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## Contributions to the dam safety management of two state entrepreneurs from Pernambuco

### *Contribuições para a gestão de segurança de barragens de dois empreendedores estaduais de Pernambuco*

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**Abstract:** This study proposes to establish an order of priorities of dams of the two main state entrepreneurs of Pernambuco, through the application of the PLANERB methodology, in order to meet the instruments of the National Dam Safety Policy (PNSB). It also proposes the financial planning for the execution of the necessary actions. The results indicate that the existence of technical documentation and monitoring of the dam directly influences the order of priorities. From the orders of priorities obtained, the proposed plans aim to serve 5% of the dams of COMPESA and 10% of SEINFRA, totaling around R\$ 2,000,000.00 and R\$ 1,800,000.00, by the end of the first year, respectively. The results provide subsidies for the PNSB implementation process, contributing to the management of dam safety, and serving as a tool to aid in decision-making.

**Keywords:** Segurança de barragens; Pernambuco; Empreendedores.

**Resumo:** Este estudo propõe o estabelecimento de uma ordem de prioridades das barragens dos dois principais empreendedores estaduais de Pernambuco, através da aplicação da metodologia do PLANERB, a fim de atender a instrumentos da Política Nacional de Segurança de Barragens (PNSB). Também está proposto o planejamento financeiro para execução das ações necessárias. Os resultados apontam que a existência de documentação técnica e monitoramento da barragem influencia diretamente na ordem de prioridades. A partir das ordens de prioridades obtidas, os planejamentos propostos visam atender 5% das barragens da COMPESA e 10% da SEINFRA, totalizando cerca de R\$ 2.000.000,00 e R\$ 1.800.000,00, ao final do primeiro ano, respectivamente. Os resultados fornecem subsídios para o processo de implementação da PNSB, contribuindo para a gestão da segurança das barragens, e servindo como ferramenta de auxílio à tomada de decisões.

**Palavras-chave:** Dam safety; Pernambuco; Entrepreneurs.

## 1. Introduction

According to the National Agency for Water and Basic Sanitation (ANA), dam safety can be defined as a condition that aims to maintain the structural and operational integrity of the dam, reducing the risk of incidents and/or accidents, so that its purpose is achieved and, jointly, preserving life and health, property, and the environment (ANA, 2021). For the Federal Emergency Management Agency (FEMA), the definition of dam safety is "the art and science of ensuring the integrity and viability of dams so that they do not present unacceptable risks to the public, property, and the environment" (FEMA, 2004; WISHART et al., 2020).

In Brazil, the theme is addressed, fundamentally, through Federal Law No. 12,334, of September 20, 2010, which established the National Dam Safety Policy (PNSB). In 2020, the PNSB underwent changes through Federal Law No. 14,066, of September 30, 2020. The Policy brought advances to the area and established the figure of the entrepreneur, characterizing him as the individual or legal entity responsible for the dam and its safety (BRASIL, 2010; BRAZIL, 2020).

Thus, one of the most important definitions contained in the PNSB was related to the responsibilities of the entrepreneur on the safety of the dams, as well as those related to the controlling bodies. Before that, it was not defined who was responsible for it, with clear disarticulation of the public power and environmental agencies dealing in isolation with accidents (ANA, 2013). Regarding the responsibilities of the entrepreneur, twenty-two competencies were defined, of which the following stand out: providing the necessary resources to ensure the safety of the dam; provide for the preparation and updating of the Dam Safety Plan (PSB); and perform Regular (ISR) and Special (ISE) Safety Inspections.

Given the importance of the theme of dam safety and the various responsibilities established by the PNSB, it is necessary to define the order of priorities of the dams in which the actions will be performed by the entrepreneurs, assisting in their decision-making processes. In this sense, several authors in the literature have proposed methodologies aimed at contributing to the management of dam safety.

Zuffo (2005) proposed the so-called Dam Safety Index (ISB), which consists of a methodology that weights criteria related to the evaluation of dam safety, resulting in a final grade that characterizes the condition of the enterprise in terms of safety, ranging from the unsatisfactory level to the good level. For this purpose, the author proposed eighteen criteria related to risk potential, performance, and environmental factors. Still, the ISB serves as a reference for the evaluation of dam safety, not having as its main objective to aid in decision making.

Aguiar (2014) proposed changes in the ISB, adding criteria and reducing subjectivity in the use of the method. To this end, 29 criteria were chosen, based on the Brazilian legislation on dam safety, on the work of Zuffo (2005) and on the bibliography regarding the accidents that occurred. The work developed by the author did not cover the final calculation of the ISB, because it is necessary to develop the value functions for each criterion, and it recommends future studies on it.

Salloum & Alrhih (2019) proposed a structure based on the process of analytical hierarchy, with the main objective of providing a relative classification of dams, with the intention of recovering them or even conducting more detailed evaluations, in order to assist in priority decisions. The proposed structure aggregated quantitative and qualitative criteria related to dam safety, operational safety, risk potential, regulatory requirements, and commercial value.

The National Integration Ministry developed the Strategic Action Plan for the Rehabilitation of Union Dams (PLANERB), with the purpose of rehabilitating the Union's dams, whose entrepreneurs are the National Department of Works Against Droughts (DNOCS) and the Development Company of the São Francisco and Parnaíba Valleys (CODEVASF), or the defunct National Department of Sanitation Works (DNOS) (MI, 2018; From Vito et. al., 2019).

