Capão Xavier Mine Water Drainage Management (Minas Gerais, Brazil)

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Abstract The Capão Xavier Mine (Brazil) applies in-advance drainage technology through deep wells, pumping water suitable for human consumption. This water extraction reduces flow in some springs used for public water supply in the city of Belo Horizonte. All decreases are compensated with mine drainage water, improving the water system guaranty. This system optimizes management of water resources, and makes it compatible with the mining operations.

Key words Brazil, iron open pit, dewatering, preventive in advance drainage, water management.

Mine location and operation

The Capão Xavier Mine (CXM) is an open pit iron mine (fig. 1), and the property of VALE Company. The exploited minerals are hematite and lateritic iron ore, locally known as canga; the steriles are itabirite and clays). CXM is located 15 km south of the city of Belo Horizonte, in the State of Minas Gerais (Brazil), in the Iron Quadrangle (Dorr 1969).

Figure 1. *Capão Xavier iron mine (Minas Gerais, Brazil).*

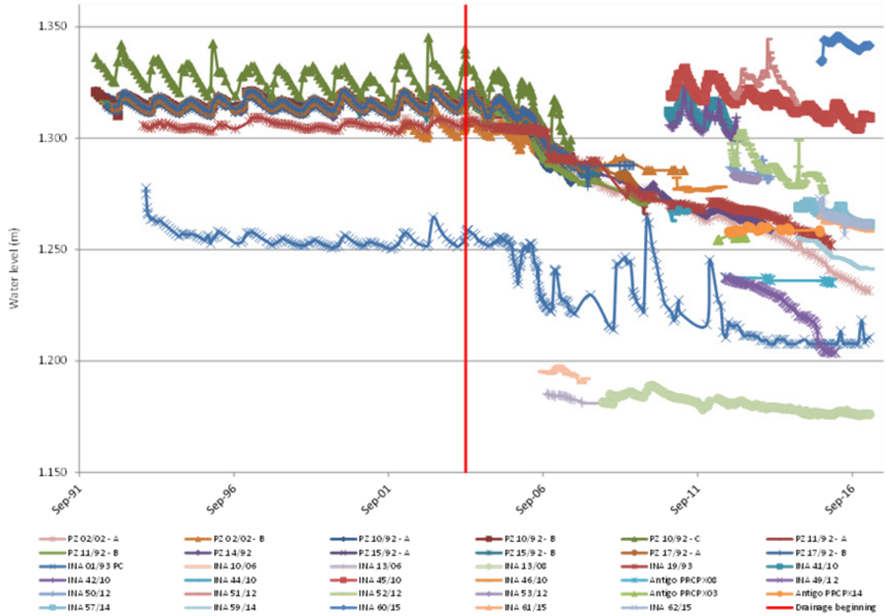
According to the current production plan, at the end of its life, CXM will have extracted 220 million tons of mineral (163 million of concentrated product + 57 million of inert waste); additionally, about 145 million tons of sterile will have been removed. All of the waste rock, as well as most of the sterile mine inert, have being placed at the exhausted Mutuca open pit, thus promoting its morphological and landscape rehabilitation.

Hydrogeological context

CXM is located in the Cauê Formation, integrated by itabirite with hematite, dolomite, and manganese interlayers. This formation is the main aquifer in the Iron Quadrangle because of dissolution of carbonates and silica in the itabirite rocks, forming deposits of iron oxides up to 500 meters deep, with high permeability and strong anisotropy. The under-layer Batatal Formation is integrated by phyllites of low permeability. The overburden consists of the Gandarela Formation, which is composed of limestone, dolomite, dolomitic itabirite, and phyllite with high karstic permeability, with thick packets of ferruginous clay with low permeability. Sub-vertical dikes and sub-horizontal sills of mafic intrusive rock individualize the whole package in hydrogeologically isolated blocks.

The main springs are associated with the Cauê aquifer, with low seasonal variability of flows. There is a record of 24 years of piezometric levels, corresponding to about 50 single, double, and triple piezometers. The records show a clear influence of rainfall, registering rapid rises with the rain, and the most extensive drawdown during the dry periods (Fernandez Rubio et al. 2009). The drain-induced drawdown occurs with varying intensity, depending on distance to the pumping well and the presence or absence of impermeable dikes.

The behavior of piezometric levels in the various observation wells, present seasonal variable oscillations, related to the annual rainfall recharge. At the beginning of each hydrological cycle, usually in October, piezometric levels achieve their minimums, rising rapidly with the onset of rains, until they reaches their maximum values, around March or April, when they begin to decay with the dry season. The amplitude of this seasonal fluctuation



Vertical red line: beginning of drainage (2004).

