

## Water Resources Management Plan for Mining Industries – A Guidance Model

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### Abstract

Water resource management is an essential process for industries whose production relies on water consumption. Mining plants processes demands water for diverse ends, such as, ore washing, beneficiation, transport, dust control, among others. Based on the necessity of granting an efficient and sustainable Water Resources Management Plan (WRMP) and the lack of a literature dedicated to this topic, this study proposes a guidance model that encompasses technology, standardization, risk management, intelligent data analysis, continuous improvement and integrated management of water resources that goes beyond the regulated and legal tools for water management. The preparation of the guidance model of water resource management plan for mining industries was based on 4.0 industry guidelines, all of 10 International Council on Mining and Metals - ICMM Mining principles and performance standards. The WRMP must be a written document available for consultancy by any employee of the enterprise and environmental agency, and it requires a compilation of all the information on water resources and wastewater treatment of the plant, encompassing: complete description of processes (production chain, grant water system, wastewater treatment), basin characteristics, water safety plan (monitoring and risk management programs), action plan for contamination, water resources indicators, consumption and reuse of water (sources and techniques of reuse) and 4.0 industry opportunities for monitoring process. The WRMP provides a holistic view of how water is managed and if the management process is efficient, it also compiles enough information that will facilitate the continuous improvement process, besides, it is an essential tool to grant the sustainable use of water resources in diverse industries.

**Keywords:** Water resources, Mining, Bauxite mining, Water management, Guidance model.

### 1. Introduction

The maintenance of environmental quality is essential for human's well-being, socioeconomic development, preservation, and diversity of ecosystems. In Brazil, for example, the Federal Constitution of 1988, in Article 225, states that "Everyone has the right to the ecologically balanced environment, asset of common use of the people and essential to healthy quality of life, being imposed to the Public Power and the community the duty to defend it and preserve it for the present and future generations" [1].

The Brazilian mineral sector is an important segment for the country's economy due to its vast reserves and good positioning in the world trade in mineral commodities, representing for Brazilian GDP about 3.19% and 3.18% in 2019 and 2020, respectively [2]. Therefore, it is important to keep under control the impacts that this activity causes in the physical and biological environment, to provide an adequate environment for future generations, as well as to ensure the maintenance of operations in this sector.

Both for the environment and for the maintenance of the quality of life of the world population,

water assumes a role of great importance in various uses, products and services from which man takes advantage [3].

Water is present throughout the mining process, from exploration to processing. According to Minera Jr. [4] the sources of water used in mining can be surface, underground and recyclable. According to the Water Resources Conjuncture Report 2017 [5], mining was responsible for the catchment of 1.6% of water in the country, which corresponds to 1.024 billion cubic meters per year.

It is evident that mining operations, due to their physical influences and water use through processes of extraction, beneficiation, transport, and operational discharges, can impact the water dynamics of a hydrographic basin. On the other hand, mining companies are also affected by the physical and socioeconomic dynamics of the basin [6].

The characteristics of the watershed area, such as: water availability, quality and extraction rates, can impact mining operations. Although these dynamics seem obvious, they are complex and require a relatively sophisticated understanding of the multiple and competing pressures exerted on water resources by its users [7]. Social pressures, development priorities, and changes in national, regional, or local policies can also impact the operation, so water management is essential to raise awareness on the complex nature of risks related to water resources and identify response options in cases where risks arise, such as action outside the mine's operational borders [7].

The Water Resources Management Plan is a strategic instrument that consists of an integrated planning process that considers both short-term and long-term needs, incorporating environmental, economic, and social considerations within the sustainability principles [8].

Given the above, it is notorious that mining is fundamental for social, technological, and economic development, but the environmental management of these enterprises is still a great challenge for professionals working in the area. Based on this statement, this work aims to develop a technical guide for professionals, who work in mining enterprises or any medium and large enterprise, to develop a management plan of water resources, whose methodology generated from the experience acquired by the authors in the daily routine of a bauxite mine located in the municipality of Paragominas, Pará State, Brazil. At the end, a block diagram containing a summary of all procedures and guidelines necessary to provide professionals and managers with conditions to improve the management of water resources in their enterprise will be presented.

