PINCOCK Perspectives

Consultants for Mining and Financial Solutions

ISSUE NO. 77 — April 2006

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Overview of Pit Lakes – Part 1

Introduction

Obviously pit lakes are not new. However, they have been gaining more attention in the US due to the prospect of a number of mine closures in the not too distant future. For example: "Gold-mining pit lakes in Nevada, when filled will contain more water than all of the reservoirs within the borders of this arid state. An estimated 35 pit lakes from all types of hard rock mining are expected to form, containing from less than 100 acre-feet up to about 540,000 acre-feet of water." (Glenn Miller, September/ October 2002; Page 16, Southwest Hydrology). To address this issue, the US Environmental Protection Agency (EPA) has sponsored Pit Lake technical transfer conferences in 2000 and 2004 to help evaluate and disseminate available research and planning tools.

Of primary concern when the mine operations cease and pit lakes form, is that they are managed is a manner such that surrounding environment is not impacted. A second consideration is developing a closure/management approach, if possible, so that the pit lake serves a purpose – such as public recreation, wildlife benefits, etc.

This is a two part article. The purpose of Part I is to provide a very basic overview of the various types of pit lakes, issues associated with them, and the basic physical/chemical/biological processes involved. Part II will provide an overview of the management and remediation approaches available, along with some examples and case study summaries.

Pit Lake Formation and Types

During active mining, surface water is diverted around open pits, and perimeter and/or in-pit dewatering pumps are used to control groundwater inflow and direct rainfall. Pit lakes form when the pumps are shut off and post-mining drainage of surface/groundwater and precipitation begin to accumulate inside the inactive pit. Depending on the size and availability of suitable fill, backfilling open pits can be impractical and prohibitively expensive. In such cases, a pit lake forms and the mine operators are saddled with ensuring it does not pose environmental and safety risks.

Based on climate, hydrologic conditions, and pit morphology, there are two basic types of pit lakes – terminal and flow-through. Terminal pit lakes are usually found in more arid climates where evapo-transpiration is greater than precipitation, and consequently water is not generally discharged from the pit lake. Due to evaporative processes, terminal pit lakes become cones of depressions in the water table with the groundwater gradient towards the pit (i.e., a groundwater discharge zone). And since evaporation is the only discharge pathway, soluble metals accumulate and increase in concentration over time.

Flow-through pit lakes are usually found in climates where direct precipitation and water inflow exceeds evapo-transpiration. Consequently, the pits fill with water and discharge occurs – either via groundwater or surface water outflow. In this instance, and depending on the individual site conditions, the pit lake could serve as a groundwater recharge area.

Primary Environmental Concerns

The primary environmental concerns associated with pit lakes revolve around water quality issues, and in particular oxidation of sulfides releasing metals, elevating sulfate concentrations, and causing acidification. Subsequently, poor water quality can cause:

- Wildlife hazards
- Surface water contamination
- Groundwater contamination

For example, migrating birds ingesting acidic pit lake water can experience severe trauma to their intestinal tracks and possible death. Additionally, the acidic water can remove the natural oils in the birds feathers exposing them to hypothermia and even death by drowning. Elevated metals concentrations can have toxic physiological and reproductive effects, and bioaccumulate through the food chain. The Berkeley Pit in Montana was lethal to 300 migrating snow geese in 1995. Note that in the US a bird kill can invoke the Migratory Bird Act – with potential financial penalties and criminal charges.

Generally pit lakes are deep and very steep sided, restricting the available space for riparian (i.e., lake banks/ shore) and shallow lentic (i.e., standing water) habitat, but obviously poor water quality could impact the establishment and maintenance of aquatic and terrestrial plants and animals using the lake.

In addition to the potential for surface and groundwater contamination, associated concerns involve impacts to groundwater systems – such as altering the groundwater flow patterns and evaporative-losses of precious water from pit lakes in arid climates.

Pertinent Physical and Chemical Processes Involved

The basic processes which need to be considered when evaluating pit lakes and associated water quality issues include hydrology, mineralology and geochemical reactions, and limnology.

Hydrology. Understanding the pit lake hydrologic regime is crucial to eventual management of a pit lake – both from a standpoint of water balance and water quality. For example, from a regulatory standpoint, demonstrating a permanent inward hydraulic gradient due to evaporative processes can show passive containment of the pit lake, eliminating surface and groundwater contaminant transport pathways. However, on the other hand the evaporative process also serves to concentrate metals in terminal pit lakes enhancing water quality problems. In many cases, operating mines have already established a solid surface and groundwater database through monitoring and/or dewatering - and thus have substantial data from which to build predictive hydrologic models for closure.

Mineralogy and Geochemical Reactions. A major factor in pit lake water quality can be the presence of sulfide-rich rock walls and surrounding host rock in the final pit – and for that matter neutralizing rock. In the presence of oxygen prior to the pit lake filling (or subsequently the presence of dissolved oxygen in the water), oxidation reactions with sulfides on the exposed walls can release acid, sulfate, and metals into the lake. Similarly, air can enter the surrounding host rock when the operating pit is dewatered, resulting in oxidation of sulfides and post-operation transport to the pit lake as the groundwater table recovers. Metals can also be released from bottom sediments through oxidation reactions.

Most mine operations have extensive knowledge of the acid generating and neutralization potential of the pit walls and surrounding host rock at closure. This data can be input to geochemical models in order to predict future pit lake water quality.

Limnology[1]. In conjunction with hydrology and geochemical reactions, limnological processes also play an important role in pit lake dynamics. For example, acidification is often controlled by hydrodynamic mixing in the lake. Two limnological components integral to a lake's ultimate water quality are the lake oxygen budget and stratification process.

