

Case study: Site-wide water balance of the Pierina Gold Mine, Peru

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ABSTRACT: Site-wide water management for the mining industry is becoming increasingly important because of the requirements for International Cyanide Management Code and internal water volume accounting. In locations where precipitation is intermittent for parts of the year, it is important to develop storage strategies for use during dry seasons. It is critical to have an accurate inventory of solution at all times in case of uncontrolled circumstances (e.g., extreme precipitation events or power outages). The following case study presents a water balance model that was created for a complex gold mine operation in Peru. Water Management Consultants (WMC) created a site-wide water balance model in GoldSim based on conceptualizations from mine visits and on the operational conditions of the process facility.

1 INTRODUCTION

Water Management Consultants (WMC) was commissioned by Minera Barrick Misquichilca S.A. to develop a site-wide water balance model for the Pierina Mine (Pierina). The location of the mine is presented in Figure 1. The location of the open pit mine is near the city of Huaraz in north-central Peru and produced approximately 45,000 tonnes per day of gold-silver ore in 2007. The open pit is within the Puca Uran watershed while all process facilities are within the adjacent Pacchac watershed. Both flow to the Rio Santa.

The model developed for this project includes water balances for individual process facilities and integrates them into a site-wide water balance and inventory. The model is based on conceptualizations from mine visits and on the operational conditions of the process facility as communicated to WMC through discussions with mine personnel (Ludwick, 2006).

The main purpose of the project was to provide Pierina with a tool for process facility solution management. The resulting model was used to assess implications of scenarios such as failure of pumping equipment and extreme precipitation events in order to size containment facilities, and to prevent unintentional releases. The overall goal of the proposed work was to develop a site-wide water balance model for Pierina to:

- provide leach operators sufficient information for daily solution management decision making in compliance with the International Cyanide Management Code (www.cyanidecode.org),
- assess implications of loss of pumping capacity with regards to solution drain-down, extreme precipitation events, and existing operational storage.
- make recommendations that reflect changes due to continued mine expansion regarding existing containment volumes and pumping capacity,



Figure 1. Location of Pierina Gold Mine.

- determine an estimate of make-up water or the volume of excess solution in the leach pad; excess solution would represent that volume necessary to be treated before discharge.

The model incorporates the following:

- general operational conditions such as ore stacking rates (varying monthly), solution application rates (varying daily), leach pad areas and leaching schedule,
- existing management of incident precipitation including exposed liner and raincoats,
- up-gradient surface water controls (including roads and drainage networks),
- current primary and secondary solution containment systems,
- representative climate conditions,
- current pumping capacity in primary and secondary containment systems.

2 PROJECT SETTING

Pierina began operations in 1998 and active mining will continue until 2011. The process facilities lie within the Pacchac watershed, which in turn flows into the Rio Santa. The following sections are intended to provide a brief overview of the climate data and site facilities.

2.1 Climate data

Daily data for precipitation and evaporation, along with temperature and wind speed/direction were collected at the Pacchac Meteorological Station (2000–2006). The total average annual precipitation in the area is approximately 1,156 millimeters (mm) with average monthly values ranging from 2 mm to 240 mm. The wet season extends from October to April, and the dry season from May to September. Daily average rainfall ranges from about 4 to 8 mm during the wet season and 0.08 mm to 1.3 mm during the dry season. The total average annual pan evaporation is approximately 1,112 mm with average monthly values ranging from 48 mm to 126 mm. The 100 year storm event, as determined by mine personnel, is 98 mm over a 24-hour period.

2.2 Site facilities

The modeled portion of the site consists of facilities within the Pacchac Valley catchment that covers an area of about 5.3 square kilometers (km²). The facilities included are:

- six holding ponds,
- the leach pad and caisson platform,
- the processing plant,
- the Acid Rock Drainage (ARD) treatment plant,
- the South Diversion Ditch (SDD),
- and the North Diversion Ditch (NDD).

