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Classification of the Juturnaíba Dam: Potential Risk and Damage

Monica de Aquino Galeano da Hora Rocha, Manoel Isidro de Miranda Neto

Master's Program in Civil Defense and Security, Fluminense Federal University, Niteroi, Rio de Janeiro, Brazil
Email: dahora@vm.uff.br

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Abstract

A Dam Safety Program aims to reduce the risks to human life, property, and the environment from dam related hazards. In Brazil, despite of the contemporary law about dam safety, there is still no cadastral information nor the classification of risk and associated potential damage to all dams. Besides that, the recent disaster caused by the failure of the Fundão dam, located in Mariana city, Minas Gerais State, is an issue that aggravates the urgency of preventive measures and plans for disaster action. The present study proposes to classify the Juturnaíba dam, which maintains the largest reservoir for water supply in the state of Rio de Janeiro, Southeast region of Brazil. It was sought to analyze the risks and potential damage associated with the dam, in accordance with two classifications: one from the Brazilian Dams Committee and the other from the National Water Resources Council. It was possible to conclude that the Juturnaíba dam potentially presents high risk and associated high rates of damage, both regarding losses of human lives and regarding environmental and socioeconomic impacts. This is mainly due to the poor state of conservation that it currently presents. It is recommended that future studies should assess the slope stability of the earth dam, and that repair work should be implemented on the degraded concrete structures, with recuperation or installation of instruments that would enable monitoring of possible movement of the earth dam.

Keywords

Dam Safety, Disaster, Hydrology

1. Introduction

The construction of dams for provisions, electricity supply, flow regulation, waste retention, and other purposes help public authorities meet the needs of communities [1].

According to the latest report on dam safety, Brazil has 17,259 dams registered by federal and state regulatory agencies. Of these, 16,313 are exclusively for water retention, 15,671 are for multiple use purposes (e.g., human and industrial supply, irrigation, navigation, animal watering and leisure), and 642 are for hydroelectric power generation. The remaining are dams that contain mining tailings (660) and industrial waste (286) [2].

Water retention dams, when properly designed, constructed and operated, are safe and have low failure probabilities. However, it is inevitable that, despite all precautions, a permanent residual risk exists [3].

[4] consider that the consequences of a possible accident involving water retention dams depend basically on the degree of danger associated with the flood, the degree of exposure and the vulnerability to destruction to which local individuals and assets are subject downstream of the dam.

Currently, there is a strong demand from society to understand the situation of the dams located in their surroundings from the safety perspective and their real risk exposure level from these structures. People are increasingly aware that safety is not an absolute condition but rather that there are risks that must be measured to know whether they are tolerable or not [5].

In this context, the purpose of dam safety programs is to recognize the potential hazards offered by these structures and to reduce them to acceptable levels. Safe dams can be built, and potential deficiencies in safety can usually be corrected before they cause socioeconomic losses, loss of life or ecological disasters [6].

Thus, it is important to act in a preventive manner, particularly in the monitoring and inspection of dams. It should be noted that human, environmental and property losses, such as those of the Fundão dam (Mariana city, Minas Gerais State), are issues that aggravate the urgency of preventive measures and plans for disaster action.

In the state of Rio de Janeiro, the situation is similar: the Juturnaíba dam, which is the largest water reservoir for human consumption in this state, has been exhibiting serious problems in recent years. It is thus imperative that an intervention is made and that there be greater regulation and maintenance control of this structure in the future [7] [8].

Considering this scenario, this paper seeks to analyze the construction process and current conditions of the site and to classify the Juturnaíba dam by risk category and associated potential damage.

2. Literature Review

The causes of dam ruptures can be divided into human and natural causes. Among the human causes, there are acts of terrorism and war, errors of design and construction, and operating faults. Natural accidents, however, cause unplanned demand or reduced strength on a dam, causing rupture. Among natural accidents, exceptional floods have been observed that result in water levels rising upstream of the dam and overtopping to occur. This event causes a flood more severe than the project design flood or, in the case of dams with controlled spillways, when very high speed of water level rise, spillways are not activated in a timely manner. In the latter case, the issue becomes critical due to the dynamics of decision-making regarding the opening of floodgates, such as occurred at the Euclides da Cunha dam located on the Pardo River in the municipality of São José do Rio Pardo, which ruptured in 1977 due to a delay in action [9].

According to [10] and [11], out of the 5,268 dams built before 1950, 117 of them (2.2%) ruptured. After 1950, excluding China, out of the total of 12,138 dams built, 59 (0.5%) ruptured. Most of these ruptures occurred in dams with a height of less than 30 m. According to the authors, most of the ruptures occurred in newly built dams, often in the first 10 years (70%) and, typically, in the first year of operation.