In order to elaborate the strategic plan of actions, with definition of priorities, a methodology was developed based on the classification of dams according to the Risk Category (CRI) and Associated Potential Damage (DPA), which is one of the instruments of the PNSB and is regulated by CNRH Resolution No. 143/2012 (CNRH, 2012). From discussions and ad hoc workshops with experts, changes and additions of other methodologies were done, aiming to obtain a better classification of risk and, consequently, of priorities of actions and investments, from the point of view of urgency (De Vito et. al., 2019).

According to Wishart et al. (2020), in view of the restricted budgets, financial planning is paramount, associated with tools to assist in the prioritization of dam safety measures and resources. Still according to the same author, financial resources for dam safety can come from two basic sources of sustainable revenue: taxes, through government budget allocations; or user payment system fees. Commonly, the combination of both is the one that most occurs. However, the total attendance of the necessary actions is hampered by the low collection rates, in addition to the competition with other demands.

In Pernambuco, the Pernambuco's Sanitary Company (COMPESA) and the extinct Secretariat of Infrastructure and Water Resources (SEINFRA), currently the Secretariat of Water Resources and Sanitation (SRHS), stand out as the main entrepreneurs at the state level. Both are important from the point of view of the number of dams under their responsibility, and from the storage capacity of their reservoirs (PRADO, 2022). Considering that the quantities of dams presented in this work refer to those in force in 2022, it was decided to maintain the use of the SEINFRA nomenclature.

Thus, the objective of this work is to apply the PLANERB methodology in the two main state entrepreneurs of Pernambuco, namely COMPESA and SEINFRA, to build an order of priorities to assist in the management and decision-making regarding the safety of their dams. In addition, a proposal for financial sizing for the agencies will also be conducted.

## 2. Methodology

### 2.1. Classification with the purpose of dam safety management

In the methodology developed for PLANERB, there is the so-called Risk Index (IR), which is defined by the product between the modified CRI and DPA (Equation 1). The IR reflects the real danger that the dam poses to the community, including the situations observed during technical inspections.

$$IR = CRI^* \times DPA^* \quad (1)$$

Where, IR – Risk Index; CRI\* – Modified Risk Category; DPA\* - Modified Associated Potential Damage.

The calculations of the CRI\* and DPA\* are similar to those of CNRH Resolution No. 143/2012, with the modifications developed and inserted by the PLANERB. Thus, they are characterized by being sums of criteria, in which the scores are assigned with the aid of tables.

Next are the sums for each variable, as well as a summary of the IR calculation (Figure 1). The tables do not appear in this study due to their great extension, however they can be seen in the work of De Vito et. (2019).

The CRI\* is calculated by the sum presented in Equation 2.

$$CRI^* = CT^* + EC^* + PS^* \quad (2)$$

Where, CT\* – Modified Technical Characteristics; ES\* – Modified Conservation Status; PS\* – Modified Security Plan.

The calculations of CT\*, ES\* and PS\*, in general, are summarized in sums of scores attributed to the criteria, which are evaluated from the characteristics and conditions of the dams, as well as the calculation of DPA\*, which also corresponds to a sum, which can be seen in Figure 1.

The necessary information for the application of the PLANERB methodology was obtained through the reports of the ISRs and ISEs, the PSBs and the recovery projects made available by the entrepreneurs. It is also pointed out that if the information was not found in the cited documents, it was considered the worst scenario for the criterion in question.

For the classification of the DPA\*, the flood spots of the dams, made available by APAC were also consulted. For the structures that do not have this information, an estimate was done using Google Earth, analyzing the proximity to municipalities. Thus, for dams located within or remarkably close to the city,  $b^* = 30$  and  $d = 8$  were considered. For the inverse situation, with the dams far from the cities,  $b^* = 15$  and  $d = 4$  were considered.

