Hydrogeologic Investigation of the Gold Reserve Incorporated Brisas del Cuyuni Concession in Southeast Venezuela

Breckenridge Larry, Hudson Amy, Brown Phillip, Henderson Mike.

Vector Colorado LLC
603 Park Point Drive, Suite 250. Golden. Colorado. USA
E-mail: breckenrigde@vectoreng.com, hudson@vectoreng.com, hydrobro@aol.com, henderson@vectoreng.com
Garcia Andres
Gold Reserve Incorporated
926 West Sprague Avenue, Suite 200. Seattle. Washington. USA
E-mail: agarcia@brisasdelcuyuni.com
Keywords: Pit Dewatering, Groundwater Modelling, Hydrogeology

ABSTRACT
The following paper discusses the hydrogeologic investigation, groundwater modeling effort, and design of an optimized pit dewatering system for the proposed Gold Reserve Incorporated Brisas del Cuyuni Concession gold and copper mine in southeast Venezuela. This dewatering design presented some unique challenges due to the size of the pit and the climate of the region. The objective of this evaluation was to design a dewatering system for a 2.2 square kilometer pit, with special consideration for dewatering unstable clay-rich saprolite pit slopes, in an area that receives over three meters of rain a year. Using a MODFLOW-SURFACT groundwater model, an optimized dewatering system was designed that uses a combination of permanent dewatering wells, in-pit temporary wells, and in-pit sumps. The result is a dewatering system which not only dewaters a final pit influx of 350 liters/second of groundwater, but also has the required flexibility over the life of the mine to conform to a dynamic mine plan and challenging hydrogeologic conditions. In addition, on-going work utilizes the groundwater model to predict pit lake filling times and the steady-state interaction between the pit lake and the regional system.

INTRODUCTION

Background

The Brisas del Cuyuni Concession (Brisas) was purchased by Gold Reserve, Inc. (GRI), in late 1992. The property is a potential gold and copper mining project. As illustrated in Figure 1, the project is located in southeast Venezuela in Bolivar State. It is 373 kilometers (km) southeast of Puerto Ordaz.

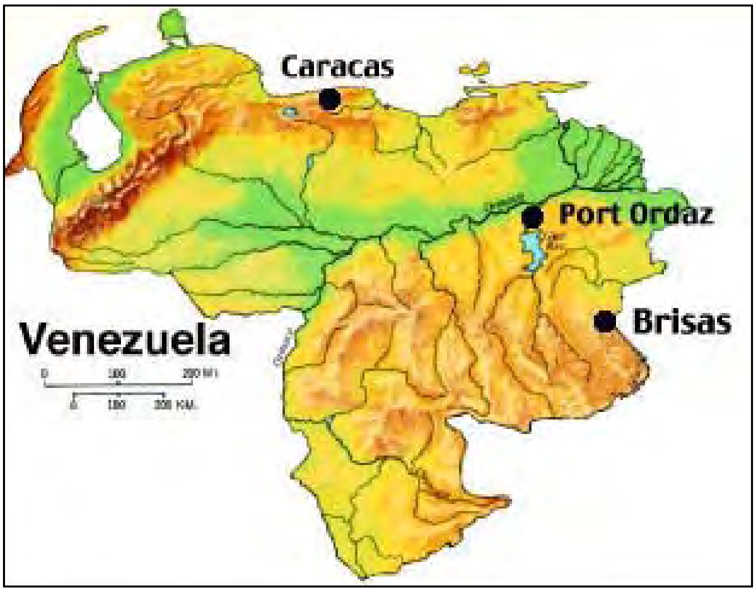

Figure 1: Brisas del Cuyuni – Location

Objectives

The objective of this study was to design and optimize a dewatering system for the Brisas pit that will maximize dewatering efficiency and minimize the geotechnical risk of saturated pit slopes.

GENERAL SITE CONDITIONS

The following sections outline the general site conditions that impacted the dewatering plan. These conditions include: site climate, physiography, geology and hydrogeology.

Climate

One of the greatest challenges of this study was the abundant groundwater recharge resulting from over three meters of annual precipitation. The Brisas concession's climate is tropical with high humidity and warm temperatures throughout the year. There are two distinct seasons: the rainy season which begins in May and lasts through October, and the dry season which takes up the remainder of the year. During the dry season rainfall occurs but storms are generally less intense.

