

# INTEGRATED WATER RESOURCES MANAGEMENT PLAN FOR THE DEVELOPMENT OF A NEW IRON ORE MINE IN THE WESTERN PORTION OF THE IRON QUADRANGLE, MINAS GERAIS, BRAZIL

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## ABSTRACT

*Due to the need to safeguard access to water and avoid future conflict, water management strategies in Brazil have made significant improvements regarding governance over the past fourteen years towards Integrated Water Resources Management (IWRM). The main improvements began in 1997 within government, then within the mining industry where water policies were created and implemented. Use of IWRM principles has led to the development of water resources management plans that consider the whole river basin and scenarios of water supply and consumption instead of the mine site in isolation. Due to the large number of agents involved, the uncertainties with water data for both availability and use and the complexity of the region, an adaptive water management strategy can avoid conflict and limit negative cumulative impacts where multiple users access this resource. An example is presented here showing congruence between the Brazilian regulatory processes and IWRM for development of new iron ore mine sites in the western portion of the Iron Quadrangle, Minas Gerais, Brazil.*

**Keywords:** *Integrated Water Resources Management, Cumulative Impacts, Mining Industry.*

## INTRODUCTION

This paper focus in the importance of approaching Integrated Water Resources Management (IWRM) since the beginning of an iron ore mining project in the western portion of the Quadrilátero Ferrífero, State of Minas Gerais (MG), Brazil (Figures 1 and 2). In this region, there is a great conurbation around the city of Belo Horizonte/MG, containing around 5 million habitants. The urban water supply in this region is mainly done by Companhia Mineira de Água e Esgotos (COPASA) which has its main sources in the Velhas River Basin and Paraopeba River Basin, both located in the Upper São Francisco Basin (Figure 3). Both hydrological basins are also known by its great potential for iron ore production, which has been reason for conflicts in the past, on going, and perhaps, in the future as well. Therefore the assessment and management of Cumulative Impacts (CI) in a river basin scale is extremely important for IWRM and any of the different concepts of Sustainable Development (SD).

Briefly, CI is defined by (Franks et al., 2010) as the “...*successive, incremental and combined impacts of one, or more, activities on society, the economy and the environment*” that lead to positive or negative effects on environmental or human receptors. Cumulative impacts can be positive and negative and variable in intensity, and spatial and temporal extent. Sustainable development is most commonly defined with respect to natural resources as “...*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” (WCED, 1987).



Figure 1: Situation of the Quadrilátero Ferrífero in the State of Minas Gerais (Rocci, 2009).

