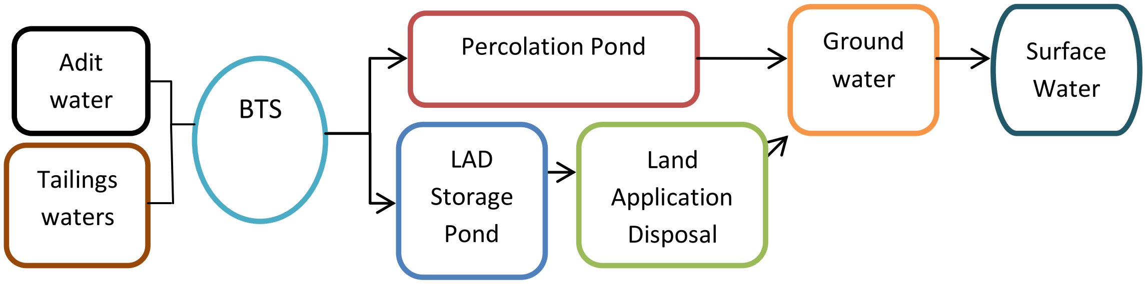

Figure 4. A typical mine water routing schematic. The mine water streams mix in the biological treatment system (BTS) during nitrate treatment, then are routed for disposal in the percolation pond and/or land application disposal (LAD) systems, and would eventually reach ground water then surface water. This schematic does not show the routing of recycle water or assumed leakage from impoundments.

(gal/min) with historic maximum nitrogen load (lbs/day) to find the treated adit water concentration, C_{TA} (mg/L). The factor 0.012 was used to convert between units (Table 1).

$$Load = Flow\ rate \times C_{TA} \times 0.012 \tag{1}$$

Table 1. Conversion factors used to obtain consistent units.

From	To	Multiply by Factor
gal/min	ft^3/day	192.513
ft^3/day	gal/min	0.0051944
gal/min, mg/L	lbs/day	0.012
cfs	ft^3/day	86,400

Abbreviations: gal = gallons, min = minute, ft = feet, cfs = cubic feet per second

BTS-Treated Tailings Waters Nitrogen Concentration. It was assumed that at least 80 percent of the nitrogen in tailings waters would be removed by the BTS based on water quality data submitted by the mines (SMC 2006). To calculate the concentration of treated tailings waters, C_{TTW} (mg/L), the median nitrate+nitrite nitrogen concentration of untreated tailings waters, C_{UTW} (mg/L), was multiplied by 20 percent (Equation 2).

$$C_{TTW} = 0.2\ C_{UTW} \tag{2}$$

Mixing treated adit and tailings waters. The adit and tailings waters would be routed to the BTS, mixed, and treated before being routed to the LAD storage pond for later disposal. A standard weighted-average calculation was used to determine the resulting concentration of nitrogen or salts in the mixed waters in the LAD storage pond. Equation 3 calculates the concentration of mixed treated mine waters, C_{TMW} (mg/L), where C_{TA} is the concentration of treated adit waters in mg/L from equation 1, Q_{TA} is the flow rate of treated adit waters in gal/min, C_{TTW} is the concentration of treated tailings waters in mg/L from equation 2, and Q_{TTW} is the flow rate of treated tailings waters in gal/min. This weighted-average equation may be expanded by additional terms to account for other sources of water, such as water residing in the LAD storage pond over the winter, if needed.

$$C_{TMW} = \frac{C_{TA}Q_{TA} + C_{TTW}Q_{TTW}}{Q_{TA} + Q_{TTW}} \tag{3}$$

Concentration of Nitrogen in LAD-Treated Waters. A polishing treatment for nitrogen occurs during growing season land application disposal where, based on a study performed by the mine, plants use at least 80 percent of the applied ammonia and nitrate+nitrite nitrogen (SMC 2006). The mine performed a study in 2002 that showed during snowmaking, 80 percent of the applied nitrogen was removed by natural processes during crystallization and sublimation of the snowpack (Cascade Earth Sciences 2008). The nitrogen not removed by plant uptake or snowmaking was assumed to enter the aquifer (Stevenson 1986), where it would mix with ground water, and eventually discharge to surface water. The concentration of nitrogen entering the aquifer from land applied water, C_{LAD} (mg/L), was calculated by multiplying the concentration of treated mine waters, C_{TMW} (mg/L) from equation 3, by 20 percent, using Equation 4.

$$C_{LAD} = 0.2\, C_{TMW} \tag{4}$$

Percolated Waters. No nitrogen treatment occurs during percolation, so no treatment credit was given in the analyses or the mine NPDES permits. No treatment of calcium and magnesium salts occurs in the BTS or during land application. All of the salts plus the nitrogen that was not removed by plant uptake or snowmaking was assumed to enter the aquifer, mix with ground water, and eventually discharge to surface water (Stevenson 1986).