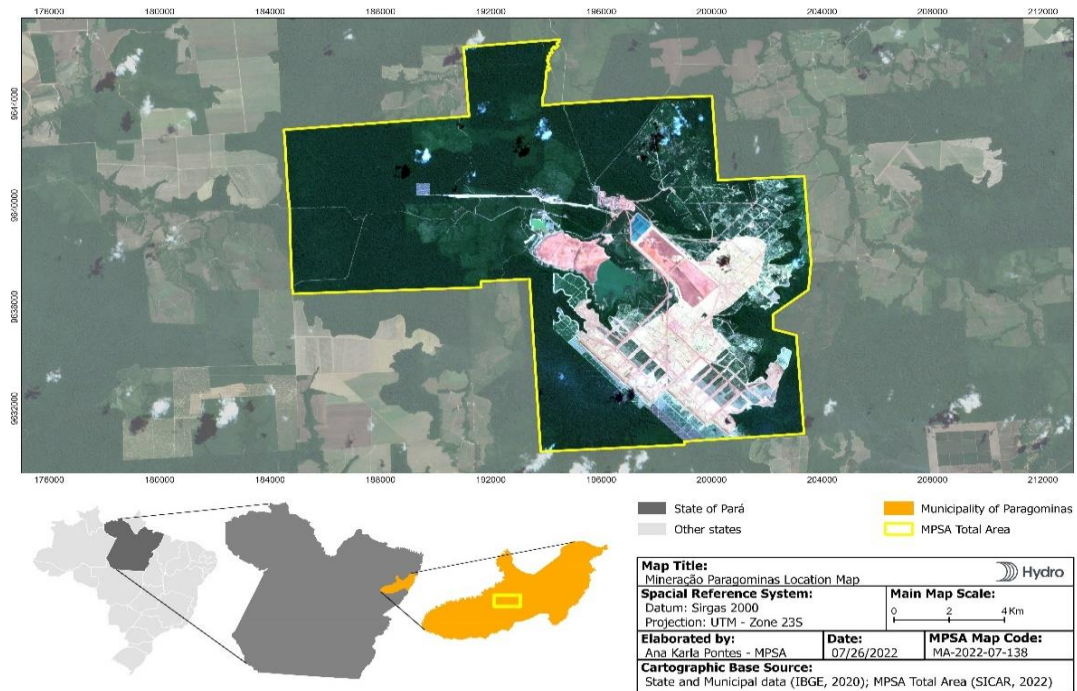
## **2. Experimental**

To achieve the objectives of this work, consultations were carried out with works of Brazilian literature (university book, technical guides from the Brazilian National Water Agency), national legislation, technical works carried out by specialized consulting companies and environmental studies that were prepared in the of the mining company's environmental licensing. In addition, it is important to highlight that the experiences obtained by the authors in the management of the working daily routine in the enterprise was the point of greatest contribution in the methodology applied to achieve the results of this work.

The work was carried out at Mineração Paragominas S.A., located in the municipality of Paragominas, Pará State, Brazil (Figure 1). The deployment and installation of the project took place in June 2003 and lasted until December 2005. The project started its activities with a production target of 4.5 million tons per year (Mtpa) in November/2006. The commercial operation began in February/2007. In 2009, there was an expansion to production of 9.9 Mtpa. Currently, the company produces approximately 11 Mtpa.

The activities implemented in the Bauxite Paragominas Project includes the following processes:

- A mine where operations are carried out to till the ore and transport it to the processing plant.
- A beneficiation plant where the ore will be crushed, ground and separated from the ultrafine fraction, pulp preparation for shipment to the ALUNORTE refinery, through a pipeline.
- A 244 km long pipeline connecting Paragominas Mining to Alunorte in Barcarena-PA.
- Tailings dikes for the safe disposition of clay material (fine material) from the beneficiation plant.
- Production support units, such as back-office buildings, cafeteria, laboratory, gatehouse and workshops located in area of the plateau Miltônia 3.
- Mine access road, PA-256 highway and electric power transmission line, infrastructure required to the operation of mining activity on the plateau.



