Modeling Application in Evaluating Environmental Impact due to Phosphate Mining Activities

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Abstract This paper presents a modeling application to evaluate the environmental impact to water resources due to proposed phosphate mining activities. The proposed project has the potential to impact surface and groundwater resources due to metals and other constituents release into the environment. A numerical groundwater flow and solute transport model has been developed to support the water resource impact analysis for the project environmental impact statement. The results of this quantitative assessment played a fundamental role in preparing the environmental impact statement and assisted in the mine design for permitting.

Keywords Mining Modeling, Environmental Impact, Permitting, Groundwater, Surface Water

Introduction

The Blackfoot Bridge Project (the project) proponent proposed to develop an open pit mine in Caribou County, Idaho, to recover phosphate ore. The proposed mining activities have the potential to impact surface water and groundwater resources and release metals and other constituents into the environment; hence, the Pocatello Field Office of the U.S. Department of Interior, Bureau of Land Management (BLM) prepared an Environmental Impact Statement (EIS). The Idaho Department of Lands (IDL), the Idaho Department of Environmental Quality (IDEQ), and the U.S. Army Corps of Engineers (USACE) were cooperating agencies for the preparation of the EIS.

A numerical groundwater flow and contaminant fate and transport model has been developed to support the impact analysis for the EIS and to analyze the proposed project's compliance with applicable Clean Water Act provisions and state water quality standards. This paper describes the development of the groundwater flow and contaminant fate and transport model and its application to predict potential impacts to surface and groundwater resources as a consequence of the proposed mining activities. Specially, the Blackfoot River, located to the north of the project (Fig. 1), is designated as a Special Resource Water recognized as needing protection to maintain outstanding characteristics and current beneficial uses.

Site background and project summary

The proposed mine consists of an open pit that would be mined in three panels (North Pit, Mid Pit, and South Pit) and includes auxiliary mine facilities (Fig. 1). Mining activities are expected to occur over a 17-year period and include construction of overburden piles and ore stockpiles, pit backfilling, construction of water control ponds, construction of water management facilities, and reclamation of impacted areas.

General goals of this groundwater modeling are to: (1) simulate the pre-mining groundwater system and its interaction with surface waterbodies in the area that could be affected by the project and (2) serve as a tool for evaluating the potential impacts on surface and groundwater resources associated with the proposed mining activities. The specific objectives of the model for the EIS impact analysis are to: (1) estimate groundwater inflow and dewatering requirements (if needed) for the open pits, (2) predict potential changes in groundwater/surface water levels and quality during mining operations and after closure, and (3) estimate potential impacts to groundwater and surface water quality associated with leachate from mine facilities including open pits, backfills, external waste dumps, and ore stockpiles. In addition to the objectives stated above, the model is intended to be used as a decision-making tool that is updatable and can be used to evaluate project alternatives. Furthermore, it may be used to establish operational monitoring and compliance points, evaluate mitigation strategies, and determine practical compliance levels for constituents of concern in groundwater and surface water.