Load to Ground Water. The NPDES permits for both mines have an effluent limit for nitrogen loading to ground water. Both mines employ a BTS. The spreadsheets modeled the nitrogen load for percolated and/or land applied waters using Equations 1, 2, 3, and 4, as appropriate to the routing for the alternative. The salts load to ground water was calculated using median adit and tailings waters concentrations in Equation 1.

Precipitation. The agencies conservatively chose not to add precipitation to the spreadsheets. The dilution effect of precipitation on land applied waters may be added to a spreadsheet model using the effective precipitation rate (*i.e.*, precipitation that reaches the soil and does not run off or evaporate but remains in the soil for plant use). The DEQ draft technical guidelines for the land application of municipal wastewater (DEQ 2005) describe the effective precipitation rate as 70 percent of the total rainfall ($f_R = 0.7$), or 50 percent (due to wind drift and sublimation) of the snowfall water equivalent ($f_S = 0.5$) where 2.5 inches of snow equals one inch of rain (US Department of Agriculture Natural Resources Conservation Service). The total inches of measured precipitation, P_m, then may be converted to volume, P_V (gallons), using Equation 5, where f is the appropriate correction factor for effective precipitation; 27,154 is the conversion factor for gal/acre-inch; and A is the area (acres) over which LAD is applied.

$$P_V = 27{,}154\, P_m f A \tag{5}$$

Unsaturated Zone**.** Nitrogen and salts are conservative parameters. That is, below the root zone no attenuation occurs. For the DEIS analyses, the water that percolates below the root zone was assumed to immediately enter the aquifer. The unsaturated zone was not modeled in these analyses.

Nitrogen or Salts Concentration in Ground Water from LAD-Treated Waters**.** To project the concentration of nitrogen or salts in ground water after LAD, a ground water mixing zone was first calculated. In Montana, the calculation for a standard ground water mixing zone is prescribed by regulation (Administrative Rules of Montana 17.30.517). The depth extends 15 feet below the water table, and the width of the mixing zone is the width of the source plus a geometric factor that takes into account advection and dispersion along the length of the flow path. The depth times the width of the mixing zone defines the area, A (ft^2), that is used in Darcy's equation (Freeze and Cherry 1979) (6), where Q_A is the volume of flow in ft^3/day (water in the aquifer available for mixing), k is the hydraulic conductivity of the aquifer in ft/day, and I is the hydraulic gradient in ft/ft.

$$Q_A = k\, I\, A \tag{6}$$

After calculating the volume of water in the aquifer available for mixing, a standard weighted-average calculation was used to determine the resulting concentration of the constituent in ground water after land application. This approach is consistent with NPDES permit calculations. Equation 7 calculates C_{MZ}, the concentration in mg/L of the constituent in the aquifer after mixing, where C_{LAD} is the maximum projected concentration in mg/L of the constituent (after plant uptake or snowmaking) in the applied water from equation 4, Q_{LAD} is the volume in ft^3/day of water land applied, C_A is the ambient concentration in mg/L of the constituent in the aquifer, and Q_A is the volume of water in ft^3/day in the aquifer available for mixing from equation 6.

$$C_{MZ} = \frac{C_{LAD} Q_{LAD} + C_A Q_A}{Q_{LAD} + Q_A} \tag{7}$$

Nitrogen or Salts Concentration in Ground Water from Percolation. To project the concentration of nitrogen or salts in ground water from percolation, C_P (mg/L), a ground water mixing zone was calculated for the aquifer beneath the percolation pond as described above, using Equation 6. Once the volume of water in the aquifer available for mixing beneath the percolation pond was known, Q_{AP} (ft^3/day), a standard weighted-average calculation was used to determine the resulting concentration of the constituent in ground water, C_{AP}, in mg/L. This approach is consistent with NPDES permit calculations. Equation 8 is the weighted-average calculation for disposal of both treated adit and tailings waters by percolation. Additional terms may be included, as necessary, to construct a mixing zone calculation that includes all sources of percolated water.