Physiography

The topography of the Brisas concession is relatively flat with elevations ranging between 126 meters (m) and 147 m above mean sea level (amsl) with a total relief of 21 m. Low-lying areas consist of wetlands or swamps, suggesting that water is perched on the lateritic/saprolitic soils. Flat-lying soils minimize runoff and maximize groundwater infiltration.

Geology

The Brisas concession lies in the granite greenstone belt of the Pastora province of the Guyana Shield. The Guyana Shield covers the eastern part of Venezuela, Guyana, Surinam, French Guyana and parts of northern Brazil. In the immediate vicinity of the site, prior geologic studies identified four distinct lithologic units which had hydrogeologic significance. Each of these units is described in further detail in Figure 2 and in the following section.

Hydrogeologic Units

The far-right column in Figure 2 shows the hydrogeologic characterization of the geologic units. The oxidized saprolite and sulfide saprolite units have similar properties and could be lumped into a single unit. This clay-rich saprolite inhibits recharge and slows infiltration to the water below. The transition zone and fractured rock zone can also be grouped as they had statistically-identical properties, despite their different compositions. This unit is the primary aquifer at the Brisas site and is the target of nearly all dewatering efforts. Beneath the fractured rock layer, the bedrock becomes less conductive with depth as fracture density decreases.

Recharge and Discharge Prior to Mining

Because of the high precipitation, most lithologic units are saturated to some extent. The water table is usually quite high (0 to 3 m below ground surface [bgs]) and intercepts the surface in swampy areas. The saprolitic and lateritic soils limit recharge, but a substantial quantity of water seeps through the soils into the underlying fractured-bedrock aquifer. Groundwater discharge occurs mainly to rivers in low lying areas where swamps and lakes exist. In addition, numerous old mining pits have become small lakes due to the high water table. Evapotranspiration is an important groundwater sink even though only in March does potential evapotranspiration exceed recharge.

Aquifer Testing

Because prior hydrogeologic testing was limited to slug testing, Vector Colorado LLC (Vector) conducted several aquifer tests as part of the study. The tests confirmed that the transition/fractured rock aquifer acts as one unit, and that the saprolite layers could be effectively dewatered by pumping the transition rock and fractured rock aquifer below them (see Figure 2). Figure 3 shows the aquifer response to pumping in the highest volume aquifer test conducted onsite.

Observation wells 1 through 4 and well 6 were located in the fractured or transition rock. Well 5A, located near the pumping well, but screened in the saprolite, showed a delayed but significant response to pumping the fractured/transition zone below it. The aquifer testing not only supplied aquifer parameters to the modelling effort, but it also confirmed the dewatering plan: pumping the high-yield fractured/transition aquifer dewaters the upper saprolite unit.

DESCRIPTION	MARKERS	GOLD RESERVE LITHOLOGIC CLASSIFICATION			CURRENT HYDROGEOLOGIC MODEL
Ground Surface **Oxidized Saprolite:** Completely weathered Iron-rich clayey soil No wet strength or cohesion ~10-20 m thick		SAPROLITE	OXIDIZED	ALL CLAY SAPROLITE	LAYER 1: SAPROLITE Approximate hydraulic conductivity (~K) = 10^{-5} to 10^{-6} centimetres per second (cm/s)
Sulfide Saprolite: Mostly weathered (some rock) Sulfide-rich clayey soil No wet strength or cohesion ~20-50 m thick			SULFIDE	MIXED SA-POLITE	LAYER 2: TRANSITION/ FRACTURED ROCK ~K = $4x10^{-4}$ cm/s Transition zone and fractured rock had statistically-identical conductivity and operated as one hydrogeologic unit
Transition Zone: Heavily weathered Mixed zone of sulfide saprolite and fractured rock ~10-20 m thick			WEATHERED		
Fractured Hard Rock: Moderately weathered Heavily fractured hard rock Rock Quality (RQD) <25% No trace of clay Variable sulfide content ~10-75 m thick		HARD ROCK		LEACHED	
Calcite Leached Hard Rock: Slightly weathered RQD <75% Extent to which calcite has been leached ~10-20 m thick			UNWEATHERED	FRESH	
Fresh Hard Rock: Unweathered Altered tertiary volcanoclasic rock Low fracture density RQD >75% Higher calcite content Ultimate depth below study interest					LAYER 3: FRESH ROCK ~K = $1x10^{-6}$ cm/s