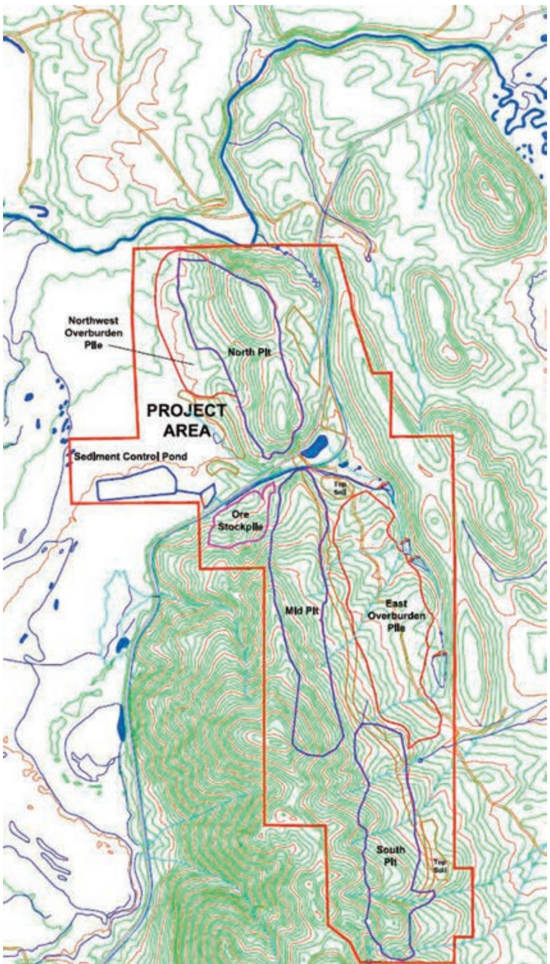

Fig. 1 *Proposed Mine Facilities*

Conceptual Site Geology and Hydrology

A generalized stratigraphic column of the project area is shown on Fig. 2. The stratigraphic section includes Quaternary-age alluvium, colluvium, and travertine deposits; Tertiary-age basalt flows, tuff, and rhyolite; and Mississippian- to Triassic-age sedimentary rocks, including sandstone, siltstone, shale, dolomite, and limestone.

The structural geology in the project area is very complex. The Aspen Range Fault is a major structural feature that discharges deeply circulating groundwater to a series of springs (such as Woodall Springs) and wetlands along the mountain front and has a significant influence on the regional groundwater flow near the project area. Rocks in the Mid Pit and South Pit are cut by a series of high-angle normal faults that strike northeast and generally dip north. Displacement of bedding along the faults is usually minor, with the exception of the Offset Fault. The Offset Fault separates the Mid Pit from the South Pit and displaces bedding on the south side of the fault about 300 m to the east.

Several streams and surface waterbodies occur within or near the project area (Fig. 1). The major surface water feature is Blackfoot River, which flows west along the northern property boundary.

Model code selection and model construction

The groundwater model was developed using the numerical code MODFLOW-SURFACT (HydroGeologic 1996), which is a comprehensive three-dimensional groundwater flow and solute transport modeling code based on the United States Geological Survey (USGS) modular groundwater flow code MODFLOW (McDonald and Harbaugh 1988). MODFLOW-SURFACT is functionally identical to the standard MODFLOW code with several enhancements for improved handling of unsaturated cells and pumping wells. MODLFOW-SURFACT was selected because of its ability to handle steep hydraulic gradients and cell re-wetting, which

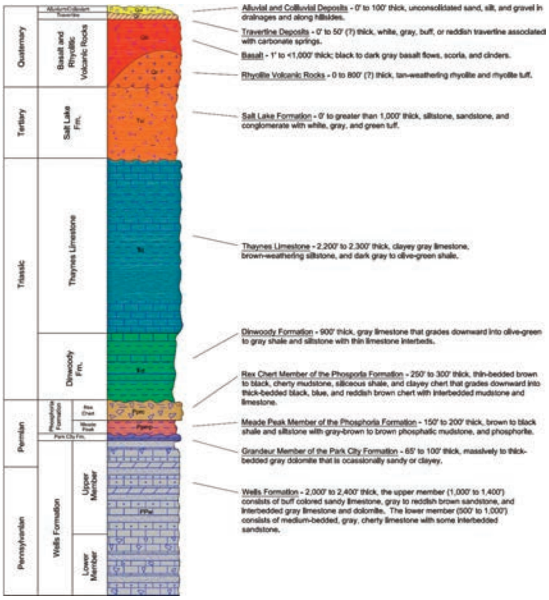

Fig. 2 *Generalized Column and Stratigraphic Section of the Project Area*

are anticipated to occur during mine inflow and pit dewatering simulations.

MODFLOW-SURFACT can simulate variably saturated groundwater flow and solute transport. Detailed descriptions of MODFLOW-SURFACT capabilities, mathematical formulation, and model verification are presented in its user's manual (HydroGeologic 1996). MODFLOW-SURFACT is also selected as the solute transport model because it uses state-of-the-art numerical schemes for solving the transport equation. The Total Variation Diminishing flux limiting schemes included in the code are designed to provide accurate, physically correct, and strictly mass-conservative numerical solutions. An adaptive implicit scheme is used to minimize temporal discretization errors. The matrix equations resulting from the finite-difference approximations are solved using an efficient Orthomin matrix solver. The primitive mass-conservative form of the transport equation is used, providing strictly mass-conserved numerical solutions.