Currently, the leach pad covers an area of approximately 1.15 km². The leach pad is lined with a HDPE geomembrane and has a series of under-drains that convey spring flows from beneath the pad. Portions of the leach pad surface are covered with “raincoats” (plastic liners positioned over large portions of the pad) to divert rainfall and prevent dilution of the pregnant leach solution (PLS). Under normal operating conditions there is no pond containing PLS exposed to the atmosphere. The leach pad includes an internal dike and caisson platform that provides containment for the PLS. The PLS level is maintained below the surface of the caisson platform and the PLS is contained within the pore spaces of the ore, under saturated conditions.

The PLS is transferred to the processing plant via vertical turbine pumps located within the caisson platform.

The six holding ponds include the raincoat pond, sedimentation pond, two sludge ponds, collection pond, and the polishing pond. The raincoat pond is used to collect the runoff from the raincoat liners placed over the leach pad. The sedimentation pond collects runoff from the waste dump area and some of the up-gradient area. The sludge ponds are used to store thickener solids from the ARD and cyanide destruction processes, and temporarily store barren leach solution from the processing plant. The collection pond stores water diverted from the sediment and raincoat ponds. The polishing pond is the final holding pond for the water on site.

The ARD Plant was originally designed for neutralization of ARD, but has since been converted to transfer water and solids from cyanide destruction to other locations. The processing plant handles all PLS solution that is pumped from the caissons. The NDD is used to divert water from the waste dump and other areas north of the site to the sedimentation pond. The SDD is used to divert runoff water around the process facility and return it to the Pacchac drainage. The SDD collects runoff from up-gradient catchment areas and can accept discharges from the sedimentation, collection, or polishing ponds.

3 TECHNICAL APPROACH

The technical approach for the water balance modeling included:

- conceptualization of hydrologic model for Pierina facilities within the Pacchac Valley,
- creation of the model and its components within the probabilistic simulation program GoldSim (GoldSim, 2007),
- development and calibration of a water balance model for the entire site using historical data from 2006,
- development of a predictive model for use in evaluating potential impacts of various scenarios requested by the mine.

The following sections discuss the different components of the water balance.

3.1 Conceptual hydrologic model

The final conceptual hydrological model is presented in Figure 2. The model incorporates all water storage facilities and flows within the process facility, including flows that are not used at