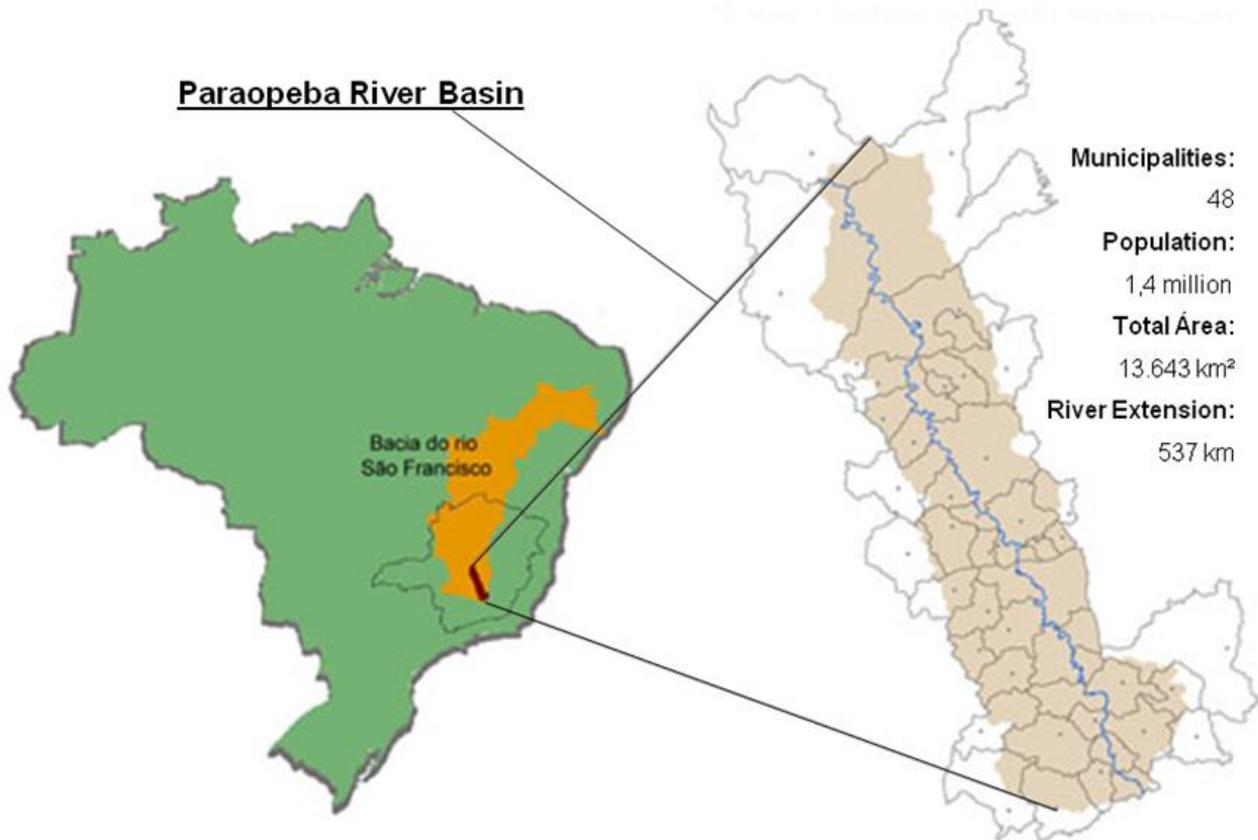


Figure 2: The Paraopeba River Basin in relation to Minas Gerais São Francisco (CBH-Paraopeba, 2011).

As contextualized by Mostert (1999), the combination of six perspectives for River Basin Management (RBM), named as “natural science”, “engineering”, “social optimization”, “law”, “decision making” and “ethics”, are essential for sustainable development and consequently for IWRM. In this way, a very good multidisciplinary knowledge of river basins is needed. Thus, where there are two essential main subjects on this matter that must be considered within IWRM: monitoring water quality and quantity in surface and groundwater bodies and water resources natural and actual availability in the catchment areas and aquifers. These are the main and essential aspects that must be considered for a consistent water resources plan for a mining project in order to be aligned with IWRM (Figure 3). This framework shows, at a first level, what needs to be understood from the three Dimensions, Physical World, Human, Governance, from the framework proposed by (Rocci et al., 2011 "in this proceedings"). Figure 3 shows components of the environment such as characterization of a river basin which includes its natural background or, if already with anthropic changes, a baseline that needs to be defined for water in quantity and quality. Also, information about all the actors within the basin and their present and future demand for water is required in order to calculate Actual Water Availability (discussed further below). In the second level of this framework, together with the Water Monitoring Plan, the framework contains the environmental constraints on water availability. Finally, an Integrated Water Management Plan can be constructed with strategic adaptive actions and mitigations perspectives.

