Modeling Mine Pit Lakes

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Managing water resources at open-pit mines often includes long-term analyses of flow rates, water levels, and geochemistry of pit-lake waters. Questions that frequently arise with regards to pit-lake hydrology include: will mine-contaminated groundwater and surface water be captured and contained by the pit lakes? Over what period of time? For what mine plan? How can storm runoff or other surface water be managed? What are the flow rates through different rock horizons and through stockpiles toward the lake?

Groundwater modeling of pit-lake infilling is one component of the modeling analyses, together with surface runoff, geochemical, and limnological modeling, that can be used to predict a range of future groundwater conditions for a mine. Groundwater modeling results are typically used to support management decisions and to help with regulatory evaluation.

For the purposes of mine management, modeling results are used to:

- Analyze the effects of alternate stormwater management plans on pit lakes.
- Evaluate alternate pit-backfilling plans.
- Derive flow patterns that can be used in fate and transport assessments.
- Compare and optimize remedial treatment options.

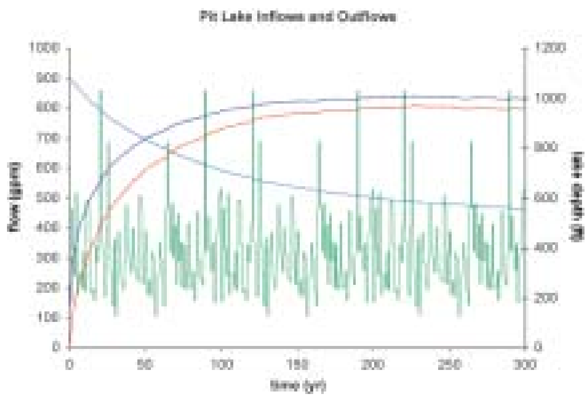


Figure 1: green line: surface water inflows (gpm); light blue line: groundwater inflows (gpm); red line: evaporation (gpm); dark blue line: pit lake water depth (ft).

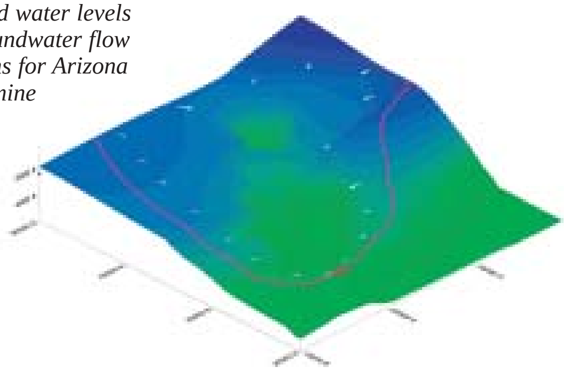
Regulatory agencies may review modeling results in order to:

- Evaluate the effects on flow patterns and water quality trends for mine closure at different points in the mine plan.
- Understand the long-term effects on mine-wide or basin-wide water resources.
- Predict hydraulic gradients and pit-lake levels that can be compared with actual data as the pit lake develops.

Modeling pit lakes involves a number of challenges due to the typically complex geologic terrains of mines, combined with large-scale mining activities. Heterogeneities, such as faults, a range of stockpile hydraulic properties, and variations in bedrock hydraulic conductivities must be incorporated into the model, along with complex 3-D geometry and multiple pits. Extremes in topography, such as deep pits in combination with surrounding stockpiles and mountains, create additional challenges to modelers. The water

Processes Simulated

Model or Approach	Lake Levels	Evaporation Function Lake Size	Complex Pit Geometry
LAK1	◆	◆	
LAK2	◆	◆	
LAK3	◆	◆	◆
High hydraulic conductivity	◆		
TARGET	◆	◆	◆
PITLAKE	◆	◆	◆
[illegible]	◆		◆
River/wells	◆		



Predicted water levels and groundwater flow directions for Arizona copper mine

budget must take into account evaporation and pit-wall runoff that vary with lake surface area as it fills over time. To further complicate matters, a pit lake may overflow into neighboring pit lakes or small pit lakes may coalesce into a single larger lake of complex geometry.

A number of possible pit-lake modeling approaches have been presented in the literature. These approaches vary in capabilities and range of applicability. Unfortunately the U.S. Geological Survey's MODFLOW lake packages are mainly prepared with puddle-shaped lakes and gentle topography in mind, quite unlike the mine-pit lake geometries encountered in the Southwest. A comparison of approaches can be see in the table below.

Case Studies

A variety of pit-lake model applications, together with problems and lessons learned, are discussed briefly below:

Southwestern Australia Gold Mine: A gold mine in southwestern Australia was evaluated using modeling analyses to compare alternate lake geometries and lake levels with the idea of a recreational end-use for the mine. The mine is located in a desert environment with moderate topographic relief. The analysis of pit lakes at this site is complicated by a peculiar groundwater flow regime, several large sinuous V-shaped pit lakes interconnected by surface streams, and episodic changes in precipitation and evaporation. Most groundwater flow occurs in a thin rind-like layer of weathered bedrock that mantles the hilly metamorphic bedrock terrain. This results in an unusual three-dimensional (3D) flow system and a complex interconnection of groundwater with pit lakes. Many groundwater models have trouble accurately simulating such systems (1D, 2D and so-called quasi-3D models are inadequate), so only a model capable of handling true 3D flow could be used.

Western Australia Diamond Mine: A pipe-shaped diamond mine in Western Australia was modeled for the purpose of evaluating pit-lake inflow rates, ultimate water levels, and likely future total dissolved solids concentrations in the pit lake itself. The model was required to simulate both flow and transport parameters, as well as the tortuous geometry of the main pit. For this project, a combined pit-lake flow and transport model was

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Stream Routing	Lake Overflow	Lake Coalescence	Transport	Practical Applications
◆				Cheng and Anderson (1993, 1994)
◆				Council (1997), Fontaine and Stone (1998), Nair and Wilsnack (1998)
◆	◆	◆	◆	Merritt and Konikow (2000)
◆			◆	Chung and Anderson (1998), Nair and Wilsnack (1998)
	◆	◆	◆	Moreno et al. (2002)
◆				Baker et al. (1998)
◆				Rember and Wenske (1998)
◆			◆	Doherty and Bengston (1998)