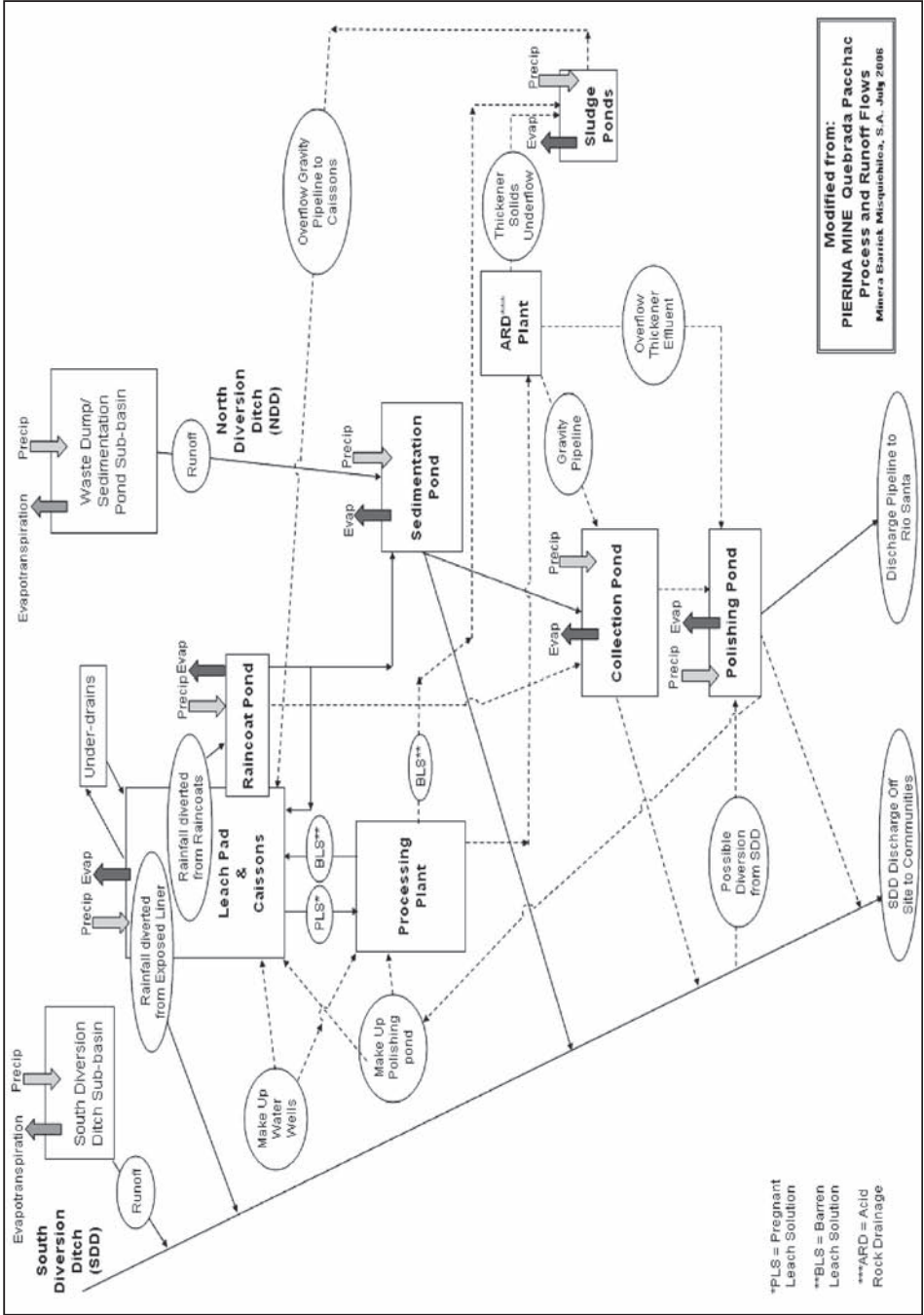


Figure 2. Site-wide water balance conceptual model for Pierina.

this time but were required for predictive purposes. The model was run on a daily timestep because of the requirement that it be used as a daily solution management tool.

The arrows in Figure 2 indicate the direction of flow for solution/water on site. The main facilities are shown in bold. All flows indicated on this diagram are represented in the model. The flow on site is described in further detail in sections 3.1.1, 3.1.2, and 3.1.3.

The model includes water balances for individual site facilities and integrates them into a site-wide water balance and inventory. The facilities include six separate holding ponds, the leach pad and caisson platform, raincoat liners used to cover the leach pad, the processing plant, the acid rock drainage (ARD) plant, and two diversion ditches. Spring flow beneath the leach pad is collected by the under-drain system and re-circulated back into the leach pad. Waste rock and the surrounding natural and disturbed areas were incorporated as part of the water balance to calculate the runoff diverted into the holding ponds and diversion ditches.

3.2 Climate

Historical data were used directly in the model, when available, and were also used to calculate the statistics utilized for the predictive climate behavior. For predictive model runs, the model uses the mean and standard deviation for daily precipitation and evaporation values from 2000 to 2006 to create stochastic data sets that change with every iteration of the model. The average monthly precipitation and evaporation are presented in Figure 3. The data sets are based on a normal distribution about the mean for evaporation, and a log-normal distribution about the mean for precipitation using the means and standard deviations of daily data. These distributions produced predicted precipitation and evaporation data sets that closely resembled historical data. A 100 year storm event, previously calculated by mine personnel, was also incorporated into the model and can be inserted anywhere in the modeled time period for prediction of necessary storage capacity.

3.3 Surface water management

The Pacchac drainage area was split into seven sub-basins which were defined for each of the key facilities included in the water balance. The sub-basins were defined based on topography, surface water diversions, and roads and were classified based on surface and soil conditions.

The surface water runoff volumes for each pond were calculated using the National Resources Conservation Service (NRCS) curve number method (NRCS, 1972). This method is typically applied in the United States, but, as Peru does not have a defined method to estimate precipitation runoff, this method was assumed appropriate for use with the water balance model.