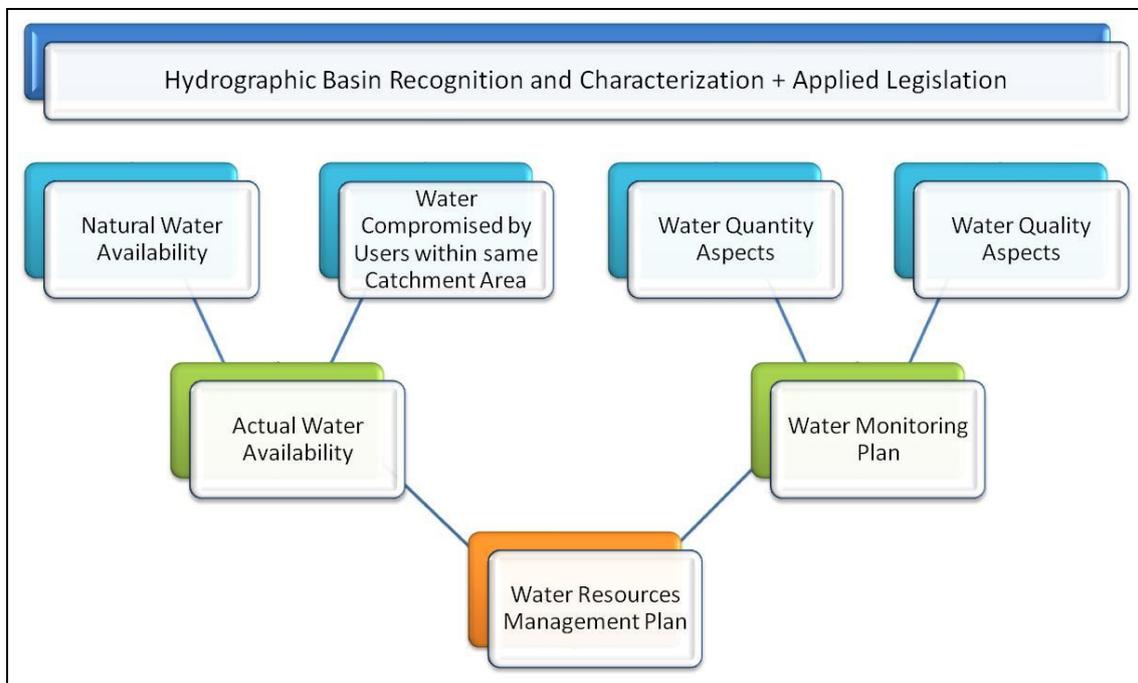


Figure 3: Flux showing the main and essential aspects for water resources plan in a mining project.

The challenge of IWRM is to integrate an understanding of the physical world with the human uses of water in regions where water availability is limiting and the governance systems used to, manage and regulate it . In particular, managing the water resource through static instruments (such as laws, regulations and policies) in locations of high variability in water supply and demand is difficult because the value of water to users is constantly changing. However, as it is described in the Brazilian Constitution (1988) (Brasil, 1998), Federal Law 9.433 (1997) (CNRH, 2011) and Minas Gerais State Law 13.199 (1999) (Minas Gerais, 1999), water resources belongs to the Union and the States of Brazil, who may grant a water use to a person, a company, a non-governmental group or even a governmental entity to use it as it is requested. In order to request and receive a water grant , the actual water availability studies must be determined for the catchment area for capturing and impounding any water.

Considering the evolution for Water Resources Management regulatory system in Brazil and its states throughout the past decades, there is increasing demand for hydrological and hydrogeological knowledge within both local and regional area for developing a mine site and its surroundings. This is required in order to start developing any mining activity. Natural surface and groundwater availability studies must be

considered as part of the initial mining projects as water resources is needed not only for processing plants but also for other industrial activities, such as, product transportation through pipelines, mining equipment washing, dust suppression, and also human consumption. Natural water quantity and quality aspects are important not only for production, but also for preservation/conservation and to avoid negative cumulative impacts. Preservation of water resources is also an important subject in the Brazilian environment and water resources legislation, where there are mentioned several types of penalties that can be applied for those who contravene regulations (Rocci, 2009).

Therefore, considering these aspects some questions can be made: How much water is there? How much water is required? How much water can be granted? From where? Is its quality suitable for industrial and human consumption needs? Are we able to return water to the environment without causing environmental harm? Answering these questions will lead to the avoidance and/or minimize cumulative impacts by promoting good IWRM practices. It is essential to always consider several variables: the natural surface and groundwater existence considering the natural quantity and quality aspects and the environment's need, human relations considering legislation, governments' projects and master plans, human and animal demands, the ecosystem, besides, of course, the requirement for water to develop a mining project and later run an operating mine site (Figure 4).