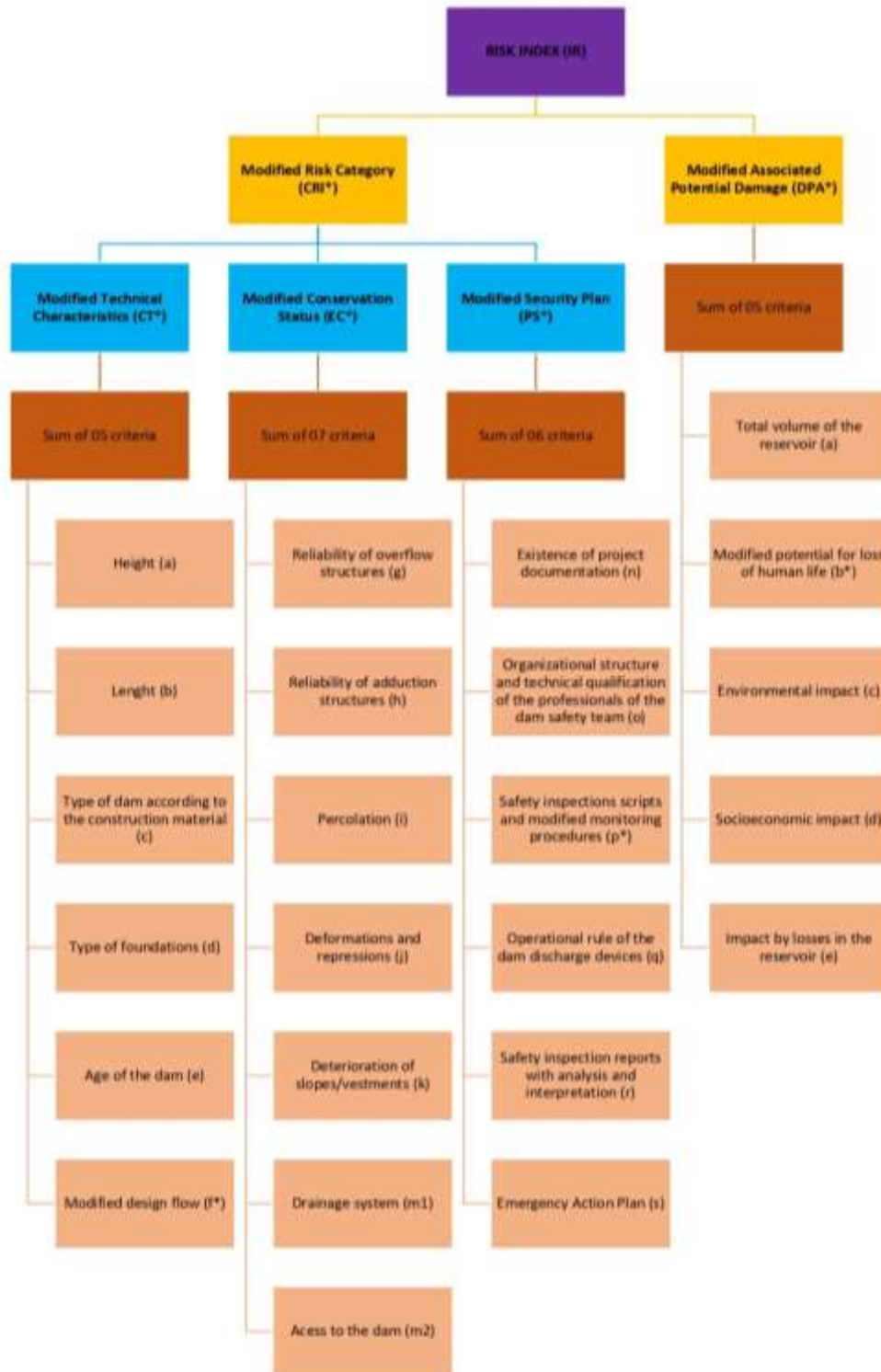


Figure 1 – IR calculation scheme.  
 Source: Adapted from De Vito et. al. (2019).

## 2.2. Financial sizing proposal

From the order of priorities obtained after the application of the previous stage, the planning of actions to comply with the legislation was conducted. Horizons of action were established, respecting a maximum financial ceiling. Both the time interval and the maximum monetary value were defined with each entrepreneur, so that they best suited the situation of each one.

The actions considered in the planning were:

- Realization of ISRs;
- Elaboration of PSB and PAE;
- Elaboration of recovery projects;
- Performing maintenance.

The stipulated financial amounts will be based on bids and/or contracts that the entrepreneurs have already made. Or, from pricing from third parties or those contained in reference documents in the literature.

## 3. Results and discussions

### 3.1. Classification for dam safety management purposes

As limitations to this stage, there is the absence of flood spots for all dams, and the estimate described above was made; and access to technical documentation of the structures, with ISR reports being the main source of data used in this stage.

It should be noted that, due to the lack of technical documentation for most dams, the worst scores were assigned to many of the criteria. On the other hand, for the few dams that have a technical collection, the effect on classification is visible, with such structures occupying lower positions in the order of priorities.

Another point that should be highlighted concerns the influence of the DPA\* classification, with regard to criterion b\*, which is related to the potential for loss of human life. The existence of people permanently occupying the affected area downstream significantly increases the IR found for the dam, and in view of the absence of technical documentation, directly influences the order of priorities.

#### 3.1.1. COMPESA

For COMPESA, 132 dams under its responsibility were considered, according to the number of structures that were inspected between 2019 and 2021, whose IR and classification are presented in Table 1. The table is not complete in this study due to its great extension; however, it can be visualized in Prado (2022).

Firstly, there is the Pirapama dam, one of the most important for the water supply of the Metropolitan Region of Recife. Next, there are four more dams of great importance and located near urban centers, with their respective flood spots implying great potential for loss of human life (Table 1).

The Cipó, Jaime Nejam, Lagoa do Barro, Gurjaú, Barriguda, Jucati, Cachoeira II and Pindoba dams are among the most worrisome in the State, according to RSB 2021 (ANA, 2022). In the present study, the dams were classified as 10th, 54th, 36th, 21st, 99th, 50th, 12th and 23rd, respectively, with worst-case criteria being adopted. The results indicated reflect the different methodologies applied. In RSB 2021, the classification is based on criteria defined by the state supervisory body, namely: the level of Global Danger of the Dam (NPGD) defined as Emergency; the analysis of the ISR/ISE presented to APAC, with priority for dams with NPGD defined as attention, with greater volume and more relevant anomalies; as well as other dams with more relevant anomalies (ANA, 2021). While the methodology of this work addresses several other criteria.

Still in the RSB 2021, other entrepreneurial entities are mentioned for some of the structures (ANA, 2022). These divergences exemplify the gaps that still exist for the definition of the real entrepreneur of the dams, whether it is the agency that built it or the one that operates.