$$C_P = \frac{C_{TA} Q_{TA} + C_{TTW} Q_{TTW} + C_{AP} Q_{AP}}{Q_{TA} + Q_{TTW} + Q_{AP}} \tag{8}$$

Multiple Contributing Areas for Ground Water. In the analyses for the DEIS, there were several areas that contributed flow and constituents prior to discharge to the receiving stream. For example, the ground water flow path of interest might flow from beneath the percolation pond, under a tailings impoundment, beneath a LAD storage pond, under a LAD area, below a buffer area, then discharge to a receiving stream. After determining and describing the flow path for the contributing areas in the assumptions section, the ground water volumes available for mixing for each area were calculated using equation 6. These areas may have contributed constituents (*e.g.,* percolation, leakage from impoundments or storage ponds, LAD) or provided dilution (*e.g.*, precipitation, buffer areas, or leaking irrigation ditches). A weighted-average calculation that included the terms for all contributing areas was used to project the final concentration of the constituents in ground water along the flow path of interest.

Such a calculation would resemble Equation 9, expanded as needed to include terms for each contribution area along the ground water flow path. Each contributing area would have terms for volume, Q, and concentration, C, for both the ground water (listed below with subscript beginning with A) and constituent addition or dilution. All Q terms would be in gal/min and all C terms in mg/L.

Equation 9 would yield the ground water concentration of a constituent, C_D, as a result of water disposal from LAD (terms with subscript LAD), percolation (terms with subscript P), and leakage from tailings impoundments (terms with subscript I) and LAD storage ponds (terms with subscript SP). Parentheses can be useful to separate the terms for each contributing area.

$$C_D = \frac{(C_{ALAD}Q_{ALAD} + C_{LAD}Q_{LAD}) + (C_{AP}Q_{AP} + C_PQ_P) + (C_{AI}Q_{AI} + C_IQ_I) + (C_{ASP}Q_{ASP} + C_{SP}Q_{SP})}{(Q_{ALAD} + Q_{LAD}) + (Q_{AP} + Q_P) + (Q_{AI} + Q_I) + (Q_{ASP} + Q_{SP})} \tag{9}$$

Nitrogen or Salts Concentration in a Receiving Stream. Both mines and their LAD facilities are near surface water and a significant amount of hydrogeologic data have been collected. The spreadsheets modeled the ground water flow paths to their discharge points into the respective receiving streams. The approach used is consistent with NPDES permit calculations. The volume of ground water discharging to the stream is the sum of the volumes of the contributing areas and is equal to the denominator of equation 9. All volumes must be converted from ft^3/day to cubic feet per second (cfs) using the factor from Table 1. Equation 10 is used to calculate Q_D in cfs, the ground water discharge to surface water.

$$Q_D = 0.0051944[(Q_{ALAD} + Q_{LAD}) + (Q_{AP} + Q_P) + (Q_{AI} + Q_I) + (Q_{ASP} + Q_{SP})] \tag{10}$$

Equation 11 calculates the concentration of the constituent in the receiving stream, C_{RS} in mg/L, after mixing with discharging ground water, where C_D is the concentration of the constituent in the ground water in mg/L discharging to the stream from equation 9, Q_D is the volume of ground water discharging to the stream in cfs from equation 10, C_S is the ambient concentration of the constituent in the stream in mg/L, and Q_S is the receiving streamflow in cfs.

$$C_{RS} = \frac{C_D Q_D + C_S Q_S}{Q_D + Q_S} \tag{11}$$

The agencies used the 10-year, 7-day lowest streamflow value ($7Q_{10}$) cited in the NPDES permit when calculating receiving stream concentrations. The $7Q_{10}$ streamflow would provide the least dilution for wastewater effluent (*i.e.*, cause the highest concentration of a constituent in the stream) and as such, is a conservative choice for most streams, except when using actual streamflow during drought conditions. Depending on the intended use of the spreadsheet models and the constituent considered, it may be more appropriate to use a larger streamflow value than the $7Q_{10}$. One suitable choice for nutrients, for example, might be based on longer annual low streamflow periods in late summer, such as the 10-year, 30-day lowest streamflow value ($30Q_{10}$). Algae grow throughout the summer months, and the discharge of nutrients during this low flow late summer period would provide the greatest potential for nuisance growth, hence the greatest potential impact to streams.