For concrete dams, foundation problems are the most frequent cause of rupture due to internal erosion (21%) or low shear strength (21%). For soil and rockfill dams, the most common cause of rupture is overtopping (31% as the main cause and 18% as a secondary cause), followed by internal erosion in the body of the dam (15% as the main cause and 13% as secondary) and foundation problems (12% as the main cause and 5% as secondary cause). For masonry dams, the most frequent cause is overtopping (43%), followed by internal erosion of foundations (29%) [11].

According to [10], when a failure is related to the auxiliary structures, the most frequent cause is insufficient spillway capacity. In this case, when failure occurs, it is typically abrupt, causing an instantaneous wave, which rapidly increases water levels as it propagates downstream. This is the most likely accident to cause fatalities due to the short time available for warning. As stated by [9], soil or rock dams generally do not withstand overflows because the erosion process causes progressive rupture and cracking, through which the water flows freely.

To minimize the risks involved in dam construction, safety standards used globally, including in Brazil, establish that the design flood should be exceptionally severe as determined using the Probable Maximum Flood (PMF) concept. It is recommended that for a satisfactory safety level, the recurrence interval (RI) associated with the PMF is equal to 10,000 years (*i.e.*, decamillennial) [9].

The criteria for dam classifications vary from country to country. In Brazil, the Brazilian Dam Committee (CBDB) classified dams based on risk potential, size and floods recommended for the design of the spillway, as shown in **Tables 1-3**.

Enacted September 20, 2010, Law 12.334, which established the National Dams Security Policy (PNSB), provides that dams shall be classified by inspection agents by risk category, associated potential damage, and volume based on general criteria established by the National Council of Water Resources

Table 1. Classification of the risk potential of dams (Adapted from [9]).

Category	Loss of life	Economic Losses
Low	None expected (no human housing structure downstream)	Minimum (undeveloped area and occasional farming structures)
Significant	Up to 5 (no urban development and no more than a small number of habitable structures downstream)	Appreciable (farmlands, industries and structures)
High	More than 5	Excessive (extensive communities, industries and agriculture)

Table 2. Classification of dams by size (Adapted from [9]).

Category	Height (m)	Storage (m^3)
Small	5.0 < height < 15	0.05×10^6 < volume < 1.0×10^6
Medium	15 < height < 30	1.0×10^6 < volume < 50×10^6
Large	height > 30	volume > 50×10^6

Table 3. Classification of the dams by spillway design (Adapted from [9]).

Risk	Size	Spillway Design Flood
Low	Small	RI = 50 to 100 years
	Medium	RI = 100 to ½ PMF
	Large	0.5 to 1 PMF
Medium	Small	RI = 100 years at 0.5 PMF
	Medium	0.5 to 1 PMF
	Large	1 PMF
High	Small	0.5 to 1 PMF
	Medium	1 PMF
	Large	1 PMF

(CNRH). All dams intended for the accumulation of water for any use, final or temporary disposal of tailings, and the accumulation of industrial waste and having at least one of the following characteristics are subject to the law: height of dam mass, from the lowest point of the foundation to crest, greater than or equal to 15 m; total reservoir capacity greater than or equal to 3,000,000 m^3; container containing hazardous waste; and associated potential damage category rated medium or high [12].

Resolution CNRH 143, dated July 10, 2012, established the general criteria for classification of dams by risk category, associated potential damage and reservoir volume [13].

With regard to risk category (RC), dams are classified according to aspects of the dam that may influence the possibility of an accident and considers the following general criteria: technical characteristics (TC); state of conservation of the dam (SC); and Dam Safety Planning (SP).

The general criteria used to classify the associated potential damage (APD) in the affected area are: the existence of downstream population with potential loss of human life; the existence of housing units or urban or community facilities; the existence of infrastructure or services; existence of essential public service equipment; the existence of protected areas defined in legislation; nature of waste or stored waste; and the dam's volume.

To classify dams used for water accumulation, the volume of its reservoir is considered: small (volume less than or equal to 5,000,000 m^3); medium (volume greater than 5,000,000 m^3 and less than or equal to 75,000,000 m^3); large (volume greater than 75,000,000 m^3 or equal to 200,000,000 m^3); and very large (volume greater than 200,000,000 m^3).

The supervisory agent must then complete the tables in Appendix II of Resolution CNRH 143/2012 and cross-check the information for classification. The RC corresponds to the sum of CT (**Table 4**), SC (**Table 5**) and SP (**Table 6**), which determine the dam risk indicator. In the tables, the numbers in parentheses correspond to the score of the development.

The final result allows the dam to be classified based on the RC, as shown in **Table 7**.

Table 8 shows the APD score, and **Table 9** lists the final classification of the dam according to the score achieved.