*Table 1 – Classification for management purposes of COMPESA dams.*

<b>Classification</b>	<b>Dam</b>	<b>IR</b>
1°	Pirapama	6222
2°	Tapacurá	6138
3°	Jangadinha	6077
4°	Duas Unas	5978
5°	Taquara	5760
6°	Severino Guerra (Bitury)	5439
7°	Goitá	5246
8°	Pão de Açúcar	5243
9°	São José I	5232
10°	Cipó	5184
...	...	...
128°	Piedade	830
129°	Macaparana	728
130°	Plaina (Riacho Brasileiro)	720
131°	Carau	700
132°	Mocambo	672

*Source: Authors (2023).*

### 3.1.2. SEINFRA

For SEINFRA, 26 dams under its responsibility were considered, whose IR and classification are presented in Table 2. The importance of the existence of technical documentation and monitoring is verified for the Serro Azul dam, which is the sixth largest reservoir in Pernambuco. Analyzing the flood spot in case of rupture, the potential for loss of human life presents the highest score, with  $b^* = 40$ . Despite this, due to the two reasons initially mentioned, the dam occupies the 24th position.

In the RSB 2021, the Senador Nilo Coelho and Poço Grande dams, located in the municipalities of Terra Nova and Serrita, respectively, are among the fourteen that most concern the state of Pernambuco. Both have anomalies in their structures, and, in addition, Poço Grande is an unfinished dam (ANA, 2022). It is pointed out that the Senador Nilo Coelho dam has been classified as global danger level in emergency since 2020, as verified in the ISR 2020 and 2021 reports. As pointed out for COMPESA dams, the methodology used to list these dams was defined by the state controlling agency, differing from that applied in the present study. Nevertheless, the two structures mentioned are among the top 15 in the order of priority, occupying the 7th and 11th positions, respectively (Table 2).

*Table 2 – Classification for management purposes of SEINFRA dams.*

<b>Classification</b>	<b>Dam</b>	<b>IR</b>
1°	Jazigo	4312
2°	Manopla	4094
3°	Chapéu	3900
4°	Chinelo	3542
5°	São José II	3528
6°	Borborema	3486
7°	Senador Nilo Coelho	3185
8°	Serrinha dos Carlos	2592
9°	Inhumas	2550
10°	Mãe D'água	2484

Classification	Dam	IR
...	...	...
22°	Poço Grande II	1917
23°	Ipanema I	1824
24°	Serro Azul	1792
25°	Cajarana	1722
26°	Ingazeira	1386

Source: Authors (2023).

### 3.2. Financial sizing proposal

Based on the order of priorities obtained after the application of the previous stage, a proposal for planning actions to comply with the legislation was established. To comply with the National Policy, many actions need to be conducted and, on the other hand, there are technical and economic limitations to the two entrepreneurs studied. For this work, the elaboration of the PSB and recovery projects or "As Is", the performing of the ISRs and the performing of maintenance were addressed.

Thus, it was sought to allude to the process used to frame water resources, from the axes "The river we have", "The river we want" and "The river we can have". In this case, it was considered "The dam safety scenario we have", "The dam safety scenario we want to have" and "The dam safety scenario we can have".

In the first scenario we have the current situation, where most dams do not have technical collection, either from the preliminary project or as a built project; do not have PSB; and do not undergo maintenance, in need of recovery. In the second scenario we have the ideal situation, in which we would have technical and financial availability to elaborate "As Is" projects, elaborate the PSB, perform maintenance on all dams, among other activities encompassed in the management of the safety of these structures. And in the third scenario, there is the prospect of a future situation, that considers the existing limitations.

To this end, it was established that, within one year, the ISRs would be carried out for all the dams of the entrepreneurs, complying with what is determined by the Resolutions of the federal and state controlling agencies, and the PSBs, PAEs and recovery projects or "As Is" would be elaborated for a certain percentage of the dams under the responsibility of the entrepreneur. In addition, maintenance for these structures would be considered.

The horizon of action considered was of 05 years and each year the number of dams subject of the actions would increase according to the percentage rate defined for each entrepreneur. For COMPESA a number of 5% will be considered and for SEINFRA of 10%. The percentages chosen are based on the number of dams of each entrepreneur, justifying the difference between the two.

Financial values were sought in bids and/or contracts of the entrepreneurs themselves, finding recent values, since the contracts were finalized between the second half of 2021 and the second half of 2022 or are still in execution. Only two recovery contracts date back to 2019. In addition to these, values presented in the PLANERB were used, as they are considered reference values for the planning proposed.

For the preparation of the Dam Safety Plan, the average value of R\$ 339,691.51 will be considered, obtained through the values presented in Table 3. It is pointed out that the values obtained in the contracts of SEINFRA/PE cover the preparation of the PSB and may also cover the PAE, ISE and "As Is" project, varying in each case. For the values obtained in the PLANERB documents, it was not possible to distinguish the scope covered, that is, whether it involves the elaboration of the PAE or even the "As Is". Thus, it was considered that PSB and EAP are covered, but not the "As Is".

Table 3 – Values for PSB elaboration.

Entity	Value
SEINFRA/PE	R\$ 179.431,00
SEINFRA/PE	R\$ 371.156,81
SEINFRA/PE	R\$ 342.662,77
SEINFRA/PE	R\$ 305.225,00
PLANERB - DNOCS	R\$ 497.482,05

Entity	Value
PLANERB - CODEVASF	R\$ 227.475,47
PLANERB - DNOS	R\$ 454.407,48
Average value:	R\$ 339.691,51

*Source: Authors (2023).*

Still on the elaboration of the PSB, it was estimated that the value involves the elaboration of the PAE. However, it is important to note that in addition to the existence of the document, it is also necessary for the PAE to be implemented in the field, including the implementation of the alert system and training with communities affected by a possible emergency situation. This action is of paramount importance, so that the Plan is not only theoretical, but that, in fact, it can be executed in practice. Thus, it is pointed out that the cost of implementation is not included in the value used in this work.