The model domain covers an area of approximately 70 km^2, which is large enough to encompass the potential water resources impacts. The model domain extends approximately 10 km along the south–north axis. Along the west-east axis, the model domain extends approximately 8 km. The southeastern model boundary runs along the State Land Creek watershed divide. The boundaries of the model grid were set at a significant distance from the project area to minimize the influence of model boundaries on simulation results. The horizontal grid cell spacing was based on the size of the area of interest, the total area of the model domain, and the degree of accuracy and precision needed. The finite-difference grid is composed of 204 columns and 400 rows. There are 979,200 cells in the model, of which 937,800 are active. The model grid was refined to 15 × 15 m within the project area to more accurately simulate groundwater flow and solute transport. Grid spacing increases and reaches up to 230 m toward the model boundaries. The model domain is discretized into 12 layers that were considered necessary to represent the significant hydrostratigraphic units identified in the conceptual site model, as well as the development of the open pits. Model layers are generally not horizontal and represent multiple hydrostratigraphic units to incorporate the complex geology at the site. Model domain and boundaries conditions are shown in Fig. 3.

The model was initially calibrated to steady-state conditions. Additionally, two types of transient calibrations were performed: one based on seasonal variations in recharge and a second calibration based on the results of a recent aquifer test. Upon completion of the transient calibration, the steady-state model was re-run to confirm that a single set of input parameter values satisfies both the steady-state and transient targets.

Site-specific geochemical characterization studies for the Blackfoot Bridge project have been prepared to evaluate the geochemical characteristics and leaching behaviors of the overburden and ore that would be produced from the proposed mine. Columns were prepared to evaluate the potential release of metals and other constituents from the proposed mine facilities, and leaching tests were conducted over several leaching cycles to obtain leachate concentrations for all potential source areas. Representative samples were prepared for the following source areas (Fig. 1): North Pit Backfill, Mid Pit Backfill, South Pit backfill Northwest Overburden Pile (NWOP), EOP, EOP – segregated Meade Peak overburden and Ore Stockpile.

Selenium was selected as the contaminant of concern for the site. Nine columns were designed to evaluate the leaching characteristics of the run-of-mine rock in unsaturated overburden dumps (NWOP, EOP), backfills (North, Mid, and South Pits), stockpiles (Ore Stockpile). Additional columns were designed to evaluate the leaching characteristics of the saturated backfill that would be placed in the North and Mid Pits. The bottom of the South Pit is located above the regional water table; therefore, no saturated backfill is expected to develop after mining. Leachate concentrations were estimated for three pore volumes for unsaturated source areas and nine pore volumes for saturated source areas.