Figure 2: Conceptual Geologic and Hydrogeologic Models – Brisas del Cuyuni

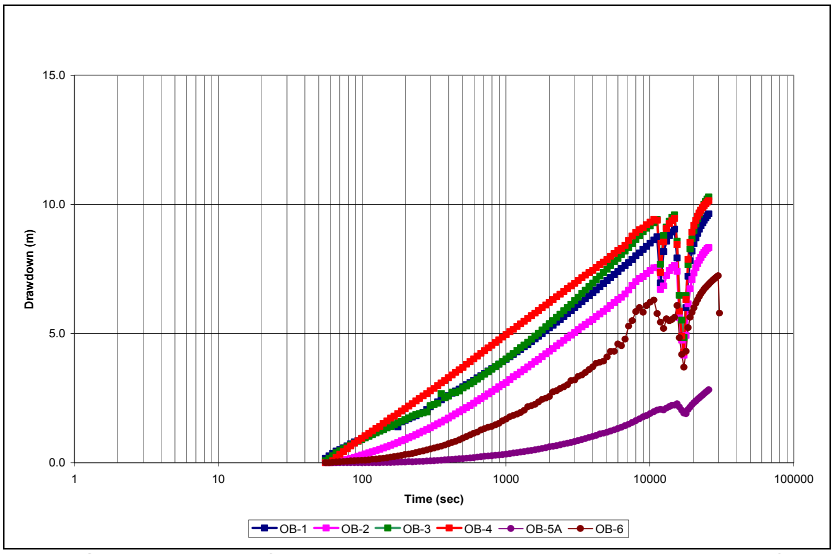

Figure 3: Semi-Log Plot of Drawdown vs Time – PW-1, High Flow Aquifer Test

Conceptual model during mining

The following section describes the changes to the system when it undergoes the significant stress of mining activities. Figure 4 shows a conceptual schematic of the hydrogeologic system during mining and active dewatering.

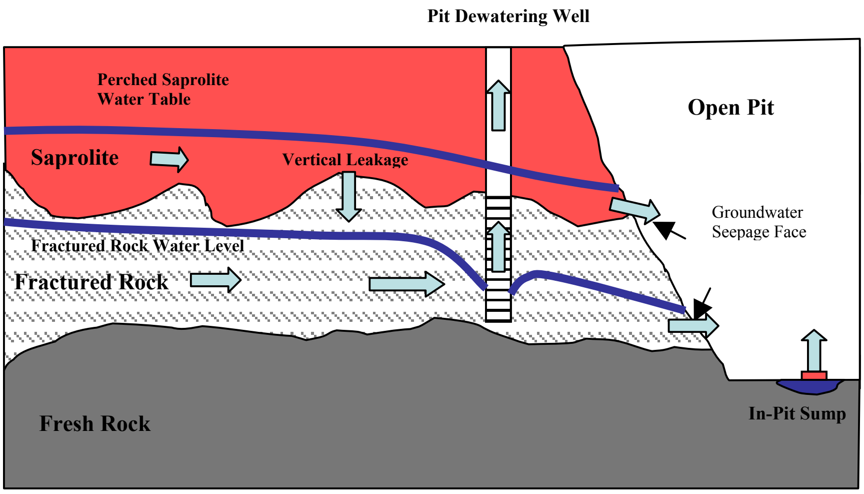

Figure 4: Post-Mining Conceptual Groundwater Flow Schematic

Dewatering the pit will create two separate aquifers: a perched saprolite aquifer and a confined/unconfined fractured rock aquifer. Most of the water in the saprolite aquifer will drain down into the fractured rock aquifer. However, due to the higher horizontal hydraulic conductivity, some groundwater may migrate to a seepage face in the pit. Water that discharges into the pit will be pumped from a sump and removed from the pit. It is predicted that the fractured rock aquifer will change from a confined aquifer to an unconfined aquifer near the pit due to the pit and pump induced drawdown.

PIT DEWATERING GROUNDWATER MODEL

The following sections describe the groundwater model created and used to determine the optimal number and configuration of pit dewatering wells. The pit dewatering wells are designed to dewater the saprolite and fractured rock aquifers to aid in pit slope stability and mining operations. The dewatering model presented some unique challenges due to the large scale (2.2 square kilometres [km^2] in area, 400 m. deep), significant natural recharge, and the dynamic mining plan. Currently, there are no other projects of this size located in a similar climate with this type of geotechnical stability concerns.