For the preparation of the recovery project or the "As Is" project, the same value was considered, based on the justification that, in SEINFRA bids, the recovery project was used as the "As Is" project. Thus, the mean value of R\$ 278,916.61 was considered, obtained through the values presented in Table 4. The values obtained from COMPESA refer to the so-called "requalification projects", which cover six activities, among them the recovery project. Thus, the total value divided by the number of planned actions was considered.

*Table 4 – Values for preparation of recovery Project or “As Is”.*

Entity	Value
SEINFRA/PE	R\$ 461.704,10
SEINFRA/PE	R\$ 382.111,75
SEINFRA/PE	R\$ 465.059,10
SEINFRA/PE	R\$ 293.942,44
SEINFRA/PE	R\$ 291.956,65
COMPESA	R\$ 75.833,20
COMPESA	R\$ 244.217,00
COMPESA	R\$ 158.250,00
COMPESA	R\$ 256.666,67
COMPESA	R\$ 159.425,15
Average value:	R\$ 278.916,61

*Source: Authors (2023).*

For the maintenance values, we sought to obtain an estimate of the value per dam, whose value was R\$ 54,249.48, which was obtained from the data contained in the PLANERB documents (Table 5). As stated in the PLANERB Final Report, this value refers to maintenance, surveillance, and annual auscultation, having received the nomenclature MANT 1 (MI, 2018). It is pointed out that the dams of the three agencies covered by the PLANERB have, in their majority, considerable size larger than those of the dams of COMPESA and SEINFRA. Thus, the value presented represents an average.

*Table 5 – Values for maintenance by dam.*

Entity	Value
PLANERB - DNOCS	R\$ 81.871,66
PLANERB - CODEVASF	R\$ 30.868,84
PLANERB - DNOS	R\$ 50.007,94
Valor médio:	R\$ 54.249,48

*Source: Authors (2023).*



Finally, to estimate the value involved in the realization of the ISR, the following considerations were made:

- 01 dam inspected per trip;
- Travel lasting 02 days;
- 02 technical professionals;
- 01 driver;
- Daily value – technical professional: R\$ 54,00;
- Daily value – driver: R\$ 80,00;
- Average distance (round trip): 824 km;
- Value of the liter of gasoline: R\$ 5.73 (Jul/2023);
- Toro – Consumption: 11.2 km/L.

The scenario described above results in the value involved in conducting the ISR for just one dam. In practice, it is known that travel involves more than one structure. However, this approximation was done to obtain a "unit value". It is pointed out that the average distance considered is equivalent to the round-trip distance between the municipalities of Recife and Serra Talhada. The city was chosen because it is located visually in the middle of the map of Pernambuco. Based on these considerations, the value of R\$ 612,02 was obtained. It is noteworthy that this value is only operational, without considering the subsequent costs for the preparation of the reports.

### 3.2.1. COMPESA

For COMPESA, 5% of the dams are equivalent to 6.65 structures, having been considered as 07 dams per year. Thus, we have the proposal for action planning presented in Table 6, covering the activities of elaboration of PSB and recovery projects or "As Is". The maximum value obtained was about R\$ 3,300,000.00, in the fourth and fifth year, and at the end of the period considered, 35 dams will have the two documents mentioned, corresponding to 27% of the total.

The dams that do not present values in one of the columns are those whose documentation is already elaborated or in preparation. Although this amount is significant for COMPESA, it was decided not to add other dams on the order of priorities, in order to maintain the annual rate and not to raise the budget too much in the initial years. In addition, most of the PSBs were prepared by the agency's own dam safety team and it may be necessary to review them, at the discretion of COMPESA, and such activity may be included in the gaps mentioned.

*Table 6 – Planning proposal for PSB and recovery projects or “As Is” for COMPESA.*

<b>FIRST YEAR</b>		
<b>Dam</b>	<b>PSB</b>	<b>Recovery Project or “As Is”</b>
Pirapama	-	-
Tapacurá	-	-
Jangadinha	-	R\$ 278.916,61
Duas Unas	-	R\$ 278.916,61
Taquara	-	R\$ 278.916,61
Severino Guerra (Bitury)	R\$ 339.691,51	R\$ 278.916,61
Goitá	-	-
Partial value:	R\$ 339.691,51	R\$ 1.115.666,42
Total value:	R\$ 1.455.357,93	
<b>SECOND YEAR</b>		
<b>Dam</b>	<b>PSB</b>	<b>Recovery Project or “As Is”</b>
Pão de Açúcar	R\$ 339.691,51	R\$ 278.916,61
São José I	-	R\$ 278.916,61
Cipó	R\$ 339.691,51	R\$ 278.916,61
Condadinho	R\$ 339.691,51	R\$ 278.916,61
Cachoeira II	R\$ 339.691,51	R\$ 278.916,61