3. Materials and Methods

3.1. Region and Site Characterization

The São João river basin covers an area of 2160 km^2 and is fully included in the state of Rio de Janeiro, Southeastern Brazil, as shown in **Figure 1**. The municipalities included in the basin are Araruama, Cabo Frio, Cachoeiras de Macacu, Casimiro de Abreu, Rio Bonito, Rio das Ostras, São Pedro da Aldeia and Silva Jardim [14].

Table 4. Classification of technical characteristics (Adapted from [13]).

Height (m) (a)	Length (m) (b)	Type of Dam by Construction Material (c)	Type of Foundation (d)	Age of Dam (e)	Design Flow (f)
Height ≤ 15 (0)	Length ≤ 200 (2)	Conventional Concrete (1)	Sound rock (1)	Between 30 and 50 years (1)	PMF or Decamillennial (3)
15 < height < 30 (1)	Length> 200 (3)	Stone masonry/cyclopean concrete-CCR (2)	Altered hard rock with treatment (2)	Between 10 and 30 years (2)	Millennial (5)
30 ≤ Height ≤ 60 (2)	-	Homogeneous soil/rockfill/soil rockfill (3)	Untreated altered rock/altered fractured rock with treatment (3)	Between 5 and 10 years (3)	RI = 500 years (8)
Height > 60 (3)	-	-	Soft altered rock/compacted saprolite soil (4)	< 5 years or > 50 years or no information (4)	RI <500 years or unknown/unreliable study (10)
-	-	-	Residual soil/alluvium (5)	-	-

Table 5. Classification of state of conservation (Adapted from [13]).

Reliability of Overflow Structures (g)	Reliability of Adduction Structures (h)	Percolation (i)	Deformations and settling (j)	Deterioration of embankments/ supporting walls (k)	Locks (1)
Civil and hydro-mechanical structures in full operation/unobstructed approach or restitution channels or spillway (free-flowing weir) (0)	Civil structures and hydro-electromechanical devices under proper conditions of maintenance and operation (0)	Percolation fully controlled by the drainage system (0)	Nonexistent (0)	Nonexistent (0)	No lock (0)
Civil and hydro-electromechanical structures prepared for operation, but with no sources of emergency power supply/channels or spillway (free-flowing weir) with erosions or obstructions, but with no risk to the slope structure (4)	Compromised civil structures or hydro-electromechanical devices with identified problems, with decreased flow capacity and corrective measures under implantation (4)	Humidity or upwelling in stabilized and/or monitored downstream areas, supporting walls, embankments or abutments (3)	Existence of small size cracks and abatements of no impact (1)	Gaps in protection to embankments and supporting walls, presence of small shrubs of no impact (1)	Civil and hydro-electromechanical structures well maintained and functioning (1)
Reliability of Overflow Structures (g)	Reliability of Adduction Structures (h)	Percolation (i)	Deformations and settling (j)	Deterioration of embankments/ supporting walls (k)	Locks (1)
Compromised civil structures or hydro-electromechanical devices with identified problems, with reduced flow capacity and corrective measures under implantation/channels or spillway (free-flowing weir) with erosions and/or partially obstructed, with risk of impairment of the slope structure (7)	Compromised civil structures or hydro-electromechanical devices with identified problems, with reduced flow capacity and no corrective measures (6)	Humidity or upwelling in downstream areas, supporting walls, embankments or abutments, untreated or in the diagnostic phase (5)	Existence of cracks and abatements of considerable impact, generating a need for additional studies or monitoring (5)	Surface erosion, exposed hardware, generalized vegetation growth, generating a need for monitoring or corrective action (5)	Compromised civil structures or hydro-electromechanical devices with identified problems and corrective measures under implantation (2)
Compromised civil structures or hydro-electromechanical devices with identified problems, with reduced flow capacity and no corrective measures/obstructed channels or spillway (free-flowing weir) or with damaged structures (10)	-	Upwelling in downstream areas, embankments or abutments with material bearing or with increasing flow (8)	Existence of significant cracks, abatements or landslides, with potential for compromising safety (8)	Significant depressions in embankments, landslides, deep erosion grooves, with potential for compromising safety (7)	Compromised civil structures or hydro-electromechanical devices with identified problems and no corrective measures (4)

The São João River begins in the Sambê Mountains on the foothills of Serra do Mar at 700 m of altitude in the municipality of Cachoeiras de Macacu. Its total length of 150 km travels in the Northeast direction until it drains into the Atlantic Ocean in the city of Barra de São João. The main tributaries to the São João River upstream of the Juturnaíba reservoir are, on the left bank, the Águas Claras, Pirineus, Bananeira and Maratuã Rivers and, on the right bank, the Gaviões, Ouro, Salto d'Água and Cambucas Rivers. The Capivari and Bacaxá Rivers flow

Table 6. Classification of the dam safety plan (Adapted from [13]).