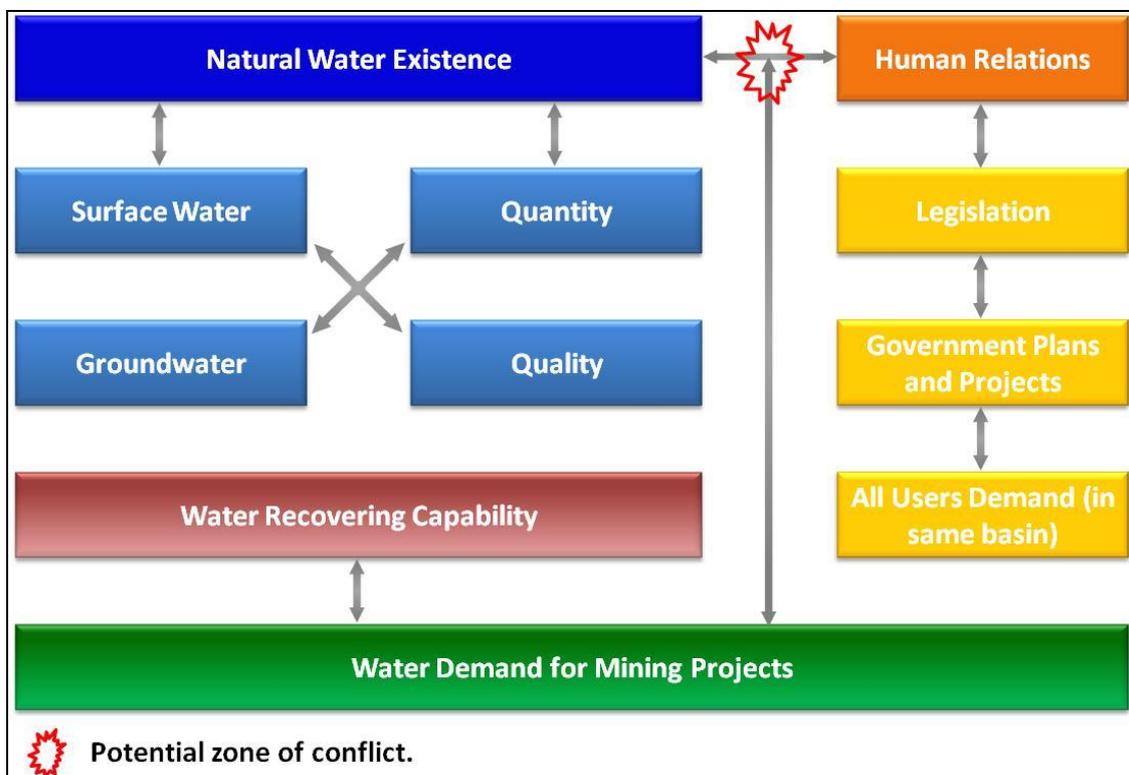


Figure 4: Flux showing the relationship between nature, human relations and mining projects.

## METHODS

In the following sub-sections the large scale, the aspects of the river basin water balance are described. The method applied focuses on an IWRM approach by the minerals industry along with governmental, non-governmental and other water users within the same river basin to facilitate the interaction between the company and governments' water resources managers and the river basin management committee. The components are water demand by the mining project, surface natural water availability, groundwater natural water availability, and finally, to calculate the actual water availability for human use, all water demand from all other users within the basin also needs to be known. At the end of this section, water quality is considered which is key to ensure "fit to purpose" use of water within the Water Resources Management plan.

## Water Demand by the Mining Project

First, it is important to be known how much water the mining project needs. This number is extremely strategic not only to the company, but to water resources management within the company and for the river basin's master plan developed within the River Basin's Committee. The demand for water from all other users is also necessary in order to find the total demand within the basin. This number can be calculated by using a water accounting framework developed for the minerals industry where the demand is a result of the input/output system proposed by (Cote et al., 2009); see also (Australian Government, 2008) and in a more schematic balance in Figure 5 (Rocci, 2009). This water accounting framework can be used to determine the total water consumption in a mine site along with the water reuse.

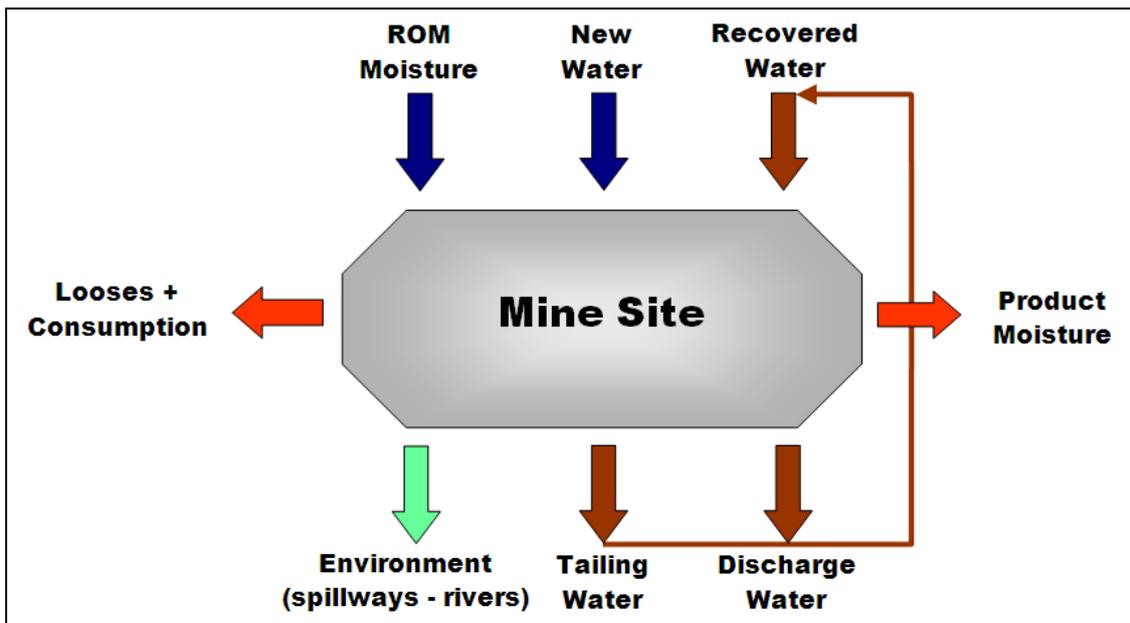


Figure 5: Simplified schematic mine site water balance (Rocci, 2009).