**Figure 1. Location map of the enterprise Mineração Paragominas S.A.1**

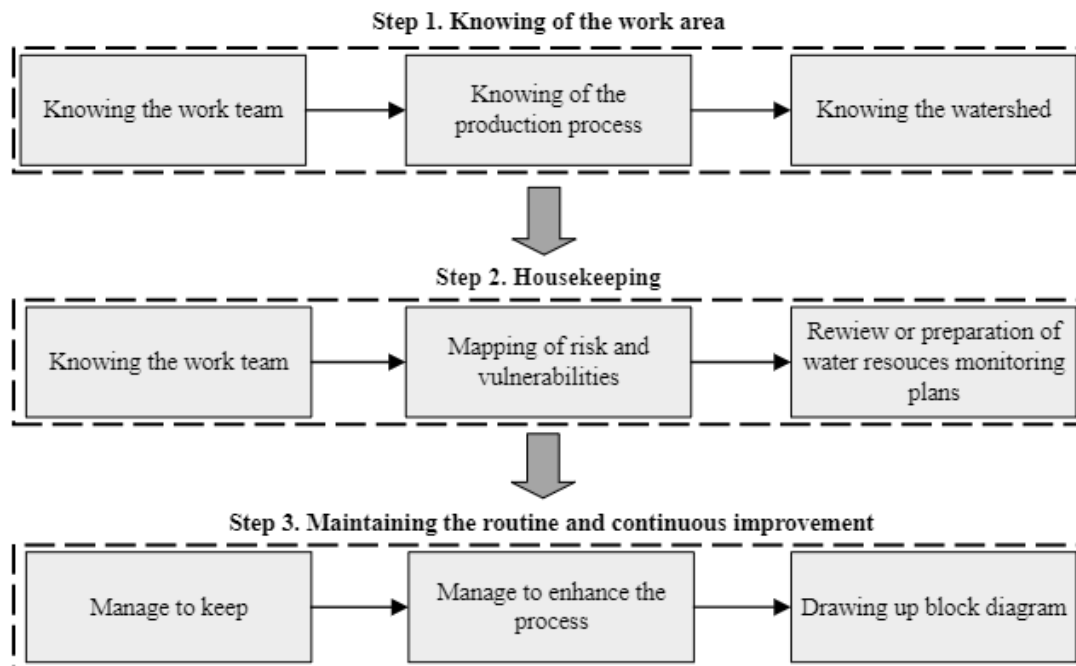
The production process begins with vegetal suppression, resurfacing (it is the operation of removal of the sterile layer, basically clay), bauxite ore mining, transport from the mine to the plant, beneficiation (washing, adequacy of granulometry, homogenization, grinding, clay removal, pulp densification and storage in tanks) and transport of bauxite pulp by pipeline.

### 3. Results

The result of this work generated a technical guide divided into 3 stages, which were: 1<sup>st</sup> stage - knowledge of the work area; 2<sup>nd</sup> stage - housekeeping; 3<sup>rd</sup> stage - maintaining the routine and continuous improvement.

Each stage is composed by steps that involve people management, knowledge of the production process, characterization of the hydrographic basin, standardization of processes, mapping risks and vulnerabilities, monitoring plans, manage to maintain, manage to improve processes. At the end a block diagram will be presented summarizing all the tools, studies and information that should compose the water resource management plan.

Figure 2 contains the summarized organizational structure of this work results.



**Figure 2. Scheme of results presentation stages.**

In the following items will be presented the results that will compose the management guide for the water resources.

### 3.1 Knowing of the Work Area

The first stage is called "Knowledge of the work area". This stage consists of the following parts: knowledge of the work team, knowledge of the production process, and analysis of technical reports and environmental studies. See the details below:

- 1<sup>st</sup> part: the presentation of the team should take place with the objective of knowing the skills and abilities of each team member so that the manager knows what Suggestion to require from each team member, in addition to establishing a base in trust and mutual respect these aspects are essential for employees to be able to come to the water resources manager and feel comfortable to share their problems and anomalies related to the process.
- In the 2<sup>nd</sup> part, the description of the entire production process should be made, through visits to each stage of the production process, aiming the recognition of all operational routines of the process to describe in detail the activities developed, such as: mine operation; operation and maintenance of machinery and equipment; dam systems; water collection; water reuse system; operational routine of the production sector; environmental control and monitoring devices; operational routines of the water treatment plant and wastewater treatment plant. In addition to the on-site visit, it is important to evaluate documents available in the enterprise, aiming to obtain information, such as: production process flowcharts, operational procedures, description, and protocols of operation of systems, as well as operational flowcharts and water balance.
- The knowledge of the watershed consists of the 3<sup>rd</sup> part of this stage, it can begin with the analysis of technical reports, maps, and environmental studies, which will allow the manager to have spatial knowledge of the territory and the enterprise influence area. The field survey