Existence of project documentation (n)	Organizational structure and technical qualification of the Dam Safety team professionals (o)	Procedures for safety and monitoring inspections (p)	Operational rule of dam discharge devices (q)	Security inspection reports with analysis and interpretation (r)
Executive and "as-built" project (0)	It has an organizational structure with a technician responsible for dam safety (0)	It has and applies inspection and monitoring procedures (0)	Yes or free-flowing weir spillway (0)	Reports regularly (0)
Executive or "as-built" project (2)	It has a technician responsible for dam safety (4)	It has and applies only inspection procedures (3)	No (6)	It issues reports without periodicity (3)
Basic project (4)	It has no organizational structure and technician responsible for dam safety (8)	It has and does not apply inspection and monitoring procedures (5)	-	It does not issue reports (5)

Table 7. Classification ranges for risk category (Adapted from [13]).

	Risk Category	Score
Classification ranges	High	≥60 or SC = 8 (*)
	Medium	35 to 60
	Low	≤35

(*) A score (greater than or equal to 8) in any State of Conservation column automatically implies a high-risk category and a need for immediate action by the dam authorities.

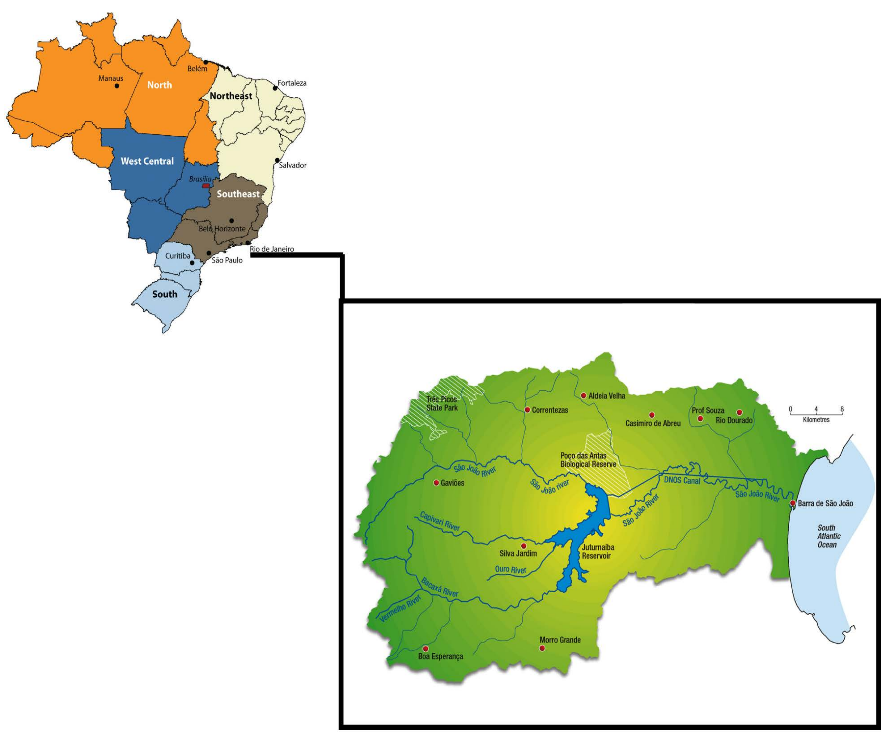

Figure 1. São João river basin (Adapted from [15]).

Table 8. Classification of associated potential damage (Adapted from [13]).

Total Reservoir Volume (a)	Potential for loss of human life (b)	Environmental impact (c)	Socioeconomic impact (d)
Small < = 5 million m³ (1)	NONEXISTENT (there are no permanent/resident or temporary/transiting persons in the affected area downstream of the dam) (0)	SIGNIFICANT (affected area of the dam does not represent an area of environmental interest, areas protected under specific legislation or it is totally devoid of its natural conditions) (3)	NONEXISTENT (there are no facilities and navigational services in the area affected by the dam accident) (0)
Medium 5 million to 75 million m³ (2)	INFREQUENT (there are no persons permanently occupying the affected area downstream of the dam, but there is a side road of local use) (4)	VERY SIGNIFICANT (affected dam area shows relevant environmental interest or protected under specific legislation) (5)	LOW (there is a small concentration of residential and commercial, agricultural, industrial or infrastructure facilities in the affected dam area or port facilities or navigational services) (4)
Large 75 million to 200 million m³ (3)	FREQUENT (there are no persons permanently occupying the affected area downstream of the dam, but there is a municipal, state, federal or other local - highway and/or possible building of potential permanence of persons that may be affected) (8)		HIGH (there is a large concentration of residential and commercial, agricultural, industrial facilities, leisure and tourism infrastructure and services in the affected area of the dam or port facilities or navigational services) (8)
Very large >200 million m³ (5)	EXISTING (there are persons permanently occupying the affected area downstream of the dam, therefore human lives may be affected) (12)	-	-

Table 9. Classification ranges for the associated potential damage category (Adapted from [13]).

