The Hydrology of Pit Lakes

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When mining and dewatering activities cease in any surface mine below the local water table, the excavation will begin to fill with groundwater and form a pit lake. The hydrologic system, both the groundwater and surface-water components, will then begin to establish a new equilibrium that might or might not be similar to pre-mining conditions.

The potential worst case may occur where both inflow and evaporation are moderate and there is outflow of evapoconcentrated water with high concentrations of certain constituents.

The rate at which this occurs and the extent to which pre-mining hydrologic conditions are restored depends on the local hydrogeology, the size of the pit, the magnitude and duration of dewatering during mining, and the climatic conditions. In any case, pit lakes act as artificial “windows” in the water table and, because of evaporation, become essentially permanent points of groundwater withdrawal.

Hydrologic Budget for a Pit Lake

The hydrologic budget (or water balance) for a pit lake can be described in terms of volumes (i.e., fluxes x time) by the equation:

$$V_{in} = V_{out} + V_e + V_{\Delta s}$$

where

V_{in} = volume of ground-water inflow
V_{out} = volume of ground-water outflow
V_e = volume of evaporation from pit lake surface
$V_{\Delta s}$ = change in volume of storage (change in water level x area)

This budget is shown in *Figure 1*. It is assumed that engineered drainage ditches and diversions will keep surface water out of a pit both during and post-mining. Of course, in some mines there may be occasional and presumably short-lived inflows of surface water, but they are not included in the generic water balance for a typical pit lake.

The rate of ground-water inflow is proportional to two primary factors: 1) the hydraulic conductivity (or permeability) of the rocks comprising the pit and 2) the hydraulic gradient between the water level in the pit at any point in time and some distant point where the water level has been essentially unaffected by mining and dewatering. The latter is a function of the hydraulic conductivity and storage properties of the intervening materials and the time since dewatering began. The near-pit hydraulic gradient, induced by dewatering and pit infilling, changes over time, with the steepest gradient occurring at the end of dewatering, when pit lake recovery begins. This is shown schematically in *Figure 2*. Because the hydraulic gradients are steepest during early pit lake recovery, the rate of infilling is greatest during early recovery and decreases with time. The rate of infilling is also a function of the volume per unit depth of the pit, which increases significantly as the pit lake fills, a function of the conical shape of the pit. If a) the hydraulic conductivity is relatively large, b) dewatering has occurred for a relatively long time (say 10+ years), and c) the storage of the rocks is low (which is the case for most bedrock), then the time of infilling can be quite long.

Evaporation can be a major variable in the pit lake infilling process. As used here, the term includes the net loss of water from the pit lake surface (evaporation less direct precipitation) and any evapotranspiration from either aquatic or phreatophytic vegetation associated with the pit lake. In some cases, the evaporation can be estimated from pan rates or published values for shallow lakes. In other cases, the process is much more complicated and factors such as water temperature, air temperature, wind speed, and humidity, and even lake factors including shape, fetch, shading, and seasonal turnover, must be considered. In areas where either the water temperature is geothermally elevated or pan rates do not represent the winter months, a simple pan rate might not be applicable.

Evapoconcentration

Evaporation from the pit lake surface causes concentrations of dissolved constituents within the pit lake water to increase over time. This is described by the approximate, transient relationship:

$$C_t = \frac{M_t}{V_t} = \frac{M_{t-1} + \sum(V_{in} C_{in} - V_{out} C_{t-1})}{V_{t-1} + V_{\Delta s}}$$

where

C = concentration
M = mass in solution
V = volume of water in pit lake
t = time

The evapoconcentration factor typically ranges from 10 to 40 times the concentration in the ground-water inflow. In the case of constituents such as arsenic, selenium, and many trace metals, evapoconcentration is a major consideration.

Terminal or Flowthrough?

An issue closely related to evapoconcentration is whether a pit lake will ultimately have outflow. Pit lakes are referred to as terminal when evaporation is such that the pit lake will always be a ground-water sink. A flowthrough lake has downgradient outflow. It should be noted that, depending on the gradient, outflow could begin well before the pit lake reaches equilibrium. Again, this depends on the size of the lake, hydraulic conductivity of the adjacent rock, and the climatic conditions.

Whether or not a pit lake is terminal or flowthrough can have significantly different environmental consequences. If inflow is small and evaporation is high, it is likely that evapoconcentration will be relatively high, but unlikely that outflow will occur. This results in a standing body of potentially undesirable water quality. Conversely, if inflow is high and evaporation is low, significant outflow will occur that most likely will have experienced little evapoconcentration of its dissolved constituents. The potential worst case may occur where both inflow and evaporation are moderate and there is outflow of evapoconcentrated water with high concentrations of certain constituents. In any case, evaporation from the pit lake will result in some loss of water resource relative to pre-mining conditions and, regardless of whether a pit lake is terminal or flowthrough, some evapoconcentration will most likely occur.