## Natural Surface Water Availability

For hydrologic studies, must be considered historic data from rain and stream gauges, must be considered along with cartographic data. This way, regional and local analyses were made in order to define surface water natural availability at the regions of each of the future mine sites.

The climate in the Quadrilátero Ferrífero region is semi tropical, with sharp distinction between a rainy season (November-March) and a dry season (May-September). The mean value for rainfall annual average varies between 1,500 mm and 1,600 mm. The orography of the region is defined as an extensive watershed, with springs of some major rivers of southeast Brazil. The climatic characteristics determine a prevalence of perennial streams, with the hydrological regime marked by the seasonal evolution of rainfall during wet season, distinguishing a period of floods and a dry period. The region waterways present hydrological regime with average contributions of long-term ranging from 18 L/s.km<sup>2</sup> and 25 L/s.km<sup>2</sup> and minimum dry season ranged from 5 L/m<sup>2</sup> and 3 L/s.km<sup>2</sup>.

Information on surface water hydrology is essential to calculate natural water availability and the water grants criteria indicator ( $Q_{7/10}$ ) required for the government's water resources management department when requesting the water grants. The natural surface water availability can be defined by characteristic variables of a rivers' hydrological regime, specifically the long-term average flow, draft-storage relations (Riggs and Hardison, 1983) and indicators of drought regime, such as the minimum flow of 7 consecutive days with 10 years return period ( $Q_{7/10}$ ) or 95% of the relation curve ( $Q_{95}$ ). As the water courses of interest to the mining projects are small and there are no stream flow historical records hydrological regionalization techniques are applied to transfer characteristic variables (Riggs, 1973). In all regionalization studies, the existence of

monitoring data from the project area, even during short periods, is essential to add reliability to the equations for calculating the hydrological variables.

Considering that the average annual rainfall can be represented regionally through their isohyets maps and that actual evapotranspiration variable shows little variability in hydrologically homogeneous regions, the long-term average flow can be estimated by the simplified equation below:

$$\text{LTM} = \text{PREC}_{\text{ANNUAL}} - \text{ETP}_{\text{ACTUAL}} \quad (\text{Equation 1})$$

Whereas:

LTM = long-term mean annual flow (mm)

PREC<sub>ANNUAL</sub> = mean annual precipitation (mm)

ETP<sub>ACTUAL</sub> = actual evapotranspiration (mm)

Once obtained a reliable estimate for LTM flow, its value can be applied as index-flow for non-dimensional values and transferring curves of the characteristic variables, such as minimum annual seven-day flow frequency curve, draft-storage relations, and mean monthly frequency curve.

The precepts of the Brazilian legislation that regulates the use of water resources (CNRH, 2011), water availability for a particular user is defined as a percentage of the flow regime indicator of drought periods ( $Q_{7,10}$  or  $Q_{95}$ ) or as the capacity limit of draft-storage relations, although it was maintaining a minimum residual flow downstream. In the state of Minas Gerais, the legislation is quite restrictive, with an impounding upper limit of 30% of the  $Q_{7,10}$  minimum flow, while the residual 70% is legally allocated to flow downstream for the ecosystem maintenance.

### **Natural Groundwater Availability**

The geological formations that host iron ore deposits in the Quadrilátero Ferrífero (the Cauê Formation) are important aquifers, forming ground water resources that are used to supply the population and maintain the condition of perennial streams. Its groundwater is more likely to occur in a reasonable quantity compared to other aquifer systems, which have very low hydraulic conductivities. Considering this, and since the locations of expansion for new projects have not been studied, there are neither water wells nor piezometers to monitor groundwater levels. Thus, hydrogeological evaluations must be done mostly using secondary data. This is achieved through field survey to generate a spring inventory. In addition, elevations of water head related to the iron formation are used as the groundwater level and used to calculate groundwater reserves.