	Associated Potential Damage	Score
Classification ranges	High	≥16
	Medium	10 < APD <16
	Low	≤10

into the reservoir. Downstream of the reservoir, the São João River ranges in slope from 6% to 1% in an alluvial plain with large flooded areas, receiving on the right bank the Morto River and on the left bank the Aldeia Velha, Lontra and Dourado Rivers [16].

In the central part of the basin, a lake is formed by the Capivari and Bacaxá rivers discharging into the São João River. This region is characterized as a valley bottom filled with sediments of fluvial and fluviolacustrine origins with deposits of peaty black clays of varying thickness, reaching up to 10 m. Originally, the lake had a water surface area of 5.6 km^2 with a volume of 10 million m^3, an almost rectangular shape, and a mean depth of approximately 4 m [17].

It is noteworthy that the São João River basin is an Atlantic Forest conservation unit, called the APA of the São João/Mico-Leão-Dourado River Basin. In addition, the Poço das Antas Rebio is downstream of the dam [18].

As stated by [17], the damwas designed in 1972 by the Ministry of Interior, and the National Department of Sanitation Works (DNOS) was responsible for the management and supervision of the site. Initially, the dam was designed to accumulate water for the domestic and industrial supply of the Lagos Region to control the floods in the São João River and to provide water to irrigate the areas downstream of the dam. The work began in January 1979 and was completed in 1984. According to [15], the dam is located at 22˚35'S and 42˚16'W.

The main physical and hydraulic characteristics of the dam and civil structures are listed in **Table 10**.

According to [17], the left abutment of the dam is supported by the Crioulas Hill, while the right abutment is supported by the Madureira Hill. Downstream of the spillway a structural concrete bridge of 180 m was built, serving as a connection between the São João River's banks.

Table 10. Data sheet of the dam and civil structures (Adapted from [17] [19] [20] [21]; [22] and [23]).

RESERVOIR(19)	
Maximum volume	78.51 × 106 m^3
Maximum water level	11.40 m
DAM(20)	
Type	Earth dam
Length	3460 m
Crest elevation	12.00 m
SPILLWAY(21);(17)	
Type	Labyrinth with 4 elements(21)
Total width	163.5 m(21)
Total development	710 m(17)
Crest elevation	8.40 m(21)
Bottom elevation	3.00 m(21)
Height	5.40 m(21)
Maximum water level on crest (NAmax max)	11.40 m(21)
Flow corresponding to maximum water level (Q)	5600 m^3/s(21)
SLUICES WITH STOP-LOG FLOODGATES(22);(23)	
Right side of spillway	4 units(23)
Left side of spillway	4 units(23)
Width of each unit	1.20 m(23)
Height of each unit	1.20 m(23)
Minimum operating water level	3.00 m(22)
Maximum operating water level	8.60 m(22)

3.2. Construction Aspects

On August 15, 1975, a technical team from the now-closed DNOS made up of engineers and geologists explored the site of the future Juturnaíba dam project to investigate the conditions of local foundations and concluded that the soil was peaty with layers of clay from soft to very soft. Given the differentiated foundation conditions along the axis, typical sections were proposed per stretch [20], as shown in Figure 2.

Section I is 1300 m long and extends from the left abutment to Crioulas Island. Because the local foundation is in sand, it was suggested that a sealing trench wall be dug. However, during excavation, pockets of soft clay were found. For this reason, the design was modified, and the geometry of the dam section was modified with the slopes of upstream and downstream embankments of 2.5 (H):1.0 (V). The crest of the dam was fixed at an elevation of 12.0 m with a width of 10 m. The construction of this section began in June 1979 and ended in January 1980. Due to the presented behavior, there was no need to install instrumentation [20].

Section II is located between the right abutment and pile 35 and has an upstream embankment composed of a 45 m berm at an approximate elevation of 5.5 m, followed by an embankment with 4.0 (H):1.0 (V) slope to the dam top elevation. The crest is 14 m wide, and the downstream embankment has a 3.0 (H):1.0 (V) slope to the elevation of 7.5 m, followed by berms at the 7.5 m, 6.5 m and 5.5 m elevations, respectively, with 30, 20 and 17 meters in length. Construction began in May 1981 and required the removal of the foundation, which had a variable thickness of 3 to 4 m from the beginning of the upstream berm up to the downstream berm at the 7.5 m elevation [24].