for the recognition of the enterprise directly affected area is fundamental to identify risks, vulnerabilities, and water consumption by external users, as well as knowing the flow regimes, physical characteristics, springs location, permanent preservation area (PPA) of water bodies. For the success of this activity, it is essential to hear from professionals who already work on site, to obtain more detailed and relevant information about the physical environment and clarify any doubts that may arise during the field visit. To enrich the information about the project area hydrography, it is important to identify the hydrographic region, watershed, sub-basin, micro-basin, and main water bodies. In addition, the morphometric characterization of the hydrographic basin is fundamental for the analysis of hydrological behavior as a function of its geomorphological characteristics (shape, terrain, area, geology, drainage network, soil, and vegetation) among others, such as anthropic action of land use and occupation [9]. This planning can help the anticipation of several situations such as flooding, floods and overflows that bring problems to the population living near the canals, because "the main problems of conservation of water resources are related to their quality and availability" [10].

### 3.2 Housekeeping

The 2<sup>nd</sup> stage of the methodology presented in this management guide was called "Tidying the House". This step begins with the standardization of processes, where the manager should know all the processes and procedures that are performed by the work team and identify which are the most important for management. Next, if non-existent, it is essential to prepare procedures for: operation and maintenance of water and effluents quantitative and qualitative monitoring equipment; handling and operation of laboratory equipment; quality requirements for tasks execution; procedures for field survey and impact assessment.

Other documents that the manager must prepare are the schedules of water collection and effluent samples; compliance with environmental constraints; delivery of technical reports; maintenance of measuring equipment and instruments; environmental studies update; and what most fit for the enterprise management.

The standardization of processes is an instrument that indicates the goal (end) and procedures (means) for the work execution, in such a way that each team member can assume responsibility for their work.

Risk mapping consists of the second part of the "Tidying the House" stage, this should occur through listing risk events linked to institutional objectives, such as mapping risk events linked to critical processes and its subprocesses. Once the mapping and listing of risk events is done, it is necessary to evaluate the possible causes and possible consequences of each mapped event.

After identifying the risks and the possible causes and consequences, it is necessary to measure the risks by calculating the risk level. The first step is to calculate the gross risk level, which is the probability and impact of a risk event before any control measure is implemented. Then, to assess the risks, when risk events have already been measured, it is necessary to define the treatment measures that will be implemented for each of them, and the possible treatments are accept, mitigate, transfer and avoid. Again, the participation of the most experienced professionals on site is fundamental for mapping risks and vulnerabilities.

In the 3<sup>rd</sup> part of this stage, the qualitative and quantitative monitoring plans of water resources and wastewater should be reviewed:

- The qualitative monitoring seeks to evaluate whether the parameters already monitored have a causal link to the enterprise operations, so this phase is a good opportunity for inclusion and/or exclusions of monitoring points (review of the monitoring network), physical-chemical

and biological variables in the monitoring program. In addition, it has been verified whether such parameters are required by national and, where applicable, international standards.

- Hydrometric (quantitative) monitoring is composed by river flow measurement and groundwater level. In the flow measurement, the location of the flow measurement tools, the measurement methods (manual or automatic), and the key curve analysis were evaluated. On the other hand, the aquifer dynamics monitoring, the measurement frequency, location of wells, reports of well drilling, construction profile and knowledge of the photometric map of groundwater were reviewed.

### 3.3 Routine Maintenance and Process Improvement

A process consists of a set of causes that trigger effects [11]. Managing or controlling a process is the act of seeking the causes (means) of the impossibility of achieving a goal and establishing countermeasures. In other words, managing to maintain routines consists of:

- Standardize all tasks.
- Address risks, vulnerabilities, anomalies.
- Monitor process results.

In the daily routine of large enterprises there are several anomalies, that is, unusual or unplanned events. This type of event is extremely detrimental to a management system, as the team loses focus on improvement activities to spend energy addressing these anomalies.

By reducing anomalies, demands of non-value-added work tend to decrease. To minimize this type of event it is necessary to standardize all tasks, in other words, the manager must:

- Develop protocols for the execution of field survey activities.
- Elaborate flowcharts and protocols of the activities of environmental monitoring (quality and quantity of water), request for environmental licensing, data management, maintenance of equipment.
- Document the lessons learned, that is, the knowledge acquired while conducting a project or activity. Here, it is worth mentioning that the lessons learned are necessary for any team to evolve, it is a cultural issue that must be worked by leaders and then by other employees.
- Develop an action plan on environmental occurrences and contaminated areas.