Model Code

In order to predict the optimal dewatering system design, a groundwater model was constructed using MODFLOW-SURFACT (Surfact). Surfact is an upgraded version of the 1988 United States Geological Survey (USGS) MODFLOW finite-difference groundwater model.

Surfact differs from the standard version of MODFLOW written by the USGS because it contains a sophisticated and mathematically stable algorithm for calculating the resaturation of dry MODFLOW cells. Additionally, Surfact has a package to accurately simulate the seepage face boundaries at the contact between the water tables and the pit. Finally, Surfact has a well package which simulates dewatering wells by constantly adjusting the extraction rate to achieve the desired water level.

Simulation Period

The model was run for the following time periods:

- Steady-state, representing the current conditions prior to the construction of the pit;
- Pre-dewatering, covering the one year period prior to the first excavation of the pit area; and
- Mining, covering the saprolite pre-strip year and continuing until the end of mine life after 18 years.

Simulation of Dewatering Operations

The mine plan for the Brisas pit is a complex series of separate excavations that eventually merge to cover the entire pit area and depth. The plan produces the required grade of ore sent to the mill at all times, but presents a significant challenge to the groundwater modeller.

The plan included three distinct phases:

- Pre-mining dewatering: This phase occurs before excavation begins and dewaters the saprolite prior to ore extraction. The model predicted that dewatering must start 1 year prior to mining to dry out the saprolite before excavation;
- Early-year mine dewatering: This phase runs from the start of the saprolite stripping through Mine Year 3. Because over this period the mine pit is much smaller than its ultimate extent, this phase uses some temporary dewatering wells located within the ultimate pit extent; and
- Cutoff dewatering: This phase runs from Mine Year 3 until the end of mining and relies entirely on permanent cutoff wells located outside of the pit extent.

By running the model in different phases, the dewatering plan was adapted to the dynamic mining plan to ensure that the wells were most efficiently placed. Multiple simulations were run at each phase to optimize dewatering while minimizing the number of wells and groundwater pumped. All simulations required the same number of pre-mining dewatering wells (13) and temporary wells within the pit (11) to achieve the desired result. Figure 5 presents the layout of the three types of wells relative to the proposed pit. The best design occurred with the addition of 39 permanent wells located near the pit rim.

Figure 5: Dewatering System Layout

DEWATERING SYSTEM PLAN AND PERFORMANCE

The study included a bankable feasibility study of the dewatering system, including the following design elements:

- Well number, layout, and pumping period (from groundwater model simulations);
- Optimal well construction;
- Optimal pumping schedule for groundwater wells; and
- Requirements for in-pit sumps to remove direct precipitation and groundwater inflow from the pit.

System performance

Figure 6 shows the performance of the optimized dewatering system over the life of the mine.

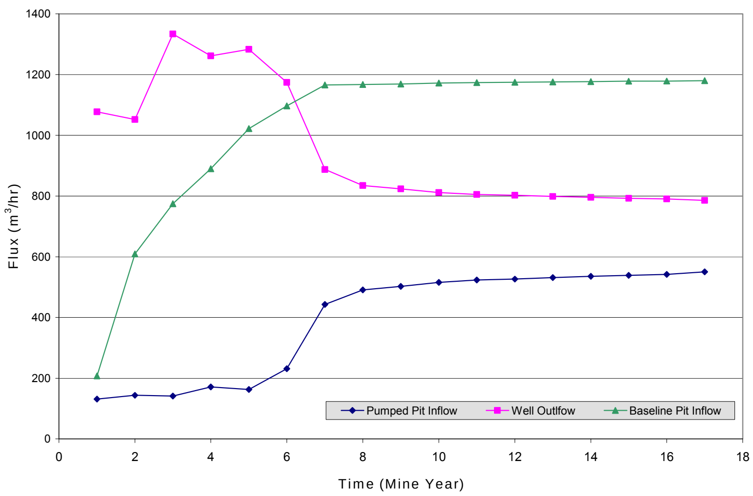

Figure 6: Pit Inflow and Well Dewatering

The decrease in efficiency of this dewatering system after year five is due to the decreased saturated thickness of the aquifer near the pit. In the later stages of mining, the regional potentiometric surface is depressed. Therefore, wells that previously had significant columns of water to pump have a smaller and smaller saturated thickness. The decrease in groundwater extraction will not negatively impact mining operations because at this point, the regional potentiometric surface is far below the unstable saprolite unit near the pit rim. The balance of the water can be recovered by in-pit sumps.