According to [20], Section III is 1,480 m in length and extends from Madureira Island to pile 40. Based on the results of the surveys, the section was subdivided into sections III-1 and III-2. The first, which had its foundation in sand, has a section with 3.0 (H):1.0 (V) slopes and began construction in November 1979 and ended construction in August 1980. In Section III-2, which had the

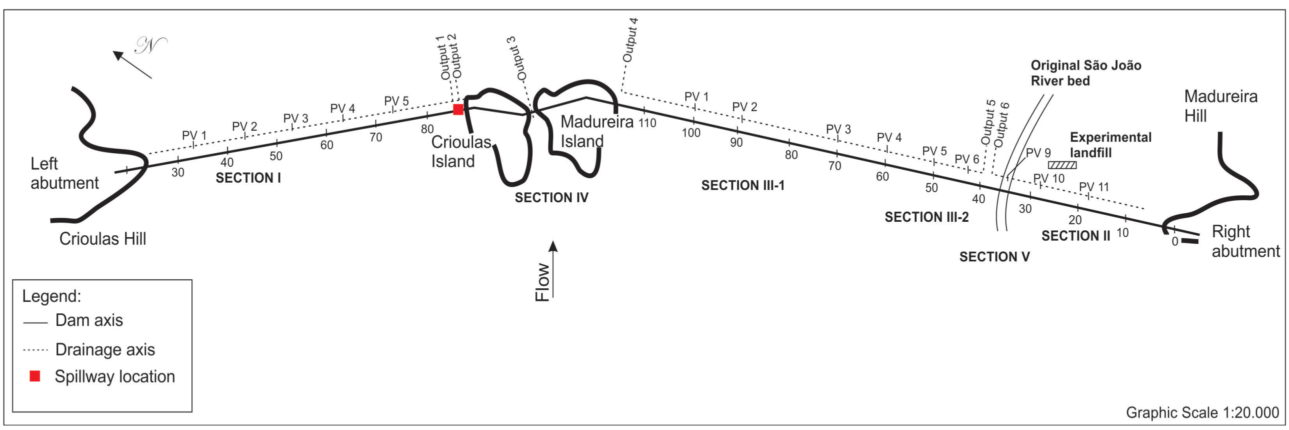

Figure 2. Axis of the Juturnaíba Dam, showing the location of the piles on the São João river bed, including inspection wells and outputs of the well drains (Adapted from [20]).

same typical section as Section II, a study of the behavior of organic soils/soft clay was performed through the construction and rupture of an experimental landfill, built from February to April of 1980, which supported the study developed by [25]; this was required due to precarious foundation conditions caused by the soft clay layer, which ranged between 7 and 10 m in thickness.

The excavation of Section IV's foundations, which were located between the two islands, also began in May 1981. All soft material composed of peat and soft clay was removed, reaching a foundation in sands. Construction of this section continued normally, achieving the crest at the 12.0 m elevation in November 1981 [20].

Construction of Section V, which is located between piles 35 and 40, began in June 1982. An important detail was the execution of the drainage at the foot of the dam. Due to the possibility of a flood in the summer, it was decided in December 1982 to raise the dam in Section V up to 9.0 m in elevation. In February 1983, it was then decided to raise Section V with maximum increments of 50 cm of landfill in 3 days. At that time, the foundation settlings of Section V had reached 60 to 70 cm. A similar decision was made for Sections III-2 and II, when settling was found to range from 70 to 90 cm. Due to the scarcity of financial resources, construction took 5 years [20].

With regard to the design and construction of the Juturnaíba spillway, no documents related to the calculation worksheets of the design flow sizing were found. The only available document found was the drawing titled "Zigzag Spillway Model-Plant-Sections-Details" [21]. In the drawing, detail "1" shows the cross-section of the spillway, in which only the design flow of 5600 m^3/s is identified without an associated recurrence interval. Thus, to evaluate the damping of this flood and its lamination through the spillway, [26] estimated the PMF and found the figure of 5587 m^3/s, showing that the DNOS design flow is compatible with the 10,000-year flood; thus, the Juturnaíba spillway was dimensioned according to dam safety criteria. **Figure 3** shows a reproduction of detail "1" from the original DNOS plant.

3.3. Current Site Situation

To understand the current situation of the site, a visit to the reservoir and Juturnaíba dam was conducted on January 13, 2016 with technical assistance from the Rio de Janeiro State Agency for the Environment (SEA).

Access to the dam allows the option for two different paths on a dirt road: one that leads to the crest, and another that leads to the foot of the dam. We decided to visit the crest of the dam. Along this access road, state agency signs can be seen, prohibiting the entry of vehicles and unauthorized persons, as well as the presence of barriers that prevent the passage of larger vehicles, such as trucks and tractors.