***Figure 2**. Temporal evolution of groundwater level in the piezometers inside and around the mine.*

varies from point to point, depending on the type of aquifer and hydrogeological conditions, involving parameters such as porosity and hydraulic conductivity, as well as heterogeneity and anisotropy.

In addition to the annual cycles, piezometric levels also feature multi-year variations, whose trends are common to all points of observation installed around the mine (fig. 2). These cycles are characterized according to hydrogeological domains distinguished in the surroundings of the mine.

Hydroclimatology

Rainfall studies were carried out based on rainfall records collected in pluviometric stations installed and monitored by VALE, together with the data of the Morro Velho station, with rainfall records since 1885.

The pluviometry regime presents a rainy season from October to March, collecting on average more than 90% of the annual rainfall, and a "dry" season, from April to September. The historical average annual precipitation (1984/2016) is 1,797 mm, with a minimum of 1,039 mm and a maximum of 2,612 mm (1 to 2.5 ratio between minimum and maximum). The last four hydrological cycles (from 2012/2013) have been below the historical average, producing a substantial water deficit during the last three years. As a result, there is a widespread decline in the aquifer's water table and in flow from springs.

Hydrological and water management context

Most of the mineral reserves of CXM are located below the water table; therefore, exploitation required an important drainage operation. CXM is located near some springs that have been used to supply the water requirements of the city of Belo Horizonte. Given this proximity, very detailed hydrogeological studies were needed to evaluate the likely effect of mining activity on water resources (Amorim et al. 1999). These studies were developed by the mining companies (MBR, and then VALE), and by the company responsible for the water administration and distribution (COPASA MG), and directed by FRASA Consulting Engineers. The studies included the implementation of a detailed network of hydrological monitoring, with records of flow and water levels for 25 years. They have highlighted the compatibility between mining and the use of dewatering waters to complement the urban supply system.

Based on very detailed and comprehensive monitoring, it has been possible to develop an exceptional database, which has proven very useful for rational water management, with protocols that allow mining to take place without any harm to the use of water resources.

In August 2005, a landmark mine water management plan based on all of the available hydrogeological studies was presented. In June 2006, the dewatering operation yielded a flow of 278 L/s. In August 2006, VALE merged its water drainage pipeline into the Belo Horizonte water supply system, adding the capability of providing 250 L/s. Since February 2008, this mine water drainage has been feeding the COPASA MG pipeline with complete success.

Mine drainage and water management

CXM lies along a hydrographic divide: to the North, Southeast, Southwest, and Northwest, water is being extracted, for Mutuca, Fechos, Catarina, and Barreiro, respectively. Based on hydrogeological studies, it was apparent from the beginning that some of the spring flows and well yields that these areas depended on would be reduced by the drawdown.

In this context, the drained water was used to mitigate the hydrological impact caused by drainage. The pumped water was more than enough to meet the needs of the mining operation and to ensure the public a water supply.

At the end of the life of the mine, it is predicted that the gradual reduction of drainage and the flooding of the open pit will generate a lake, with a maximum depth of 177 m and an average depth of 70 m, capable of holding 55 million cubic meters. The lake will receive water from rain, runoff, and groundwater discharges. This lake, in addition to contributing to biological diversity, will operate as a large reservoir. It will be connected to the water supply system and will help optimize the management of the available water resources, providing water during the dry season. The area adjacent to the mine will be rehabilitated, so that it can be integrated into the Serra do Rola Moça State Park.

With the recovery of the piezometric levels, impacts on spring flows will gradually cease. However, given the water balance, the dimensions of the hydrological basin, the water table evolution, the evaporation rates and the adopted water management, full flooding of the open pit could take many years. Until spring flow is restored to the original status of the hydrogeological systems, the areas' water requirements can be met by using the existing deep wells, in quantities corresponding to the remaining impacts on watershed springs.

In this context, the water management plan is based on using the pumped groundwater and then the lake to compensate for reduced water availability during operation, deactivation, and post-deactivation, against any dewatering influence. A hydrological monitoring program will be maintained, supported by systematic and reliable measurements of the hydrogeological parameters, to predict, identify, and quantify any interference of mine activities on the water management system. Potential impacts and the effectiveness of mitigation measures will be carefully managed, and information on the management of water resources will be provided to the local authorities and to the public.

Moreover, relative to water quality, the studies have shown to everyone's satisfaction that, due to the low mineralization of the groundwater, the positive water balance between precipitation and evaporation, and the absence of soluble salts in the rocks, good water quality is predicted. Having said that, this groundwater must be protected from contamination by organic content and the potential impact of urban sewage.