As for risks, vulnerabilities, and mapped anomalies, they should be mitigated through monitoring plans, protection devices, technical studies, and spot contracts. Anomalies will only be eliminated by the action of the function's operation, supervision, and management. Therefore, working to reduce anomalies is essential to gain productivity in process improvement activities.

As well as risks, mapping the environmental vulnerabilities associated with water resources is very important for the prevention of environmental incidents. Environmental vulnerability can be defined as the degree to which a natural system is susceptible or unable to cope with the effects of external interactions. In this context, Figueiredo [12] conceptualizes environmental vulnerability to the susceptibility of a system to environmental degradation, considering:

- The exposure of the system to environmental pressures typical from agro-industrial activities, evaluated by indicators that show the anthropogenic pressure exerted in the system.
- The sensitivity of the system to the pressures exerted, evaluated through indicators that show the characteristics of the physical and biotic environment proper to a region (type

of soil, climate, vegetation) that already occur before any disturbance and that interact with the pressures.

- The environment response capacity, evaluated by the adoption of environmental conservation or preservation actions that mitigate or reduce the possible effects of the pressures exerted.

Based on these criteria, the characteristics, and magnitudes of the interactions between the activities of the enterprise and the environment are exposed, in addition to the sensitivity of the system and its ability to adapt to any type of change, allowing the identification and classification of environmental vulnerabilities.

It's necessary an intensive work to improve standards for water management, that is, to achieve improvement goals it is necessary to establish new standards or modify existing ones. However, it is worth mentioning that to achieve new standards it is necessary to ensure compliance with the enterprise current standard.

For both management maintenance and management improvement the definition of environmental indicators is fundamental, because it is through them that it is possible to analyze the conditions, changes in environmental quality, in addition to supporting the understanding of sustainability interfaces, as well as trends, as a support tool for the decision-making process and formulation of the company's internal problems and sustainable practices.

At Mineração Paragominas, for example, some environmental and operational performance indicators are specific water consumption ( $m^3_{\text{water}}/\text{ton}$  produced), catchment percentage, water availability downstream of water catchment (ecological flow), percentage of water reuse and concentration of solids in the tailings.

It is worth mentioning that the indicators should be defined according to the activity and needs of the enterprise, and should not, therefore, use a large number of indicators and select them at random, since the main objective of the indicators is to aggregate and quantify information in a way that its significance becomes more apparent.

In addition to performance indicators, water quality indexes are fundamental in the decision-making processes of the environment management of the enterprise and for monitoring the results obtained in monitoring surface water quality, groundwater, and effluents. For the public, the information of the concentration values of pollutants in water bodies has little meaning, due to the technicalities involved in the results interpretation. The main advantages of the indexes is the easier communication with the lay public, the status greater than the isolated variables, and the fact that it represents an average of several variables in a single number, combining different units of measure into a single unit. However, its main disadvantage is the loss of information of individual variables and their interaction.

Still addressing the theme "Manage to improve processes", the use of computerization and mechatronics systems to automate data management, monitoring, field survey and reporting is crucial today for any enterprise. Besides increasing the quality and reliability of the work performed by the team, the use of 4.0 industry can reduce the waste of time and optimize the use of resources. Some examples of technologies that can be applied in the management of water resources are:

- Multiparameter probes and portable equipment for monitoring parameters (turbidity, dissolved oxygen, conductivity, temperature, pH, salinity, dissolved solids, nitrate,

chloride, ammonia, and other parameters) quality water with sending data via telemetry (satellite).

- Pressure transducers for water level measurement in rivers with sending data via telemetry (satellite).
- Applications for collecting information in field activities. These can be created in the enterprise itself through the Microsoft Power App.
- Cloud data storage to ensure data storage security.
- Preparation of technical reports in an automated way. These can be created in the enterprise itself through Microsoft Power Automate.
- Reporting charts and KPI dashboards automatically. These can be created in the enterprise itself through Microsoft Power BI.
- Applications for sharing data and information with any team member and stakeholders. These can be designed through Microsoft Power BI.