During the inspection, agricultural activities were visible in the area surrounding the lake. When crossing the ridge, the undesired presence of animals was observed, especially cattle and termites. Inspection wells were also observed,

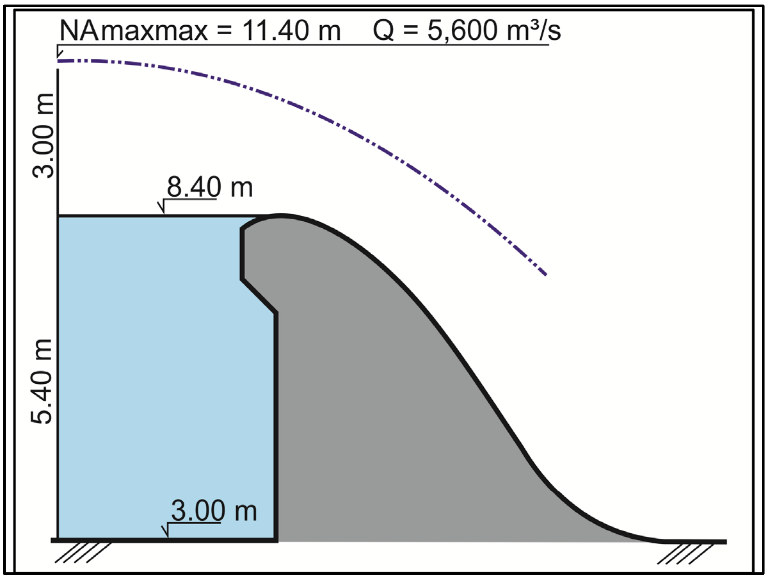

Figure 3. Diagram of the cross-section of the spillway ([26] adapted from [21]).

some near the foot of the dam and others in the downstream embankment. Some of the covers in these inspection wells were found to be damaged by rust, while others did not have covers. Given the dangerous conditions, it was not possible to inspect the interior of the wells, **Figure 4**.

Following a dirt road, we arrived at the site of the hydraulic structures of the dam after passing Crioulas Island. The dam has a labyrinth spillway with 4 cycles and 8 sluices, 4 on each side. It was observed that each side of the spillway also has a concrete channel. This complementary structure would allow the construction of channels adjacent to the São João River, which would lead outflow water for irrigation of local agriculture. However, the irrigation channels do not exist.

The hydraulic structures on the right side of the spillway are damaged, as shown in **Figure 5**. The structure of the restitution channel on the right side had collapsed; broken concrete blocks were visible. Vegetation was also found where the complementary channel should be. In addition, four sluices were found to be closed by their respective floodgates; however, water still flowed downstream, indicating poor sealing.

The walls of the restitution channel on the left side of the spillway were also found to be collapsed, as shown in **Figure 6** and **Figure 7**.

The structure was also found to be collapsing downstream of the dam. A large concrete block has already broken off and is now in the São João River just downstream of the spillway. If there is no adequate restoration of the structure, there will probably be a final separation of this main channel from the dam body and damage to the complementary structure for the irrigation channels. Another important observation is that only the left-side floodgates are in operation. During the visit, water flowing through the rightmost floodgate was observed, as shown in **Figure 8**.

Figure 4. Cattle circulating freely on the crest of the dam near an inspection well without a cover [26].

Figure 5. Broken concrete structure on the right side of the spillway [26].

Figure 6. Downstream view of the restitution channel on the left side of the spillway [26].

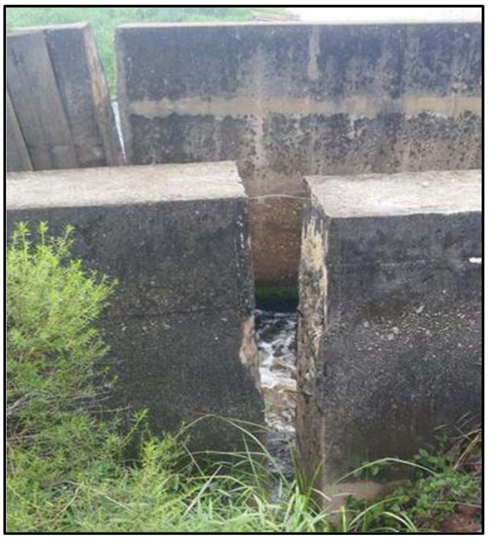

Figure 7. Detail of the rupture of the restitution channel on the left side of the spillway [26].

Figure 8. Rightmost floodgate of the left side with spillway detail in the background [26].