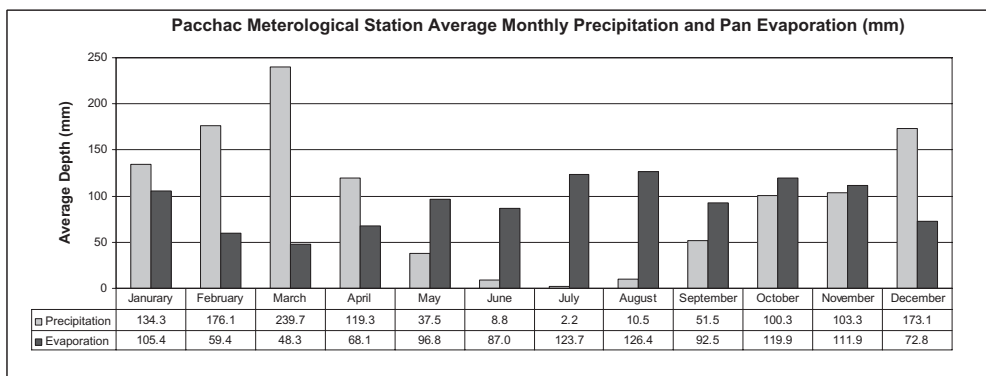


Figure 3. Average monthly precipitation and pan evaporation values.

The NRCS approach uses climate data, and accounts for infiltration losses based on antecedent moisture conditions (AMCs). The following equation is used to calculate the runoff from a specific area:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)}$$

where Q is the runoff depth, P is the precipitation depth, I_a is the initial abstraction depth including surface storage, interception and infiltration prior to runoff, and S is a storage parameter determined using the following equation:

$$S = (1,000/CN) - 10$$

where CN is the curve number. Curve numbers range from 0–100 and are a function of the soils ability to infiltrate water. The CN is determined by the AMC described below, and the land use. I_a is typically approximated as $0.2 * S$, for a final runoff equation of:

$$Q = \frac{(P - 0.2 * S)^2}{(P + 0.8S)}$$

Runoff curve numbers for each sub-basin area were chosen based on site soil conditions. Curve numbers as a function of AMC were assigned based on surface conditions and are explained below.

The AMC allows the model to account for water already in the soil when rainfall occurs. The AMC is based on dry (AMC I), moist (AMC II) or wet (AMC III) soil. The model handles this by looking at the previous five days of precipitation. If rainfall over that five day period totals less than 12.7 mm, the soil is at AMC I, if it totals between 12.7 mm and 27.9 mm, the soil is at AMC II, if the total is greater than 27.9 mm, the soil is at AMC III. The different curve numbers for each AMC used in the model are listed in Table 1 (Ward, 2004). Curve numbers were estimated from comparing surface conditions on site to the NRCS curve numbers listed for agricultural and commercial use for hydrologic soil group B, or C (NRCS, 1972). Soils classified as group B and C have moderate and slow infiltration rates when wet, respectively.

The roads and surface water diversions work similarly to convey water off site and to different holding ponds (Figure 2). The NDD and SDD serve as the major surface water diversions on site. The NDD conveys surface water from the waste dump/sedimentation pond sub-basin to the sedimentation pond, and the SDD conveys the surface water from its surrounding sub-basin, as well as some of the process water off site.

Table 1. Curve numbers for antecedent moisture conditions.

On site surface conditions/NRCS surface conditions/ hydrologic soil group	AMC I	AMC II	AMC III
leach pads	0	0	0
waste rock/cultivated with conservational tillage/B	52	71	86
disturbed areas/cultivated with conventional tillage/B	63	81	92
partially disturbed areas/cultivated/B	60	76	87
undisturbed areas/thin stand forest/B	48	66	80
haul roads/roads/B	66	84	96
other dirt roads/roads/C	78	90	96
liners	100	100	100

3.4 Process water management

All flows are modeled as instantaneous flow from one location to another except the flow through the leach pad where storage in the pore space was modeled to include time for pore-space wet-up and drain-down.

The downward movement of precipitation and leach solution applied to the leach pad is delayed during the “wet-up” period. That is, by the process of increasing the water content in the ore from the initial moisture content (average of 10.7% by volume, based on column test data received from the mine, Ludwick, 2006) to the moisture content where solution begins to flow directly through the ore (average of 18% by volume, also based on column test data received from the mine, Ludwick, 2006). The model uses the thickness of the ore and the leach application areas to calculate the volume of ore under leach. The outflow from the pad is then calculated as a function of the irrigation rate for each area.