Current situation

Today the dewatering of CXM is being carried out by deep wells (fig. 3). There has been a gradual flow reduction over time due to reduction of the aquifer-saturated thickness and lower transmissivity. Total water production has been maintained at values below the maximum permitted discharge (278 L/s).

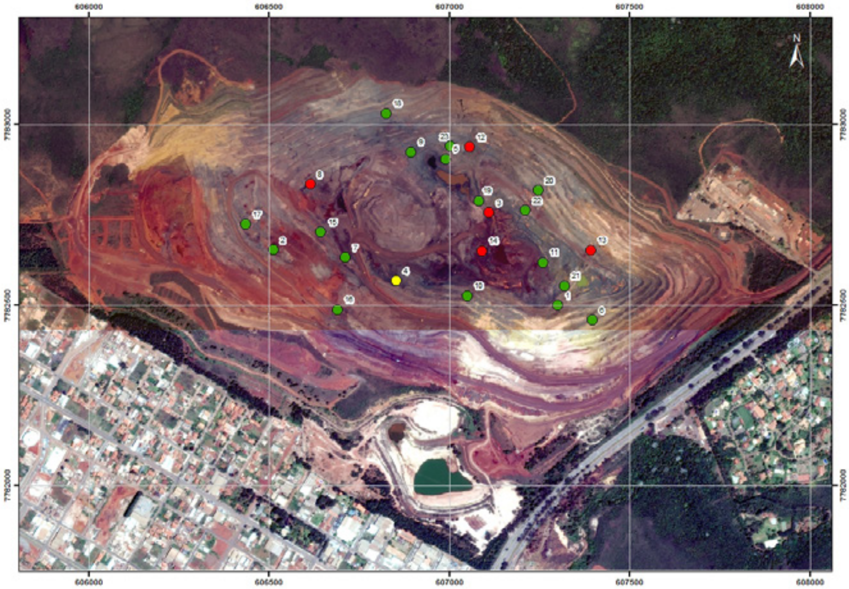


Figure 3. *Location of the dewatering wells in Capão Xavier Mine.*

Drainage water management

As discussed above, there are four basins surrounding CXM. Urban water supply is administered by COPASA MG. Weekly measurement of flows are maintained, mostly by fixed instruments like level gauge or Parshall (fig. 4).

In general, during the dry season, the entire tributary water is used for urban supply while during the rainy season, spillovers of surpluses are frequent. In recent years, the reduced rainfall has added to the effect of the mine dewatering on flow from some of the springs, but despite this, the flows generally correspond well to the conceptual hydrogeological model forecasts.

Looking at the flow evolution, it is possible to identify a highly variable flow regime, with strong seasonal variation of flow rates. The minimum occurs predominantly in September and October, with a fast increase with the onset of the rainy season. Flow its maximum in January and February, followed by a slow decay until it again reaches the minimum flow.

There is also a less variable flow regime that corresponds fundamentally to the drainage of the deep aquifers. This is related to a micro-fissured aquifer system, without major conduit collectors, in a regime of several years' regulation. The corresponding water points show common multi-year variability. Total discharges are often greater than the total rainfall on the watershed, which indicates that the hydrogeological basin is greater than the surface watershed runoff. As a general feature, the trend of decreasing flows during the hydrological cycles of low rainfall can be seen very clearly in the last four cycles (fig. 4).

