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STATE OF THE ART REVIEW
Water Balance

Introduction

The water balance of the entire mine, a number of components, or a single entity, such as the heap leach pad, may be quantified as part of the water quality and/or quantity management activities at a mine site. Reasons for undertaking a facility or site water balance study may include: (a) evaluate strategies for optimum use of limited water supplies; (b) establish procedures for limiting site discharge and complying with discharge requirements, particularly control of the quality of the water and/or the quantity of contaminants discharged from the site; and (c) limiting or controlling erosion due to flow over exposed surfaces or in channels, swales, and creeks; and (d) estimating the demands on water treatment plants, holding ponds, evaporation ponds, or wetlands.

Industry Perspective

The following is adapted from a checklist compiled by a mine engineer who studied a water balance compiled by his consultant:

- ***Model***: Have an effective, robust, calibrated and easily updated and adjusted water quality and quantity (volumetric flow) model to understand the complex relationships of the mine for the prediction of water changes. Model all sources of contamination and the inputs as well as outputs. The stakeholders should agree that the model is accurate and appropriate.
- ***Measure***. Have an effective sampling regime to keep the water quality and quantity model up to date and continuously evaluate its effectiveness and test its assumptions.
- ***Calibrate***. Have the model checked each week initially (then monthly) with water quality and quantity numbers and monitor discrepancies between reality and model; evaluate and explain discrepancies.
- ***Contingency Plans***. Have a full set of costed contingency plans with established implementation timelines. Complete the engineering for likely long-term options.
- ***Manage***. Understand all possible actions that can be taken to minimise water quality and quantity issues and have them costed to +/- 35% accuracy. Know at what levels what actions need to be taken when pre-specified levels are reached so that management can confidently make decisions which meet its license limits while incurring the least expenditure.

General Relevant Information

The U.S. approach to and issues surrounding mine water balances is described by the U.S. EPA.. The following is a summary of information needed to design, construct, and operate a typical mine sediment dam.

Climate

The climate of the site is needed for an accurate facility or site water balance. Data are required to quantify: precipitation, snow depths and melt patterns, evaporation, evapotranspiration, wind, and solar radiation. Such data may come from one or more of many sources, including site measurement records, regional databases—usually the local airport, local and national databases accessible on the web, or synthetically generated data that many computer codes produce.

Surface Water

Data may be needed for a water balance study about local stream flow, surface runoff patterns and quantities, and infiltration patterns and rates. Establishing these quantities may again involve consulting site-specific measurement records, local data bases, or running computer codes that enable one to calculated infiltration through a soil surface such as the cover of a waste pile. The most common code for infiltration estimation is HELP, copies of which are commercially available from many vendors.

Groundwater

Groundwater flow patterns and rates must be known or predicted to model the water balance of a facility or mine. At some sites, the groundwater emerges as springs which add to the quantity (as sometimes the constituent loading) of a site. At most facilities and mines, protection of groundwater quality by limiting seepage to the groundwater is a prime objective. Quantification of groundwater flow regimes is complex even at the simplest of sites, and usually involves detailed site-specific studies based on monitoring wells and a history of water quality sampling.

Facility Layout

Before starting and water balance study it is imperative that you have good information about the site and facility layout. This includes quantification of area, topography, runoff, slopes, location and condition of streams and man-made channels, and possibly even the layout of the mine pit itself. Preferable the data should include digital maps that may be used with CADD systems to calculate areas, slopes, etc.

Facility Material Characteristics

Geologist and geotechnical engineers will probably have to be involved to characterize the materials of the facilities that are part of the water balance study. The prime characteristic is, or more correctly the hydraulic conductivity, of the soils and rocks that make up the strata at the site, that constitute the mass of the waste rock dump, heap leach pad, or tailings impoundment, or which serve as the cover of reclaimed and closed waste piles. Sampling and laboratory testing quantify the hydraulic conductivity of soil and rock. In situ wells testing quantifies bedrock permeability.

Vegetation

Evapotranspiration via vegetation is often the primary route by which water is lost or removed from a mine water balance system. The analyst needs to know the types and distribution of vegetation. Most computer codes that enable the analyst to quantify evapotranspiration require input of vegetation coverage, density, rooting depth, and periods of growth and quiescence. Collect such information by field observation, and supplement with studies, in situ testing, regional studies, or calibration of models by collecting data and comparing measured and calculated quantities.

Types of Water Balance Studies

There are in practice as many types of water balance studies as there are mines, as there are stages of development of a mine. For the purpose of this review, we define and use the following:

- Pre-Mining Prediction, Evaluation, and Design
- Mine Operation Modeling and Control
- Closure Planning and Design
- Post-Closure Maintenance

Here is a water balance model description from http://www.goldsim.com.

> Antamina Mine Operations Simulation Model. The purpose of the Antamina Mine Operation Simulation Model is to provide on-site personnel with a predictive tool to quickly assess the potential impacts of operational changes (e.g., changing the ore type or quantity to be processed, or pumping water from the tailings pond) with respect to environmental compliance. Of primary concern are possible water quality or minimum instream flow violations in the river to which water is released from the tailings pond under varying climate conditions. The model consists of a series of integrated submodels which represent the water balance at the mine site (tailings pond, clean water reservoir, diversion ditches and pumps), the climate conditions (precipitation, runoff, and evaporation), the operational conditions (ore being processed, fresh and recycle water), and the compliance conditions with respect to a variety of regulatory guidelines.

Case Histories

At this Barr web site, is a project description that nicely captures the many aspects of a mine water balance study: I quote:

> *An important part of the Environmental Impact Statement was to estimate the water balance during the project's life, including mine-pit dewatering and groundwater flow. Barr developed a model to evaluate whether enough water-shed runoff existed to provide water to the facility. The study accounted for minimum and maximum contributing watershed areas, groundwater contributions, plant consumption, tailings pond evaporation, tailings void loss and seepage loss, and water stored in unused mine pits. The model was calibrated to local and regional runoff data.*

I liked the story of the water balance study for the Rodeo Tidal Lagoon—this is not a mine, but the study incorporates all the elements of a site-specific water balance:

Knight Piesold describes their work in quantifying the mine water balance at the Kemess Copper and Gold Mine. .

ANALYTICAL APPROACHES

The most common way to build a water balance model of a facility of site is to use that famous stand-by, Excel. The reason is that most water balance models generally involve no more than successive solution for each component of a facility and hence for each facility of the simple equation:

> Inflow – Outflow = Change in Storage

And Excel is easy to program and easy to use in the successive solution of this equation. The computer code GoldSim is the best way to do it if you can afford the code—at least so I am told by my friends who earn their living doing mine water balance studies.

Regulations

The Indian Bureau of Mines requires a water balance as part of the mine closure documents. where the following is stated: *4.2 Water Quality Management : Describe in detail the existing surface and ground water bodies available in the lease areas and the measures to be taken for protection of the same including control of erosion, sedimentation, siltation, water treatment, diversion of water courses , if any, measures for protection of contamination of ground water from leaching etc. Quantity and quality of surface water bodies should also be indicated and corrective measures proposed to meet the water quality conforming the permissible limits should also be described. Report of hydrological study carried out in the area may also be submitted. The water balance chart should be given. If there is potential of Acid Mine Drainage the treatment method should be given.*