When a new area is placed under leach, or irrigation, the volume of solution required to increase the volumetric water content from the average 10.7% to 15% represents the initial solution uptake. Solution will flow, or leak, from the new ore into the under-lying ore at a rate of 1% of the total volume applied per day until wet-up is completed. When the moisture deficit has been met, the volumetric water content will be 18% and steady-state operational conditions will result in the inflow rate equaling the leakage rate. The leakage rates were determined during model calibration. This process is illustrated in Figure 4.

When leaching stops, the solution drains out of the ore until a volumetric water content of 15% is reached. This is the estimated residual water content of the ore.

The model also includes a delay of one day to account for the time required for solution to move along the bottom liner of the leach pad.

The leach pad is directly connected to the caisson platform, as all flows of PLS from the leach pad reach the caissons. The solution contained within the caisson platform is pumped to the processing plant, and barren solution is pumped back to the leach pad. If cyanide destruction is

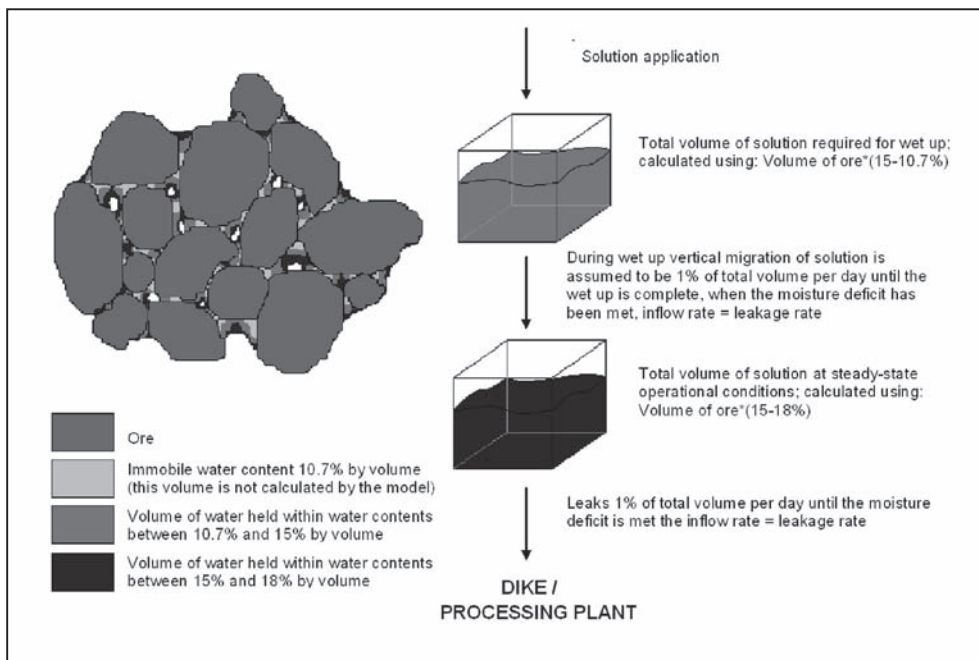


Figure 4. Schematic of the processes modeled for solution movement through the leach pad.

necessary to manage the water balance, barren solution is sent from the cyanide destruction circuit to the ARD plant for pH adjustment. ARD plant overflow can be sent to either the collection or polishing ponds. Thickener underflows are transferred to the sludge ponds.

Any solution stored in the sludge ponds can be transferred back to the caissons. There are two surface water diversions within the pad, one to divert precipitation falling on the exposed liner to the SDD, and a series of canals from the raincoats to divert precipitation to the raincoat pond.

The raincoat pond discharges to either the sedimentation or collection pond, depending on cyanide level. The sedimentation pond collects a large amount of surface water runoff and allows eroded sediments to settle out. Overflow from the sedimentation pond can go to either the SDD or the collection pond. The collection pond can also be diverted to the SDD, or to the polishing pond, and the polishing pond can then divert water to the SDD or off site. The polishing pond is also used as a source of make-up water to the processing plant and leach pad if necessary.