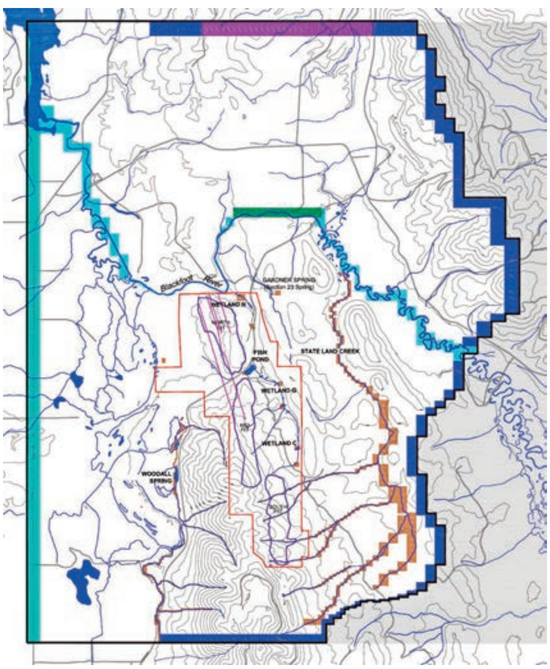

Fig. 3 *Model Domain and Boundary Conditions*

Selenium leachate concentrations collected from unsaturated columns ranged between 0.002 mg/L at the Dolomite/Limestone and 1.361 mg/L at the unsaturated South Pit backfill source area for the first pore volume. The leachate concentration from the saturated column is significantly lower at 0.003 mg/L for the North and Mid Pits backfill source areas, which is below the applicable regulatory groundwater standard of 0.005 mg/L. The different leaching behavior of selenium in saturated versus unsaturated columns is likely related to different oxidation-reduction potential conditions in the two environments (Whetstone 2010). These results indicate that the most significant potential source of selenium contributing to loading in groundwater is leachate from unsaturated source areas. The actual amount of selenium potentially discharging to groundwater would also depend on the net percolation rate through each cover type applied over the source areas.

Three scenarios were evaluated using the constructed model: (1) Proposed Action, (2) Alternative 1A, and (3) Alternative 1B. Three types of cover systems were considered in the three scenarios: the Base Case cover system, the Simple 1 cover system, and the "Complex 2" GCLL cover system. The Base Case cover system design consists of 46 cm of topsoil and 1.2 m of chert. The Simple 1 cover system design consists of 46 cm of topsoil, 0.3 m of weathered alluvium, and 0.6 m of chert. The Complex 2 cover system design is comprised of 46 cm of topsoil, 0.3 m of weathered alluvium, a GCLL layer (sodium bentonite encased between a geotextiles and a synthetic laminate high-density polyethelene or polyvinyl chloride), and 0.3 m of weathered alluvium cover material. The Proposed Action cover involves placing the "Base Case" cover system over a total area of 187 ha, and the "Simple 1" cover system over 9 ha. Alternative 1A involves placing a combination of the "Complex 2" GCLL cover system over 127 ha and the Simple 1 cover system over the remaining 68 overburden pile ha. Alternative 1B consists of the same cover system as Alternative 1A does, except that it will replace the Simple 1 cover over the 48.5 ha of external overburden in the EOP with Complex 2 cover system, which results in covering the entire EOP with a GCLL cover.

The simulation results for Alternative 1 A are shown in Fig. 4 and Fig. 5. Fig. 4 presents the simulated maximum selenium plume in the groundwater due to the mining activities; and Fig. 5 shows the anticipated impact of selenium to the surface water in the vicinity of the project. Reach 1 concentrations reach the maximum after about 50 years and remain stable until year 248. Selenium concentrations at Reach 2 reach a plateau after approximately 250 years and remain stable for a long period of time. Selenium concentrations at Blackfoot River Reaches 1 and 2 are not expected to exceed 5 µg/L. A sensitivity analysis was conducted to evaluate uncertainties related to two key parameters: the hydraulic parameters within the Wells Formation and the unsaturated and saturated source strengths.

Conclusion

Numerical modeling and quantitative analysis are necessary to facilitate mining activity evaluation and to mitigate unacceptable impacts