Groundwater reserves can be divided in two categories: renewable and permanent. The renewable reserves are defined as natural discharge draining from the aquifer. Considering the conditions of equilibrium and mass balance, this discharge can be seen as the volume of infiltration within the hydrological cycle. These reserves are directly proportional to the area where the recharge occurs and to the magnitude of this recharge, but, in turn, the magnitude of the recharge depends directly on the water balance considering: precipitation, runoff, infiltration and evapotranspiration. Thus, the renewable reserve annual flow capacity can be calculated as:

$$Q = A \times P \times F_{\text{AP}} \times 10^{-3} \quad (\text{Equation 2a})$$

Whereas:

Q = Flow (m<sup>3</sup>/year)

A = Recharge Area (m<sup>2</sup>)

P = Annual precipitation average (mm/year)

F<sub>AP</sub> = fraction of the annual precipitation average converted into effective recharge (non dimensional)

10<sup>-3</sup> = Conversion coefficient (m/mm)

Studies in the Quadrilátero Ferrífero shows that the fraction of precipitation that becomes effective recharge when it comes to iron formation are not less than 38% (Mourão, 2007), while others believe that 20% is a reasonable number, which is being used in the Paraopeba Basin's Water Resources Master Plan (CIBAPAR and HOLOS, 2009).

The permanent reserves are those that do not renew, they remain stored independently of the outflow of natural draining. These reserves are directly proportional to the volume of the aquifer's geological formation situated below the water table and are a function of the effective porosity of this formation. Considering an existing geological block model, a simple way to calculate the permanent reserve is by estimating the volume of the iron formation based on the block model. Thus, the permanent reserve volume can be calculated as follows:

$$V_{PR} = V_{IF} \times n \quad (\text{Equation 2b})$$

Whereas:

$V_{PR}$  = Volume of Permanent Reserve (m<sup>3</sup>)

$V_{IF}$  = Iron Formation's Volume (m<sup>3</sup>)

$n$  = Porosity (non dimensional)

The Iron Formation's porosity varies along the entire Quadrilátero Ferrífero. It depends mainly on the rock type, structures, texture and mineralogy, showing variations from 2% to 46% (Mourão, 2007). Therefore, for general studies it is common to consider an average porosity of 20% for the iron formation.

Mining activities access groundwater for dewatering of pits throughout a mine's lifetime. Lowering the water table affects aquifers and consequently surface water bodies' reducing water flow or even drying completely springs and small creeks. This potential outcome can be harmful for any mining activity once many communities, residential areas, have their water supply affected. The existence of several mines leads to negative cumulative impacts impacting on other sectors. It will reach the government that will have to enforce the law by taking reasonable decisions that is usually unwanted by the industry since accessing water is fundamental for mining feasibility.

### **Water Compromised by Other Users**

All water grants are registered and kept in State and National databases. It is possible to consult online at any time these two official registries existent in the Institute of Water Resources Management of Minas Gerais State (IGAM) and in the National Water Agency (ANA). These registries have important information about each user granted and its water grant characteristics, such as water source type and its location, flow granted (litre/second), period (hours/day) allowed for impounding, monthly volume allowed to capture, among other conditions to use the grant. To know all users demand is also extremely important to find the total human activities' water demand within the basin so the Actual Water Availability which is essential to evaluate the sustainable use of water within a river basin can be calculated.

### **Actual Water Availability**

It is not possible to consider only the natural amount of water found in a catchment area as the actual amount of water available for mining. Brazilian legislation requires that everybody must have access to water resources, being enough to request and receive a water grant to use this resource. So all granted users must be considered in an IWRM scheme. In this way, the actual water availability is the amount of water existing in nature minus the amount of water already compromised by other users within the same catchment area. Therefore, to find the actual water availability in a river basin a simple calculation must be done using the equation below:

$$(S_{NA} + G_{NA}) - U_{WC} = W_{AA} \quad (\text{Equation 3})$$

Whereas:

$S_{NA}$  = Natural Surface water availability

$G_{NA}$  = Natural Groundwater availability

$U_{WC}$  = Water compromised by all Users within the same basin

$W_{AA}$  = Actual Water availability

Knowing the actual water availability, then it is possible to confront this number with the water demand from the mining project. If there is more demand than water available, then it may be a great challenge to obtain the amount of water necessary to attend the project developing and its operation. But if there is more water available than demand, the mining project ought to succeed as it should be very likely that the amount of fresh water needed may be granted.