4 MODELING RESULTS

4.1 *Calibration*

The model calibration was conducted using site data from January to August 2006, while the site was under normal operating conditions. The purpose of this calibration was to make sure that the model matched the simulated water elevations to historical water elevations in three of the holding ponds and the solution elevation in the caissons.

4.1.1 *Calibration approach*

Calibration of the water balance model involved use of historical climate data along with available historical facility process flow data. Some of the process flows were not measured or recorded on site; reasonable maximum flows were estimated based on site visits and evaluation of each facility. Some reasonable adjustments (based on estimated error in the measurements of flow) were also made to the historical data in order to fully calibrate the model. The final calibration model matched the historical solution elevation in the caissons as well as the collection, polishing, and sludge ponds relatively well, as described below.

4.1.2 *Calibration results*

To calibrate the model to the historical caisson elevation, the historical irrigation and PLS pumping rates had to be adjusted. None of the precipitation onto the exposed liner was diverted to the SDD. Other data used during the calibration were historical values received from the mine including precipitation, irrigation areas, make-up water, and under-drain diversions.

To calibrate the water elevations in each of the holding ponds, assumptions of pumping rates from one facility to another were made. Pumping rates needed to match the pond elevations were limited to 150 m³/hr. This is the flow limit for most of Pierina's pumps and conveyance systems at the site.

Figures 5 through 8 present the calibrated solution elevations versus historical solution elevations for the caissons and for the holding ponds where there were historical data available. Typically, the difference between the two data sets is less than one meter, except in the case of the sludge ponds, where the difference is up to two meters. The difference in water elevation is much larger in the sludge ponds than seen in the other ponds because the total volume of the sludge ponds is relatively small when compared to the other storage facilities. There were no historical data available to calibrate flows for the sedimentation and raincoat ponds.

4.2 *Predictive runs*

The main purpose of the predictive model is to provide Pierina with a tool for daily facility solution management. The model will be used to assess implications of the scenarios such as

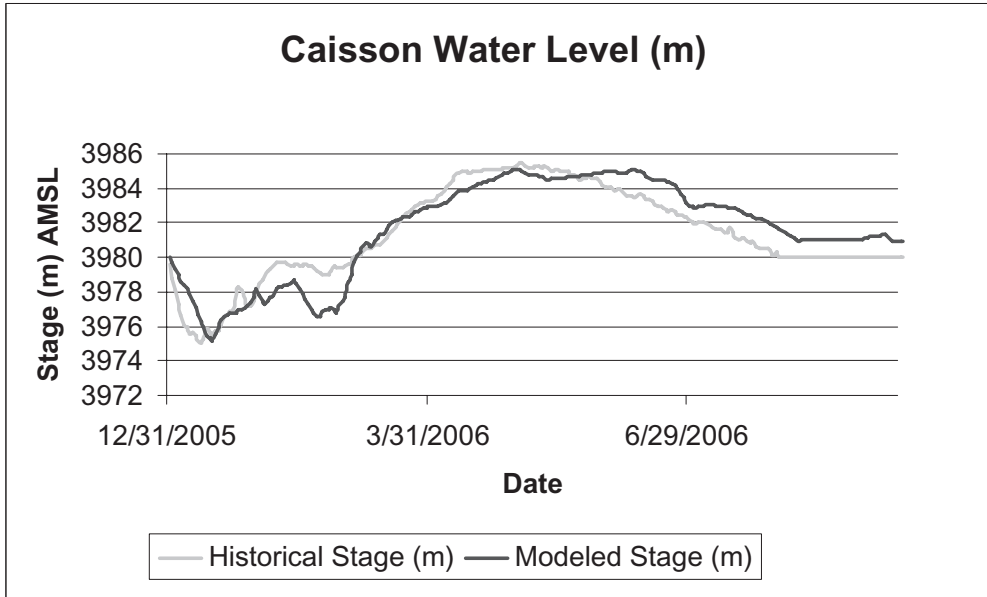


Figure 5. Calibrated water elevation in the caisson.