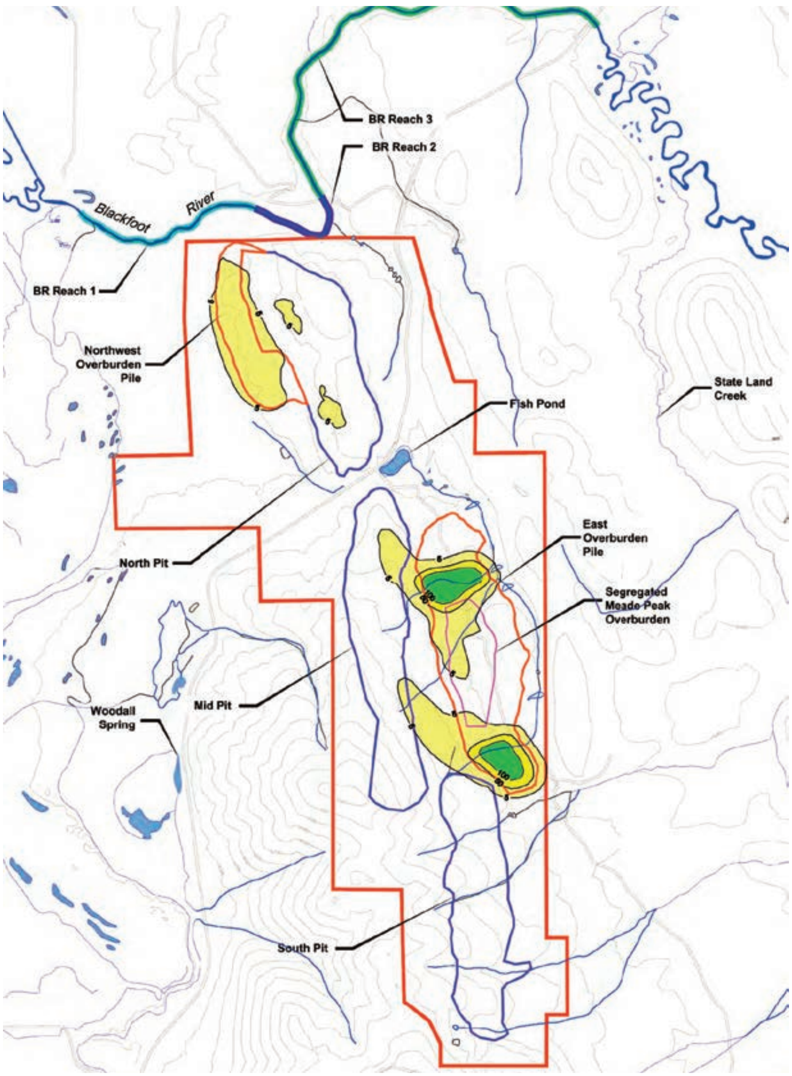

Fig. 4 *Simulated Selenium Extent in Alternative 1A*

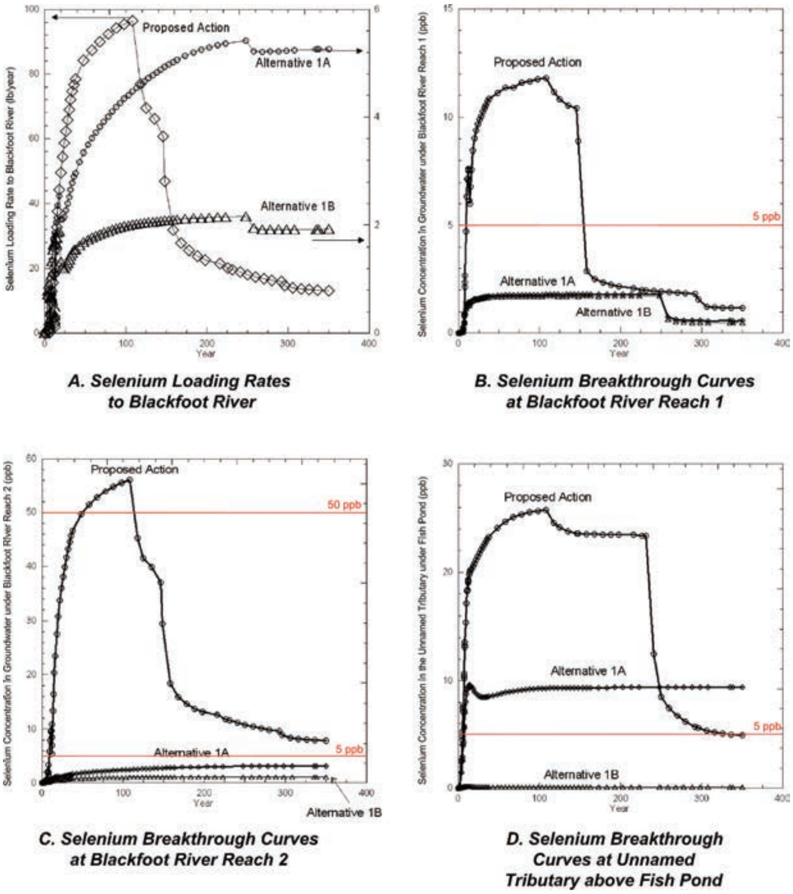

Fig. 5 *Simulated Selenium Impact to Surface Water*

to ground and surface water resources. The numerical modeling analysis conducted in this study was able to evaluate project alternatives by quantifying the potential impact to groundwater and surface water resources in the vicinity of the project; hence, support the preparation of the EIS.

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