### **Water Quality Aspects**

The Brazilian legislation (CONAMA, 2005, CONAMA, 2008) defines and divides natural water bodies into classes, from poor quality to very good quality. The law also limits the quantity of all possible constituents in effluent discharged in natural water bodies. It is known that water courses and aquifers may have natural environmental (physical and chemical) characteristics, which may exceed parameters that supposedly indicate what should be the ideal quality of water. Therefore, it is of extremely importance to diagnose the hydro-geochemical background of the region of interest and define whether its parameters are natural or altered due to human interventions, by the discharge of non treated effluents.

Considering that in a new project there still aren't any monitoring installed, it is possible to consult various data on water quality available in the Minas Gerais Water Program, IGAM's monitoring database, among other programs. These databases are considered consistent on this subject and can surely be used for analysis. The spatial distribution of sampling points allows the evaluation of the water quality along the River Basins, including locations close to the areas of future iron ore mine sites.

Combining the quantity aspects with the quality aspects of water resources in a river basin, and knowing the types of water uses there are and their demand for quantity and quality is the key for IWRM. This approach leads to a refinement of planning allocation and distribution of water within the river basin's master plan in a way that is fit for purpose. Such a strategic approach to water management aims to improve sustainable use of these resources.

### **FINDINGS AND DISCUSSION**

The water quality aspects of the Quadrilátero Ferrífero can be related to the Iron Formations. Therefore, it shouldn't be any surprise to have high concentrations of iron and manganese in water. The quantity of these elements, many times, naturally exceeds the legal limits predicted by law, which indicates what should be the ideal concentrations for high quality water. Baseline monitoring studies are required during prefeasibility stage before a mining operation can start, so that both the company and community can have a good basis on which to determine whether mining activity has impacted on these water bodies.

By the application of the methodology described above, there are some results expected by the mining company regarding the feasibility of the project and preparation for the operations in the future. Regarding the quantitative aspects of water, it is possible to say that in the western portion of the Quadrilátero Ferrífero there is good natural water availability, but a poor actual water availability due to the great amount of urban areas and other industrial activities that implies a high demand for human and industrial supply.

Even though it is feasible to have water grants to impound surface water (main source considering the great amount needed) and considering that in an region that demands great amounts of water for human consumption, priority indicated by law (CNRH, 2011, Minas Gerais, 1999) it is strategic to have a backup plan for projects as part of an adaptive management strategy to build dams in order to increase natural water availability (Equation 1) and, consequently, actual water availability (Equation 3).

Surface and groundwater quantity and quality monitoring plan must be developed focusing on the legislation, future water availability and requirements, and safeguard the company from possible future accusations of polluting the environment. The quality parameters that should be analysed, at least for the first year of monitoring should be as more complete as possible, considering the applicable laws. From the second year, the parameters can be reduced depending on the results. These examples can benefit not only the mining company doing these studies, but also communities by generating and providing information for water balances and allocations which in the future can be very useful for tradeoffs and fit to purpose inputs in the River Basin's Master Plan.

Hydrogeologic evaluations must be continuous until mine closure, but depending on the situation monitoring and evaluations may be required for decades. From preliminary evaluations, there should be constructed a set of piezometers to monitor more effectively groundwater levels as they oscillate with the hydrological cycle. There also must be constructed at least one pioneer water well focusing to collect more hydrodynamic parameters to detail the hydrogeologic model and create a plan for dewatering the pit whenever becomes necessary. Thus, it will become possible to develop a numeric simulation for the hydrogeologic detailed model focusing, mainly, to subsidize the process to obtain water grant for pit dewatering and to evaluate if there could be any impact in the surrounding springs.

All activities mentioned above should be systematized for the creation and implementation of a coordinated Water Resources Management System (Figure 6). This system also must include operation and monitoring in real time, having the environmental and operational water balances (mine site water balance) fully automated (Rocci, 2009). This system should be the main water resources management tool and can be adapted for each mine site for supporting control of the use of water resources and strategic decisions taking on mining operations and development of new projects, as one of its main features are the water use indicators provided by the output subsystem. These indicators can be then disseminated within the whole company including corporate areas for strategic management for the use of water resources.