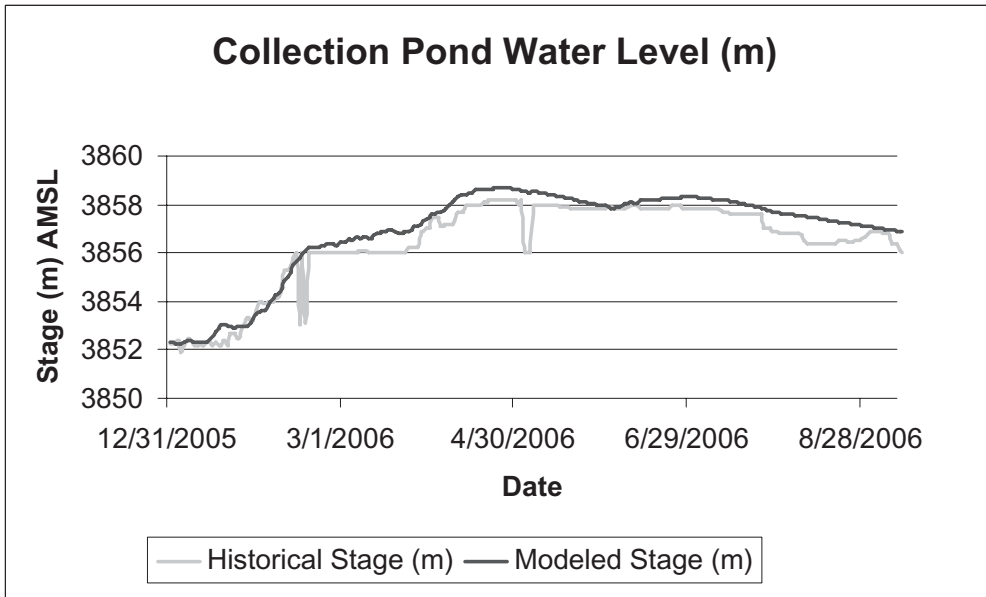


Figure 6. Calibrated water elevation for the collection pond.

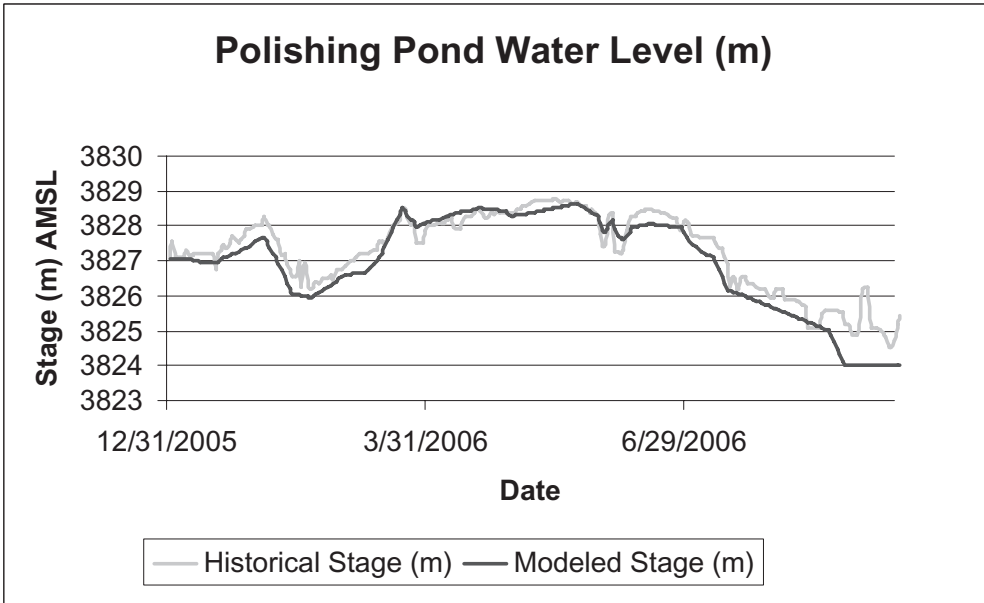


Figure 7. Calibrated water elevation in the polishing pond.