Direct Discharge of Adit Water at Post-closure. Equation 10 may also be used to calculate the concentration of a constituent in a receiving stream, C_{RS} in mg/L, when treated or untreated adit water is discharged directly to the receiving stream. This approach is consistent with NPDES permit calculations. For this calculation, Q_S is the receiving streamflow in cfs, C_S is the ambient concentration of the constituent in the stream in mg/L, Q_D is the volume of adit water discharging directly to the stream in cfs, and C_D in mg/L, is the concentration of constituent in ground water discharging directly to the stream.

Comparison of Spreadsheet Results to Real-Time Data

The agencies found that, when the values generated by the spreadsheets were compared to surface and ground water data collected by the mines, in general, the results were conservative with respect to real surface water data, and consistent with ground water data. That is, the spreadsheets over-predicted the concentrations of constituents in surface water and were within the observed range of constituent concentrations in ground water.

The over-prediction of surface water values is reasonable and expected because the assumptions made for surface water analyses were conservative. The spreadsheets used the

$7Q_{10}$ (10-year, 7-day lowest streamflow value) for the receiving streams to account for closure during a dry or droughty year. During wetter years when the $7Q_{10}$ streamflow is likely to be met or exceeded every month of the year, more water is available for dilution of the constituent, and the in-stream concentration is over-predicted.

At the LAD facility, the spreadsheets had a fairly accurate rate of prediction for constituent concentrations in ground water. For example, the spreadsheets predicted a ground water concentration of 1.3 mg/L nitrate+nitrite nitrogen at the compliance well, and ground water data collected between 2005 and 2009 varied from 0.25 to 1.57 mg/L. The difference of predicted concentration from ground water concentration may be due to precipitation (which the spreadsheet model did not take into account) or to different volumes of water disposed of at the LAD facility.

Limitations

The spreadsheet models are best suited to less complex scenarios. Spreadsheets have limitations when aquifers are heterogeneous on a scale such that any of the following conditions are met: differences in permeability along the flow path are significant and difficult to describe geometrically or cannot be generalized; hydrogeologic parameters and ground water flow paths are unknown; a three-dimensional approach is needed; or constituents are attenuated and the attenuation cannot be addressed by retardation factors (Bair and Lahm 2006). In general, the unsaturated zone is quite complex, requiring the use of nonlinear functions as parameters (Schwartz and Zhang 2003), and is, therefore, not well-suited to spreadsheet modeling.

Summary

Based on the spreadsheet modeling analyses in the DEIS, the agencies have concluded that these two mines have the water management systems available to adequately discharge water at closure to prevent violation of water quality standards. The analyses identified the critical elements of the water management systems, indicated where the systems have the potential for improvement, and spotlighted the flexibility of the water management systems to address contingencies at closure. The results of these calculations were consistent with observed concentrations of constituents from surface and ground water monitoring data.

As a result of the spreadsheet models, the DEIS Agency-Mitigated alternatives have added mitigations such as operational monitoring and annual reporting of changes in the volumes of tailings supernatant and water in LAD storage ponds; tracking the trend of salt and nitrate loading in adit and tailings waters; identifying efforts made by the mine to reduce salts and nitrogen concentrations each year; and monitoring soil health in the vicinity of the LAD areas. The usefulness of the spreadsheets extends throughout mine life and provides the mine and the agencies a venue to better evaluate operational water management and minimize costly issues at closure. A .pdf version of the spreadsheet models is included as Appendix C of the DEIS (DEQ and USFS 2010).

While the mine operator and the agencies had considered various disposal scenarios for closure, the spreadsheet models identified some potential inaccuracies. One inaccuracy was in regard to which disposal methods were optimal for a constituent. In comparison to percolation, which is strictly a disposal option, LAD provides a polishing treatment for nitrogen, and would be a preferable disposal method for nitrogen. The spreadsheet analyses indicated that percolation is a preferable disposal method for salts because of the reduced potential for soil salinization and sodium-adsorption issues that can occur during LAD.

Another inaccuracy was identified with respect to the optimal disposal rate for LAD. An agronomic application rate may be preferable to maximize the LAD polishing treatment efficiency for nitrogen. A greater-than-agronomic application rate may be needed to leach accumulated salts and minimize soil salinization and sodium-adsorption.

The spreadsheets helped identify shortcomings in the water management plan, such as the availability of water storage and increased constituent concentrations in recycled process waters. The spreadsheets can be used during mine life to evaluate how adjustments to the treatment system(s) (*e.g.,* the addition of reverse osmosis to further reduce ammonia and its subsequent effect from disposal of brines on the salinity of mine waters) would affect the quality of adit and tailings water at closure.

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