It was also found that 3 of the 4 sluices were closed with their respective floodgates and that only two protection grids were present to guard against floating material on the upstream wall, as shown in **Figure 9**. The operating sluice did not have a protection grid (detail).

The presence of vegetation was also observed in the spillway, indicative of the relevant siltation and sediment accumulation process in the reservoir, as well as the lack of maintenance of the hydraulic structures of the dam, as shown in **Figure 10**.

In the restitution channels on both sides of the spillway, grooves for the descent of the stop-logs panels were visible. However, the panels were not located in the grooves nor in any location near the observed location. Thus, if there is a problem or need for maintenance of the floodgates, water will flow through the dam restitution channels without any type of control.

Figure 9. Detail for the grid of the upstream wall of the left side of the spillway [26].

Figure 10. Presence of vegetation above the spillway [26].

Downstream of the spillway there are two sediment islands that have large amounts of vegetation, as shown Figure 11. These islands were probably formed by the sedimentation of the São João River banks and the transport of sediments and vegetation through the spillway.

4. Results and Discussion

Regarding the CBDB criteria listed in Tables 1-3, the Juturnaíba dam can be classified as high risk potential in terms of life and economic losses (Table 1) because there are extensive areas of agriculture and livestock downstream of the dam. Additionally, the 2nd district of Casimiro de Abreu, called Barra de São João, is at the mouth of the São João river and has a population of approximately 9000 inhabitants according to information from [27]. In the classification of the dam size (Table 2), the Juturnaíba site can be considered small in relation to height (5 to 15 m) but large in relation to stored volume (above 50,000,000 m^3). In the classification of spillway design (Table 3), the associated risk was

Figure 11. Islands of sediments downstream and close to the hydraulic structures of the dam [26].

considered high because the design flood should have a recurrence interval of 10,000 years (*i.e.*, 1 PMF) regardless of the dam size being medium or large.

Tables 4-9 show the general criteria for the classification of dams by risk category, associated potential damage and reservoir volume, as established by resolution CNRH 143.

Regarding the technical characteristics (Table 4), the Juturnaíba dam achieves the following scores: height (0); length (3); type of dam as to building material (3); type of foundation (5); age of the dam (1); and design flow (3). It should be noted that the foundation soils in the region are predominantly soft clay, very soft clay and peat; however, in the classification considered in this study, there are no such distinctions. Thus, the worst condition (residual soil/alluvium) was considered, resulting in a total TC score of 15.

Regarding the state of conservation (Table 5), the site achieves the following scores: reliability of the overflow structures (10); reliability of adduction structures (6); percolation (3); deformations and settlements (1); deterioration of embankments/walls (5); and locks (0). In some places, access was not possible during the field visit; however, it was determined that no instrumentation is in operation based on information from the technicians responsible for inspection. Therefore, it is not possible to monitor displacements and pressures on the dam body. The sum of SC points was 25.

Regarding the dam safety plan (Table 6), the site achieves the following scores: existence of documentation (4); organizational structure and technical qualification of the dam safety team (8); procedures for safety inspection and monitoring (5); operational rule of dam discharge devices (0); and safety inspection reports with analysis and interpretation (3). The total SP score was 20.

The final score of the risk category corresponds to the sum of the TC, SC and SP scores, and the result was 60. It should be emphasized that if the RC is greater than or equal to 60 or if the SC score is greater than or equal to 8 in any analysis parameter, the dam is automatically classified as a high-risk category, requiring immediate action by the developer (Table 7). The Juturnaíba dam was thus classified as high risk.

Regarding the associated potential damage (Table 8), the site yielded the following score: total reservoir volume (3); potential loss of life (12); environmental impact (5); and socioeconomic impact (8). The total score for the APD resulted in 28, which allows rating the dam as having high associated potential damage.

These results allow us to infer that by both the classification of the CBDB and the classification of Resolution CNRH 143, the risk potential associated with the Juturnaíba dam is high.

5. Conclusions

Both the potential and risk category of the Juturnaíba dam are high. Thus, due to the reservoir volume, potential human losses and environmental and socioeconomic impacts, potential damages can also be classified as high.

Efforts must be concentrated on defining prevention, mitigation, preparation, response and recovery actions, through the preparation and training of the Civil Defense teams of the surrounding municipalities, minimizing damage to the environment and to the populations located in the downstream valleys in the event of the dam rupture because overtopping is unlikely to occur.

In this study, no questions were raised about the integrity of the civil structures nor the geotechnical conditions of the dam mass. In view of the poor state of conservation of the site as ascertained during a field visit in January 2016, necessary interventions are urgently needed in addition to an assessment of the stability of the earth dam embankments.

Conducting interventions on degraded concrete structures and recovering or installing instruments to monitor the stability of the earth dam are also recommended.

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