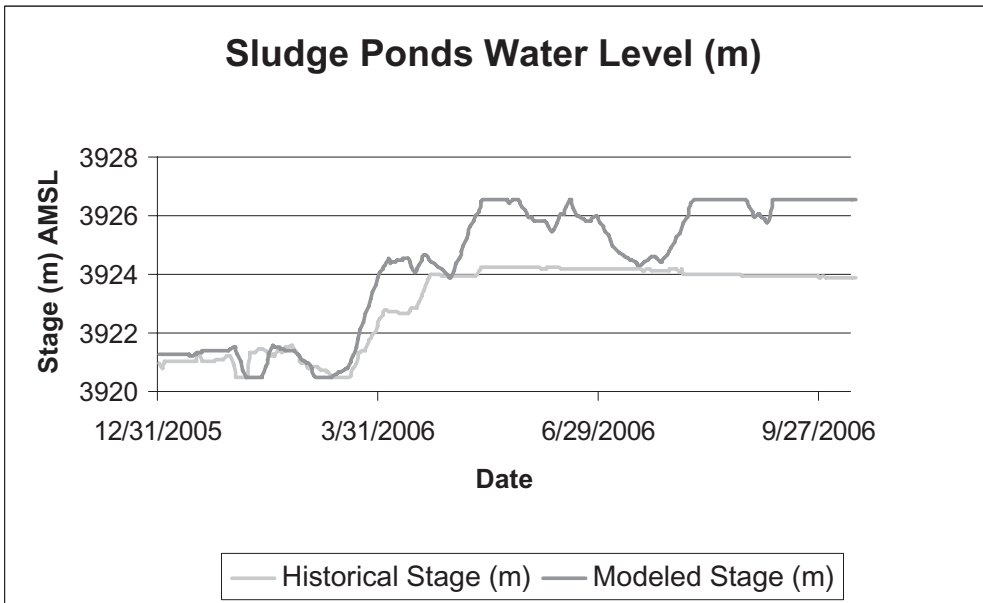


Figure 8. Calibrated water elevation in the sludge ponds.

failure of pumping equipment, and extreme precipitation events to size containment facilities and prevent accidental releases. Two examples of predictive runs are explained in the following sections.

4.2.1 *Loss of PLS pumping capacity*

A model run simulating loss of PLS pumping capacity was developed to predict the length of time required for the caisson platform to fill up to its maximum elevation of 3,990 m from a starting elevation of 3,981 m (the high elevation at normal operating conditions with a total available storage volume of 349,800 m³). Three scenarios were modeled: barren solution application continues as normal, barren solution application is reduced by 50 percent, and barren solution application ceases during the shutdown.

The model predicted that the solution elevation in the caissons would near the maximum elevation within seven days if the leaching is continued at the normal rate. With the leach rate cut in half, it takes 12 days to reach the maximum elevation. With leaching shut off completely, the dike did not overtop within 20 days, it reached a solution elevation of 3,986 m.

4.2.2 *Impact of extreme precipitation events*

A model run with a synthetic 100-year-storm event occurring during the wet season (98 mm over one day) was executed to predict what would happen to the caissons and pond water elevations. The starting elevations of water in the ponds were based on normal operating levels. The model predicted that the sedimentation and raincoat ponds will overflow.

In this scenario, the overflow from the raincoat pond goes to the sedimentation pond, and the sedimentation pond overflows to the collection pond. The sedimentation pond overflow is not transferred to the SDD, because there is likely to be a large amount of sediment involved with this size of storm. This sediment would be discharged to the collection pond. No discharge offsite would occur from the collection pond because there is enough volume in the storage facilities to hold the runoff water from this storm.

5 CONCLUSIONS

The Pierina site-wide water balance provides the information required to safely manage daily solution management on site. The model can also be used as a decision-making tool by entering all historical data into the model and creating predictive runs. Day-to-day management can be simulated easily by mine personnel using the Graphical User Interface (GUI) that comes with the GoldSim model. The results of the model runs provide the user with a summary of flows around the mine site. This will allow the user to determine the necessity for make-up water or excess solution that will need to be put through cyanide destruction.

The objectives of this project were fulfilled through use of the site-wide water balance model. Mine personnel currently use the model for daily solution management decision making in compliance with the International Cyanide Code. With estimation of key model inputs for future operations, mine personnel can evaluate extreme storm events and volumes required for make-up or cyanide destruction.

SPECIAL THANKS

It is important to acknowledge the vital contributions made by the people of the Pierina Process Department, especially Wesley Ubillus and Pedro Puente, and to thank them for their efforts to make the project a success.

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