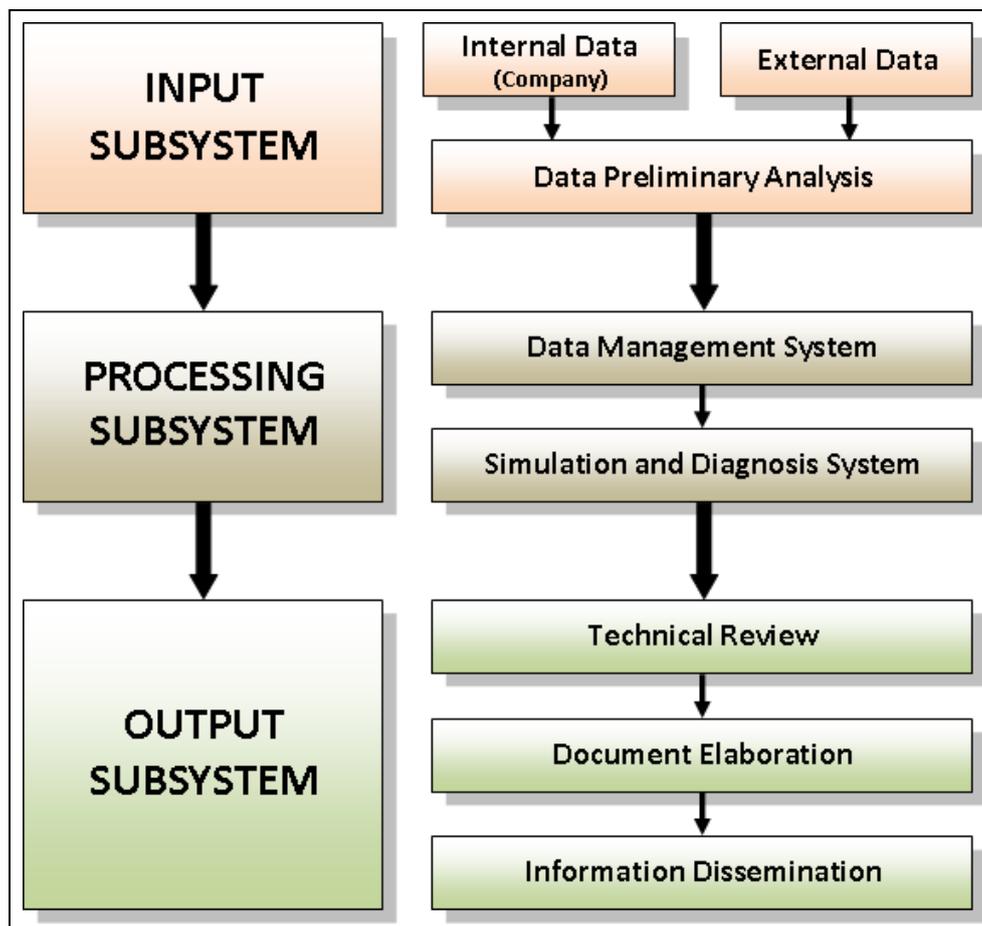


Figure 6: Flux of the Proposed Water Resources Management System.

## CONCLUSION

Although the region presents an abundance of natural water availability, over time population growth is pushing the need to reserve greater amounts of water for public supply of human consumption and sewage dilution. This scenario is creating restrictions for industries and mining companies to access water. This problem, combined with the legal regulation for water use in Brazil justifies the importance for the minerals industry to create operating systems for integrated water resources management aiming to improve the sustainable development of mining activities within its catchment area. This integrated approach can also support new project development minimizing the generation of conflicts with other water users or reduced production through water shortages.

The laws that regulate water use in Brazil are based on regulatory instruments and the riparian doctrine, which guarantees the right of access to water use, qualified as a public good to all sectors of user, safeguarding, however, the priority for public supply. The basic regulatory tools under the law are: granting the right to use, charging for the use of water (capture, consumption and effluents discharge) and organization of an information system for the management of water natural availability and demands. The granting instrument is used for registering all users and to limit the amount of water that can be derived or captured, in terms of a percentage of a characteristic flow of the regional dry regime. In case of conflict over water use in situations of scarcity, the legislation gives priority to supply the population, making secondary the industrial use. Besides, it is noteworthy that all hydrographic basins that have their springs areas close to the mining areas drain into waterways that are heavily used to generate hydroelectric power in plants that were designed for the natural regime conditions of the watercourses, without the inclusion of consumptive uses upstream.

Given this situation, there has been an increasing pressure on water use in the mining sector, imposing mining operators and project developers to rationalize their activities towards reduction of water consumption and interventions in the water bodies. Under the precepts of Brazilian laws, although state and federal governments are responsible for integrated water management in their respective jurisdictions, each user sector tends to create its own management system as a way to make rational water management and to gather information for appropriate interactions with other sectors of users and the government as well. To date, it is considered that the energy and sanitation sectors advanced towards IWRM, while the mining sector only recently is starting to create its structure. In this context, this article aimed to describe the actions for water resources management that are being done and planned for some new iron ore mining projects in the Quadrilátero Ferrífero.

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