Hydrologic Impacts of Pit Lakes

A possibly non-intuitive effect of pit-lake infilling is that the dewatering-induced drawdown actually continues to increase in lateral extent during the early stages of pit infilling. The ultimate extent of drawdown can continue for several years after the dewatering ceases. This is illustrated in *Figure 3* using the 10-foot drawdown isopleth of the water table, a criterion for quantifiable impact used in the EIS process in some Western states.

If drawdown induced by dewatering and pit lake infilling impacts surface-water bodies, the maximum extent of the impact also continues past the end of dewatering. This is shown in *Figure 4*.

Although the general concepts of the hydrology of pit lakes and their impacts on the quantity and quality of water resources are quite simple, no general conclusions should be drawn. Each pit lake is unique depending on the local hydrogeology, the size of the pit lake, and the climatic conditions.

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Hydrologic Budget of a Pit Lake

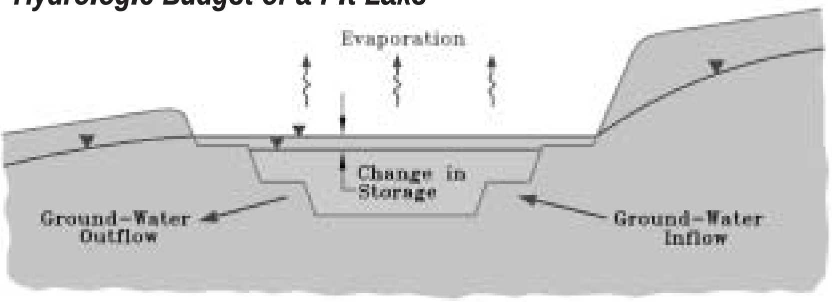

Figure 1

Pre- and Post-Groundwater Levels

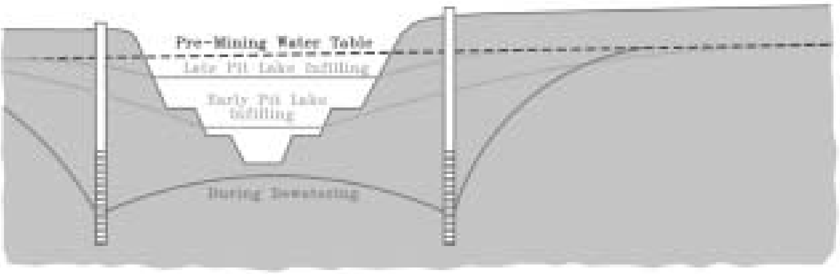

Figure 2

Drawdown Associated with Dewatering and Pit Lake Infilling

Figure 3

Potential Impacts on Nearby Stream Flow

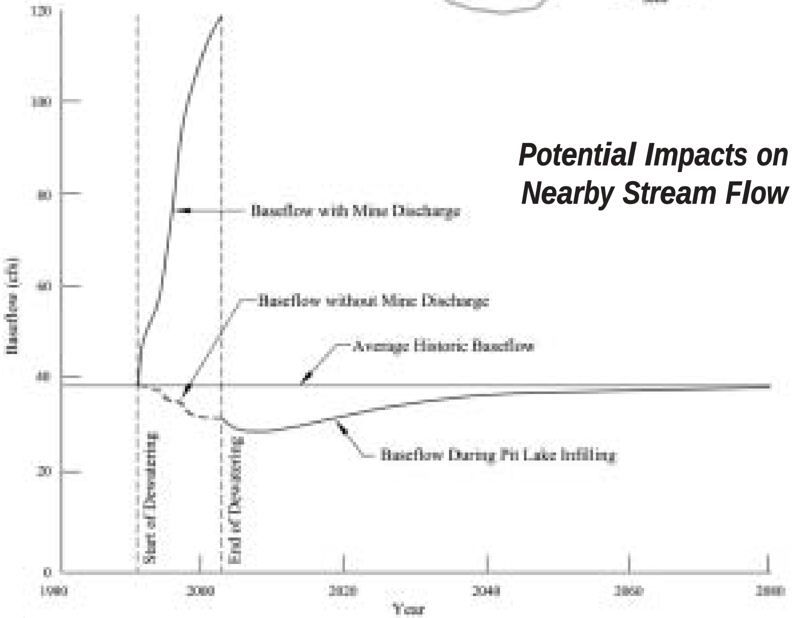

Figure 4