Botafogo	-	R\$ 278.916,61
Zamba	R\$ 339.691,51	R\$ 278.916,61
Partial value:	R\$ 1.698.457,56	R\$ 836.749,82
Total value:	R\$ 2.535.207,37	
<b>THIRD YEAR</b>		
<b>Dam</b>	<b>PSB</b>	<b>Recovery Project or "As Is"</b>
do Prata	-	R\$ 278.916,61
Marrecas	R\$ 339.691,51	R\$ 278.916,61
Cursaf	-	R\$ 278.916,61
Tiúma	-	R\$ 278.916,61
Cajueiro	R\$ 339.691,51	R\$ 278.916,61
Machado	-	R\$ 278.916,61
Gurjaú	-	R\$ 278.916,61
Partial value:	R\$ 679.383,02	R\$ 1.952.416,24
Total value:	R\$ 2.631.799,26	
<b>FOURTH YEAR</b>		
<b>Dam</b>	<b>PSB</b>	<b>Recovery Project or "As Is"</b>
Vertentinha (Açude Cruzeiro)	R\$ 339.691,51	R\$ 278.916,61
Pindoba	R\$ 339.691,51	R\$ 278.916,61
Queimadas	R\$ 339.691,51	R\$ 278.916,61
Pedro Moura Junior	-	R\$ 278.916,61
Comunaty	R\$ 339.691,51	R\$ 278.916,61
Poço Fundo	-	R\$ 278.916,61
Matriz Da Luz (Queira Deus)	-	R\$ 278.916,61
Partial value:	R\$ 1.358.766,05	R\$ 1.952.416,24
Total value:	R\$ 3.311.182,28	
<b>FIFTH YEAR</b>		
<b>Dam</b>	<b>PSB</b>	<b>Recovery Project or "As Is"</b>
Utinga	-	R\$ 278.916,61
Duas Unas Velha	R\$ 339.691,51	R\$ 278.916,61
Mororó	R\$ 339.691,51	R\$ 278.916,61
Besouro	R\$ 339.691,51	R\$ 278.916,61
Gercino Pontes (Tabocas)	-	R\$ 278.916,61
São Sebastião	-	R\$ 278.916,61
Tatuaçu	R\$ 339.691,51	R\$ 278.916,61
Partial value:	R\$ 1.358.766,05	R\$ 1.952.416,24
Total value:	R\$ 3.311.182,28	

*Source: Authors (2023).*

For activities related to maintenance, seven dams were added each year, following the 5% rate established for the agency. The monthly values start around R\$ 380,000.00 and reach approximately R\$ 2,000,000.00 at the end of the five years (Table 7). The proposal presented does not specify the priority of the dams, because the entrepreneur will be able to adjust to its needs on a daily basis.

For example, for the first year one can start with the first seven dams of the order of priorities. Already in the second year, one can keep the initial seven and add another seven, and so on in later years. Another option is to start with the seven

dams already mentioned, but in the second year, perform maintenance on fourteen other structures different from those of the first year. Thus, maintenance would be conducted on more dams, in less time, and at the end of the five years considered, 105 dams would have undergone maintenance, reaching 80% of the total of 132 structures.

*Table 7 – Financial proposal for maintenance-related activities for COMPESA.*

<b>FIRST YEAR</b>		
<b>Dam</b>	<b>Unit value</b>	<b>Total value</b>
07	R\$ 54.249,48	R\$ 379.746,35
<b>SECOND YEAR</b>		
<b>Dam</b>	<b>Unit value</b>	<b>Total value</b>
14	R\$ 54.249,48	R\$ 759.492,69
<b>TJIRD YEAR</b>		
<b>Dam</b>	<b>Unit value</b>	<b>Total value</b>
21	R\$ 54.249,48	R\$ 1.139.239,04
<b>FOURTH YEAR</b>		
<b>Dam</b>	<b>Unit value</b>	<b>Total value</b>
28	R\$ 54.249,48	R\$ 1.518.985,38
<b>FIFTH YEAR</b>		
<b>Dam</b>	<b>Unit value</b>	<b>Total value</b>
35	R\$ 54.249,48	R\$ 1.898.731,73

*Source: Authors (2023).*

As for performing the ISRs, the annual total is R\$ 80,786.64, considering the inspections in all the dams of the agency. In 2021, COMPESA conducted the largest number of ISRs identified, with 85 inspections performed, which represent 64% of the proposed target. It is pointed out that, due to the regional distribution of COMPESA's headquarters throughout the state territory, the cost of doing the ISRs may decrease, in view of shorter distances and reduction of the amounts paid in the daily rates of the professionals.

Thus, considering the three proposed actions, we have that the annual budgets presented in Table 8, whose maximum value reaches, approximately, R\$ 5,300,000.00. As expected, the values tend to grow over the years and the increase of the group of dams' subjects of the activities.

*Table 8 – Summary of the financial proposal for COMPESA.*

<b>FIRST YEAR</b>	
<b>Actions</b>	<b>Value</b>
PSBs and recovery projects / "As Is"	R\$ 1.455.357,93
Maintenance	R\$ 379.746,35
ISR	R\$ 80.786,64
Value:	R\$ 1.915.890,92
<b>SECOND YEAR</b>	
<b>Actions</b>	<b>Value</b>
PSBs and recovery projects / "As Is"	R\$ 2.535.207,37
Maintenance	R\$ 759.492,69
ISR	R\$ 80.786,64
Value:	R\$ 3.375.486,70
<b>THIRD YEAR</b>	
<b>Actions</b>	<b>Value</b>
PSBs and recovery projects / "As Is"	R\$ 2.631.799,26