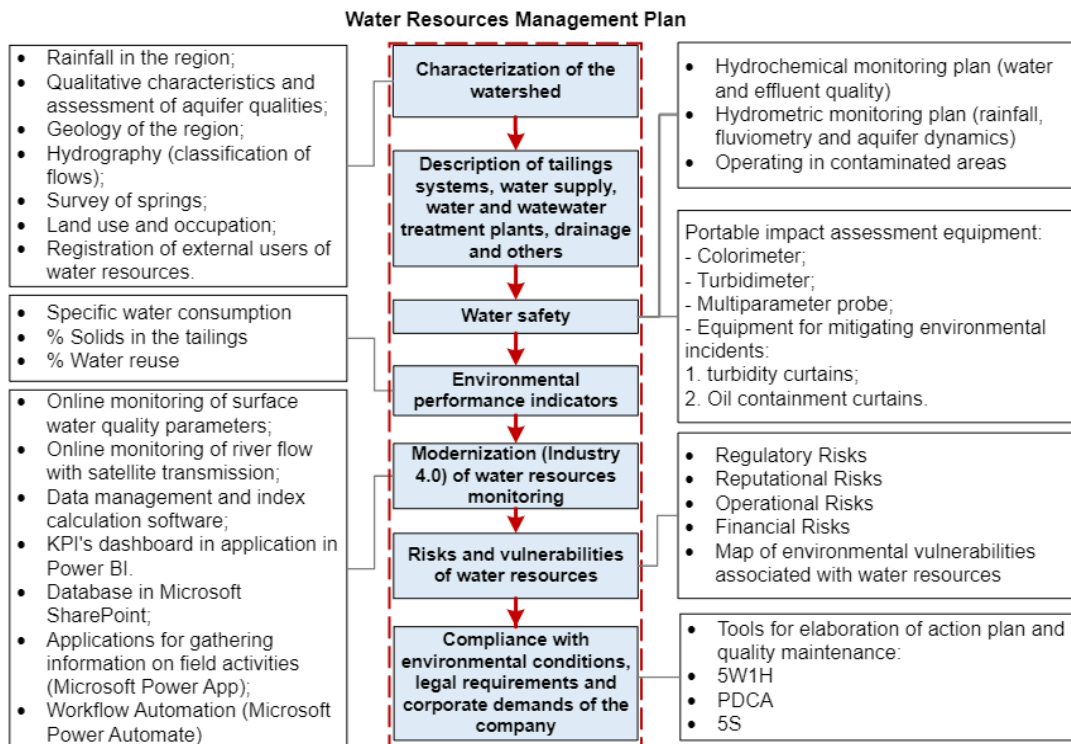
These are just few examples of technologies that can promote productivity gain from the performance of new technological tools that, every day, are improved to yield more in less time, so that the water resources manager can put efforts on critical analysis issues. Moreover, the use of these technological tools for the water resources monitoring is important for the environment manager to save time to work in areas that have a greater number of anomalies and that need more attention from the team.

For the maturation of the water resources management plan, it is important that the manager always seeks to implement improvements in the process and identify optimization opportunities. For this, the use of tools such as PDCA (Plan, Do, Check and Act) to develop plans and operationalize the continuous improvement process, the 5W1H tool for the elaboration of action plan and the 5S methodology to improve the quality of deliveries and higher productivity of employees, can contribute significantly to the maturation of water management in the enterprise.

### **3.4 Block Diagram**

The block diagram is an effective way to represent the logical steps of a given process. One of the main advantages of this type of graphic representation is that it facilitates the assimilation of information by readers in general and, also, a faster visualization of the entire management process.

To simplify and facilitate the understanding of the results presented in this article, in Figure 3 can be visualized the block diagram of the water resources management plan of Mineração Paragominas S.A., composed by: studies, tools, monitoring programs, KPIs, risks, quality indices, technologies and other information relevant to the water resources manager.



**Figure 3. Diagram of blocks of management of water resources in enterprises.**

#### 4. Conclusions

This technical guide can be used by engineers, environmental technicians, employees in general and other professionals willing the adoption of environmental management practices or environmental practices focused on water resources. It will also help those professionals who seek the increase of efficiency for their processes, and reduce impacts on the environment, in an integrated and preventive way. The dissemination of these good practices in the management of water resources in small, medium, and large companies can contribute to the promotion of sustainable development in the industrial and mineral sector.

The work presented different techniques, methodologies, indicators, technologies, good practices applicable to the implementation of a water resources management system in mining enterprises, and briefly exposed a successful case implemented in Mineração Paragominas. Therefore, the information contained in this document may help management teams to identify the main environmental aspects associated with their activities and to seek the best ways to mitigate them, in addition to encouraging the adoption of an active behavior in relation to environmental issues.

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