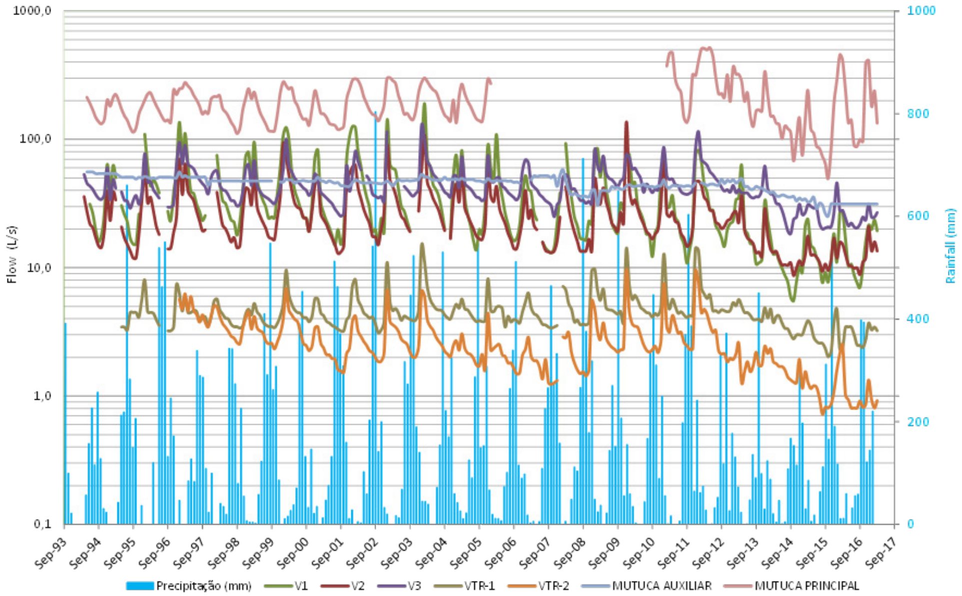


Figure 4. *Temporal evolution of rainfall and flows in the Mutuca basin.*

Hydrological impacts and mitigation

For the assessment of the impacts on systems of **highly variable flow regime**, the following methodology is applied:

- Calculation of average expected flow rates for the months of August, September and October, based on predefined equations;
- Calculation of the difference between the monthly average flow rates and calculated measures;
- Checking if the difference is within the margin of error of the estimate value by comparing the absolute values with the largest positive and negative differences obtained earlier;
- Characterization and quantification of the impact when the difference is negative and are outside the margin of error for two consecutive months.

On **less variable flow regime** systems, the following methodology is used:

- Comparison of registered flow (monthly average) and the lowest monthly average previously registered;
- Characterization and quantification of the impact when the monthly average flow rate recorded is less than the lowest monthly average previously registered for two consecutive months.

To enable the immediate replacement of the water supply system, a structure was prepared, sized to contribute up to 250 L/s to the COPASA MG pipeline. The terms of commitment between VALE and COPASA MG established that VALE should provide the COPASA MG, a flow rate equivalent to at least 1/3 of the total pumped. If new hydrological impacts are identified in the future, it will be necessary to check to see if the sum of the reductions in flows exceeds the value of preventive replacement (1/3 of the pumped flow). Should this occur, the supply of water would be immediately increased to the pipeline, in order to mitigate the full impact.

Compensation

The lowering of the water level is monitored in order to mitigate the hydrological spring impact, i.e. maintain the availability of water. To achieve this, at least 33% of the pumped water is supplied to the CXM COPASA for urban supply (besides 20% for the Mar Azul Mine). If the impact on watersheds were higher, it would compensate with pumped drainage.

Since February 2008, CXM has delivered substantially more water than this commitment to COPASA, as can be seen in Figure 5. This is how, for example, in the year 2015/2016, the hydrological value impacted by lowering the water level of the mines Capão Xavier, Mar Azul and Tamanduá was 44.77 L/s. According to the agreement with COPASA MG, VALE should have provided 56.96 L/s, while actually it provided 91.69 L/s from the drawdown of the water level in Capão Xavier, significantly over its commitment with COPASA MG.

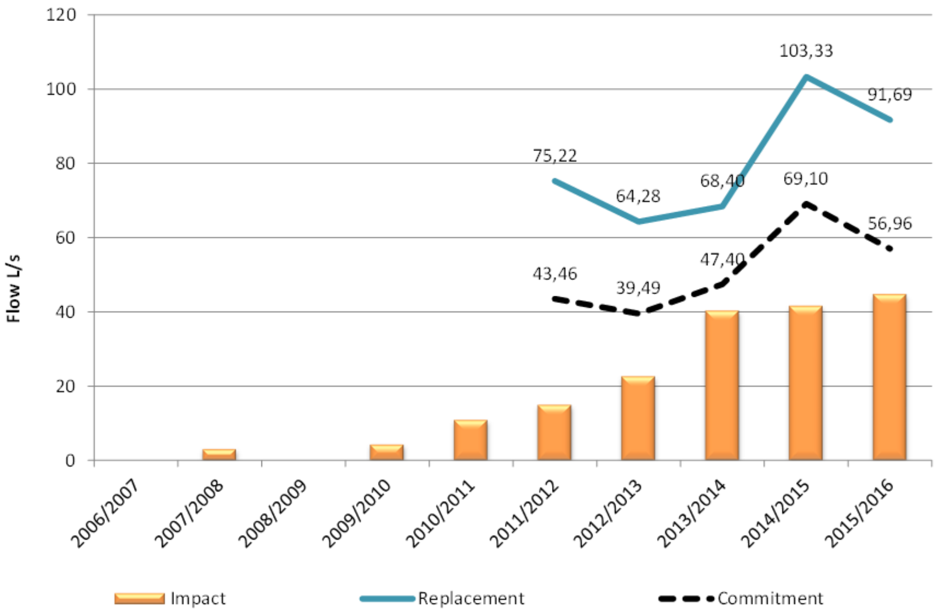


Figure 5. *Drawdown-related impacts of mining drainage water level (and the low rainfall in recent years) and compensation.*