Maintenance	R\$ 1.139.239,04
ISR	R\$ 80.786,64
Value:	R\$ 3.851.824,94
<b>FOURTH YEAR</b>	
<b>Actions</b>	<b>Value</b>
PSBs and recovery projects / "As Is"	R\$ 3.311.182,28
Maintenance	R\$ 1.518.985,38
ISR	R\$ 80.786,64
Value:	R\$ 4.910.954,30
<b>FIFTH YEAR</b>	
<b>Actions</b>	<b>Value</b>
PSBs and recovery projects / "As Is"	R\$ 3.311.182,28
Maintenance	R\$ 1.898.731,73
ISR	R\$ 80.786,64
Value:	R\$ 5.290.700,65
Total value (05 years):	R\$ 19.344.857,51

*Source: Authors (2023).*

### 3.2.2. SEINFRA

For SEINFRA, 10% of the dams are equivalent to 2.6 structures, considered as 03 dams per year. Thus, we have the proposal for action planning presented in Table 9, covering the activities of PSB and recovery projects or "As Is". At the end of the five years, 15 dams would have PSB and project, representing 58% of the total. The dams that do not present values for recovery project or "As Is" are those that the entrepreneur already has contracts in progress or that the projects have already been prepared.

*Table 9 – Planning proposal for PSB and recovery projects or "As Is" for SEINFRA.*

<b>FIRST YEAR</b>		
<b>Dam</b>	<b>PSB</b>	<b>Recovery Project or "As Is"</b>
Jazigo	R\$ 339.691,51	-
Manopla	R\$ 339.691,51	R\$ 278.916,61
Chapéu	R\$ 339.691,51	R\$ 278.916,61
Partial value:	R\$ 1.019.074,53	R\$ 557.833,21
Total value:	R\$ 1.576.907,74	
<b>SECOND YEAR</b>		
<b>Dam</b>	<b>PSB</b>	<b>Recovery Project or "As Is"</b>
Chinelo	R\$ 339.691,51	R\$ 278.916,61
São José II	R\$ 339.691,51	R\$ 278.916,61
Borborema	R\$ 339.691,51	R\$ 278.916,61
Partial value:	R\$ 1.019.074,53	R\$ 836.749,82
Total value:	R\$ 1.855.824,35	
<b>THIRD YEAR</b>		
<b>Dam</b>	<b>PSB</b>	<b>Recovery Project or "As Is"</b>
Senador Nilo Coelho	R\$ 339.691,51	-
Serrinha dos Carlos	R\$ 339.691,51	R\$ 278.916,61
Inhumas	R\$ 339.691,51	-

Partial value:	R\$ 1.019.074,53	R\$ 278.916,61
Total value:	R\$ 1.297.991,14	
<b>FOURTH YEAR</b>		
<b>Dam</b>	<b>PSB</b>	<b>Recovery Project or “As Is”</b>
Mãe D'Água	R\$ 339.691,51	R\$ 278.916,61
Poço Grande	R\$ 339.691,51	-
Açude da Nação	R\$ 339.691,51	R\$ 278.916,61
Partial value:	R\$ 1.019.074,53	R\$ 557.833,21
Total value:	R\$ 1.576.907,74	
<b>FIFTH YEAR</b>		
<b>Dam</b>	<b>PSB</b>	<b>Recovery Project or “As Is”</b>
Tabira	R\$ 339.691,51	R\$ 278.916,61
Oitis	R\$ 339.691,51	R\$ 278.916,61
Laje do Gato	R\$ 339.691,51	R\$ 278.916,61
Partial value:	R\$ 1.019.074,53	R\$ 836.749,82
Total value:	R\$ 1.855.824,35	

*Source: Authors (2023).*

For the activities related to maintenance, each year three dams were added, following the rate of 10% established for the agency. The monthly values start around R\$ 160,000.00 and reach approximately R\$ 810,000.00 at the end of the five years (Table 10). As for COMPESA, the proposal presented to SEINFRA does not specify the priority of the dams, because the entrepreneur can adjust to its needs on a daily basis.

*Table 10 – Financial proposal for maintenance-related activities for SEINFRA.*

<b>FIRST YEAR</b>		
<b>Dam</b>	<b>Unit value</b>	<b>Total value</b>
03	R\$ 54.249,48	R\$ 162.748,43
<b>SECOND YEAR</b>		
<b>Dam</b>	<b>Unit value</b>	<b>Total value</b>
06	R\$ 54.249,48	R\$ 325.496,87
<b>THIRD YEAR</b>		
<b>Dam</b>	<b>Unit value</b>	<b>Total value</b>
09	R\$ 54.249,48	R\$ 488.245,30
<b>FOURTH YEAR</b>		
<b>Dam</b>	<b>Unit value</b>	<b>Total value</b>
12	R\$ 54.249,48	R\$ 650.993,74
<b>FIFTH YEAR</b>		
<b>Dam</b>	<b>Unit value</b>	<b>Total value</b>
15	R\$ 54.249,48	R\$ 813.742,17

*Source: Authors (2023).*

As for performing the ISRs, the annual total is R\$ 15,912.52, considering the inspections in all the dams of the agency. In 2021, SEINFRA conducted the ISRs of 21 structures, reaching 81% of the proposed target.

Thus, considering the three proposed actions, the annual budgets presented in Table 11, whose maximum value does not exceed R\$ 3,000,000.00. As expected, the values tend to grow over the years and the increase of the group of dams' subjects of the activities.

Table 11 – Summary of the financial proposal for SEINFRA.