♦ **Oxygen.** "Oxygen is the most fundamental parameter of lakes, aside from water itself" (Wetzel, 1975). Dissolved oxygen is essential to the metabolism of aquatic organisms, and the distribution of dissolved oxygen strongly affects the solubility of many inorganics and nutrients. A number of chemical/geochemical reactions (e.g., redox reactions) which affect water quality are dependent on the presence or absence of oxygen. Primary pit lake oxygen sources include:

- Aeration from the atmosphere
- Production of oxygen through photosynthesis
- Dissolved oxygen in surface or groundwater inflow

Generally, the aeration process is the major source of oxygen in pit lakes, occurring through the interaction of the atmosphere and the lake surface, and dependent on such things as local climate, lake morphology and fetch. Consequently, most oxygen is introduced at the surface of these deep, steep sided lakes and requires a circulation mechanism to mix the oxygen throughout the water column.

♦ **Stratification.** The regulation of lake physical/chemical dynamics and mixing is governed to a large extent by differences in water density. The maximum water density occurs at 3.94° C. Thus ice, at 0° C and water at 10° C will "float" on 4° C water. Consequently, depending on the climactic conditions, lakes can become thermally stratified, with a mixed surface layer (epilimnion) at one temperature; then a thermocline layer which has a reduction in water temperature with depth; and the uniform bottom layer (hypolimnion) at a colder temperature (Figure 1, page 4).

Note that stratification prevents mixing between the epilimnion and the hypolimnion – so during periods of stratification, the dissolved oxygen in the aerated surface water is not transferred throughout the lake. In warm regions, the stratified water layers can be maintained throughout the year. However, depending on the climatic conditions, the stratification can break down during seasonal changes when the lake temperature, and thus water density, is the same throughout the lake depth. This is commonly called "turnover", can occur once or twice a year, and results in mixing throughout the water column.

Note also that lakes can become chemically stratification. High concentrations of dissolved solids in a denser, bottom water layer (monimolimnion) are separated from the upper mixolimnion waters by a steep dissolved solids/ salinity gradient (chemocline). Again, with these so-called meromictic lakes, the stratification inhibits mixing throughout the water column.

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[1] Limnology is, in broad terms, the study of the functional relationships and productivity of freshwater biotic communities as they are affected by the dynamics of physical, chemical, and biotic environmental parameters. (Limnology, Robert G. Wetzel, W. B. Saunders Company, 1975)

Summary

As indicated above, it is the interaction of the various physical, chemical, and biological processes that determine pit lake dynamics and water quality. On a very basic level, note that oxygen is required for a number of geochemical and biochemical (e.g., ongoing acid generation) reactions, and the availability of the oxygen is dependent to a large extent on the limnological and hydrological processes going on in the pit lake. Thus knowledge of these processes can be used to develop an appropriate approach for closure.

Part II will consider how knowledge of these processes can be used to evaluate pit lake remediation/closure options and management techniques. Different approaches will be reviewed, including induced stratification, neutralization, and eutrophication. Additionally, several examples and case studies of pit lake closures will be summarized.

Look for Part II in a future issue of *Pincock Perspectives.*

This month's article was provided by Thomas Noyes, P.E., Principal Environmental Specialist tom.noyes@pincock.com

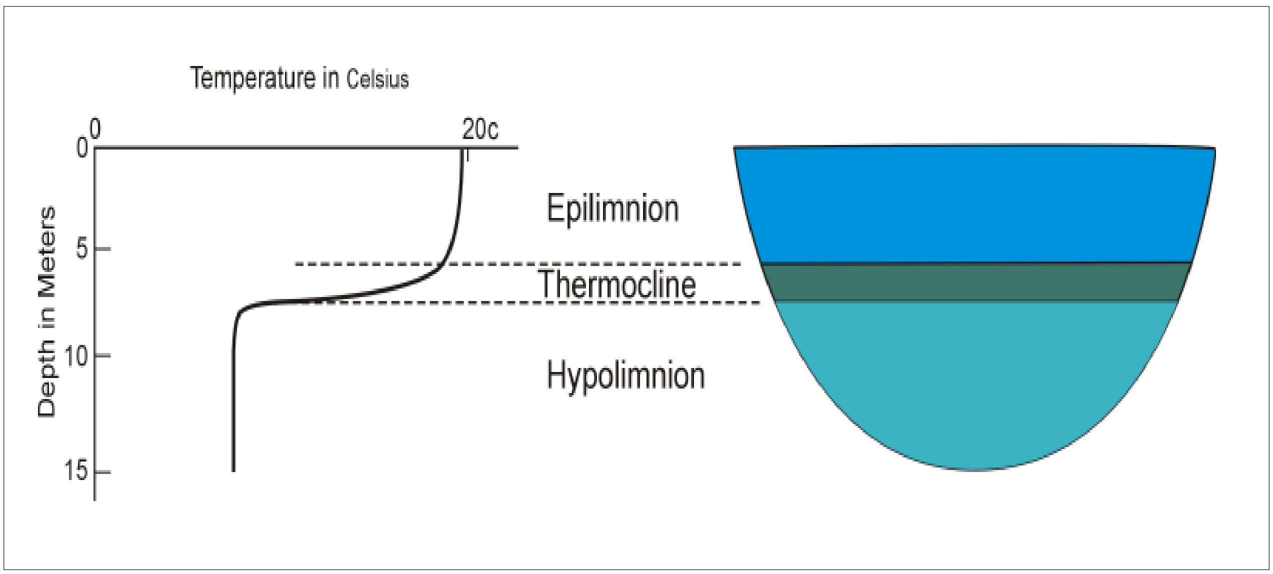

FIGURE 1
Stratified Pit Lake and Temperature Profile

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