POST-CLOSURE PIT LAKE FORMATION

After the model was used to simulate the dewatering system, it was used to predict the filling of the post-closure pit lake. In order to perform this task, the final post-mining water levels were imported into a new model simulating the open pit as an aquifer with infinite conductivity and with 100% specific yield. This method for modelling a pit lake was first presented at the 1999 Geological Society of America Annual meeting (Ronayne et al., 1999). Filling the pit lake involves the following sources of water:

- Direct precipitation;
- Runoff of upstream surface water (4.2 km^2 total drainage basin); and
- Groundwater inflow.

Using these three sources of water, the pit lake will take 20 years to fill. The filling curve is shown in Figure 7.

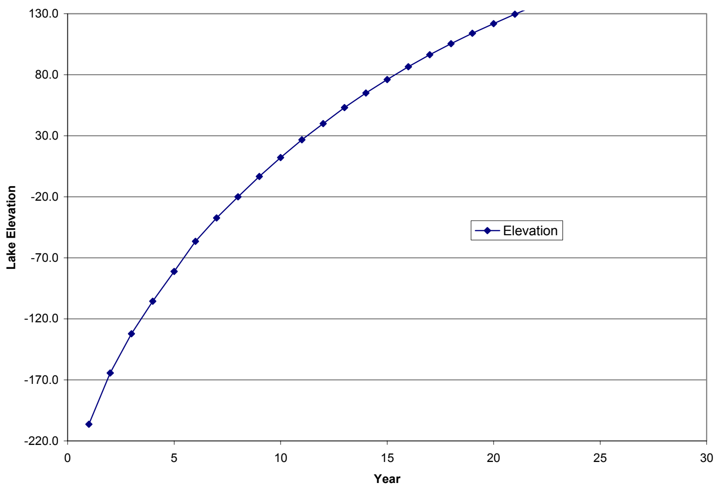

Figure 7: Post-Closure Pit Lake Filling Curve

The final pit rim elevation will be approximately 130 m amsl. Because of the diverted surface water and the significant direct precipitation, the pit filling curve does not have the classic exponential shape usually seen when filling a pit lake from groundwater sources.

The final application of the groundwater model was to determine hydraulic behaviour of the filled pit lake. This phase of modelling has been combined with ongoing geochemical modelling to predict the final water quality and environmental impact of the Brisas pit lake. Because the deeper water may be poor quality, the lake/groundwater interactions are critical to the eventual clean closure plan. Modelling revealed that due to the low groundwater gradients in the steady-state hydrogeologic system, groundwater through-flow from the lake will be insignificant.

As a result, the pit is closer to a terminal sump (zero net flux to the aquifer) than a flow-through pit and is likely to have an isolated low-quality stagnant zone.

CONCLUSIONS

Mining in tropical environments can create some unique problems when trying to plan and manage an open pit mine. With the site averaging approximately three meters of rainfall a year, and with the pit covering 2.2 km^2 with a depth of over 400 meters, pit dewatering will be a critical component of the overall operation of the pit.

Groundwater modeling was used as a critical element in the prediction of dewatering requirements, in the optimization of dewatering system design, and in the prediction of the hydraulic behaviour of the post-closure mining pit lake. The end result of the study was a feasibility-level report used in planning and financing the mining operation.

REFERENCES

Environmental Simulations, Inc., 2000, *Groundwater Vistas Version* 4.14, Reinholds, Pennsylvania.

Hydrogeologic, Inc., 1996, *MODFLOW-SURFACT Version 2.2*, Herndon, Virginia.

HYDRO-TRIAD, LTD., 1996, *Brisas del Cuyuni –Hydrogeologic Report*, prepared for Gold Reserve Incorporated.

J.E. MinCorp, 1998, *Detailed Pre-Feasibility Study, Brisas del Cuyuni Project*, prepared for Gold Reserve Incorporated.

McDonald, M.G., and A.W. Harbaugh, 1998, A Modular Three-Dimensional Finite-Difference Groundwater Flow Model, *Techniques of Water-Resources Investigation of the United States Geological Survey*, Book 6, 586 pp.

Ronayne, M.J. et al. 1999. Simulation of Mine Pit Lake Recovery in a Block-Faulted Porphry Copper Deposit. *Geological Society of America, Abstracts with Programs – 1999 Annual Meeting.*

WESTEC, 1998, *Hydrologic Characterization for Brisas del Cuyuni – Bolivar State, Venezuela*, prepared for Gold Reserve Incorporated.