<b>FIRST YEAR</b>	
<b>Actions</b>	<b>Value</b>
PSBs e recovery projects / “As Is”	R\$ 1.576.907,74
Maintenance	R\$ 162.748,43
ISR	R\$ 15.912,52
Value:	R\$ 1.755.568,69
<b>SECOND YEAR</b>	
<b>Actions</b>	<b>Value</b>
PSBs e recovery projects / “As Is”	R\$ 1.855.824,35
Maintenance	R\$ 325.496,87
ISR	R\$ 15.912,52
Value:	R\$ 2.197.233,74
<b>THIRD YEAR</b>	
<b>Actions</b>	<b>Value</b>
PSBs e recovery projects / “As Is”	R\$ 1.297.991,14
Maintenance	R\$ 488.245,30
ISR	R\$ 15.912,52
Value:	R\$ 1.802.148,96
<b>FOURTH YEAR</b>	
<b>Actions</b>	<b>Value</b>
PSBs e recovery projects / “As Is”	R\$ 1.576.907,74
Maintenance	R\$ 650.993,74
ISR	R\$ 15.912,52
Value:	R\$ 2.243.814,00
<b>FIFTH YEAR</b>	
<b>Actions</b>	<b>Value</b>
PSBs e recovery projects / “As Is”	R\$ 1.855.824,35
Maintenance	R\$ 813.742,17
ISR	R\$ 15.912,52
Value:	R\$ 2.685.479,04
Total value (05 years):	R\$ 10.684.244,43

Source: Authors (2023).

### 3.2.3. Possible sources of resources

The values presented in the proposals for both entrepreneurs are significant, exceeding R\$10,000,000.00 at the end of the period considered. Obtaining these resources is a challenge. SEINFRA does not have any revenue from the dams under its responsibility, so that the origin of the resources for dam safety actions is, in general, from the State budget itself. And COMPESA, although it generates revenue from the operation of the dams, also has other demands and costs involved that may compromise the budgetary allocation for dam safety actions. In addition, the service fee charged to users does not include a portion intended for the maintenance of the dams.

One of the alternatives for the origin of resources is financing from international organizations. The World Bank, for example, has financed several projects in the water resources sector, at state and federal levels, involving dams, such as the federal project PROÁGUA, which had technical assistance from the agency directed at the planning, construction and maintenance of dams, as well as other activities, such as the preparation of emergency preparedness plans. In 2012, after

ANA was commissioned as the country's dam safety regulator, there was a partnership with the World Bank through the provision of analytical and advisory services in dam safety (ANA, 2012).

Another possibility is the State Water Resources Fund (FEHIDRO), whose resources are intended for the financial support necessary to comply with the State Water Resources Policy and the actions of the components of the Integrated Water Resources Management System (SIGRH). The actions related to the safety of dams are part of the management of water resources since they have a direct impact on the planning of the water uses of a hydrographic basin. Menescal (2009) points out that the management of water resources is not complete without the management of dam safety.

The plans for the application of resources from SEINFRA's FEHIDRO were analyzed, in the period from 2019 to 2022, and the existence of the planning of actions aimed at dam safety was verified. Since 2019 there have been actions related to projects, recovery, and maintenance of dams, with the inclusion of consulting in 2020 and preparation of PSBs in 2022. These resources are a possibility for SEINFRA, as it is the Managing Body of the State's Water Resources.

Still, another source of funds would come from the collection of water, which, although not currently implemented in Pernambuco, is an alternative that can be implemented. In Paraíba, for example, there is the Dam Maintenance Program, created in 2019 by the Executive Agency for Water Management (AESAs), whose resources used to come from FEHIDRO, through the collection of raw water. In the same year of creation, 15 dams were contemplated and in 2020, the estimate was between 20 and 25 structures (AESAs, 2020).

#### 4. Conclusions

The development of studies that address the theme of dam safety is relevant since recent accidents in the country alerted society about the serious consequences that the ruptures of these structures can cause. Linked to this, there is the fact that the PNSB is still considered a recent policy and has undergone new changes in 2020, not being implemented in its entirety.

Thus, the methodology presented in this work, as well as the results obtained, seeks to assist in this implementation process, contributing to the management of dam safety under the responsibility of the two main state public entrepreneurs of Pernambuco, regarding the number of structures framed in the PNSB and the capacity of their reservoirs.

In contrast to the high demand, there are entrepreneurs who suffer from limitations of technical staff and budget. The case of SEINFRA represents a great challenge in this regard since no revenue is obtained from the dams under its responsibility. In practice, almost all of the structures were "inherited" from extinct entities, whose history of design and construction was lost over the years.

In this scenario, the proposition of tools to aid the decision-making of the two entrepreneurs, cooperating for the safety of the dams and, consequently, avoiding possible accidents and their disastrous consequences, presents a character of great importance. The application of the PLANERB methodology enabled the construction of an order of priorities of the structures and, consequently, of proposals for financial and technical planning, which will serve as support to the entities.

It is noted that the non-existence and/or lack of access to technical documents about dams was a limiting factor, with the worst scores being adopted to enable the construction of a first scenario. Aiming for better understanding and daily professional practice, it is suggested that the assessments carried out for this research are reviewed and deepened by entrepreneurs. So that, with a greater degree of knowledge about the operation and possible specificities of dams that are not included in inspection reports, the methodology applied can be even more assertive, directly contributing to the daily practice of dam safety management.

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