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Quantitative Simulation of the Coremas-Mãe D'Água Water System Located in Brazil's Hinterland Using ACQUANET Model

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Abstract. The main objective of this research is to analyze quantitatively the water situation of the Coremas water system considering the last water crisis that began in 2012, located in the hydrographic basin of the rivers Piancó-Piranhas-Açu, using the ACQUANET simulation model. A series of inflows was also constructed using the rainfall-runoff model Soil Moisture Accounting Procedure. Analyzing the results obtained for the simulated time horizon of the two reservoirs, the efficiency of meeting demands in the simulation of scenario 1, which evaluated the two reservoirs individually, some failures were observed in the sectors of human supply, irrigation, industry and pisciculture, where they presented guarantees above 95%. In the simulation of scenario 2, which was considered in the analysis as a single reservoir, both in the rainy and dry periods, all demands related to the system, such as human supply, animal feeding, irrigation, industry and fish farming, had 100% reliability. Therefore, the Coremas system, despite the water crisis experienced, is considered sustainable and can be used to transfer water to other hydrographic basins during the water crisis period.

Keywords. Simulation; Interconnected Reservoirs; Models

Introduction

Water resources are at the center of the most discussed environmental issues today and are present in various areas of knowledge due to their interdisciplinary nature. This concern with water is due to the increase in demand in quantity and quality, causing conflicts among those who enjoy it, especially in regions where the scarcity of these resources is more severe.

Brazil stands out worldwide for having one of the largest water reserves on the planet, but it has suffered from several conflicts over water use. This requires planning and management that can provide a better exploitation of this resource, since the big problem is to be able to meet the demands of the many uses, whether domestic, agricultural, industrial, among others. Besides their irrational use, we still experience the pollution of the springs, which makes the water resources scarce both in quantity and quality. Thus, it is evident the need to reduce the levels of water scarcity by applying innovative technologies that promote the rational use of this valuable resource for society.

In the Northeast, to mitigate the problems related to water scarcity, the most used practice is the construction of dams. In practice, this policy does not work, because of the large investments for the implementation of these works, related to the high costs of expropriation and the relocation of the population to other spaces, not to mention that some watersheds are already at the limit of surface water availability (LIMA, 2004).

In continuous severe years of low precipitation in the semi-arid Northeast, the region still remains in a critical situation in terms of water availability, since the rainfall rates from 2012 to 2018 were not sufficient for the restitution of water stocks, causing a large reduction in the volume of reservoirs, leaving many even to dry up completely (ANA, 2018). The Coremas - Mãe D' Água system, located in the hinterland of Paraíba, is an example of this water situation, where it has been operating well below its capacity due to the few rains in the region.

According to Lima (2004) act nº 9.433 created in 1997, better known as the Waters' Law, constitutes important instruments for the management of water resources, to guarantee a better use, control, and conservation of these resources within a participative and decentralized policy, involving government and society. Furthermore, it plays an important role in the modernization of water management in Brazil, through the National Policy for Water Resources, which aims to guarantee water in quality and quantity for the present society and future generations.

Act nº. 6,308, of the year 1996 in the State of Paraíba, established the Integrated System of Planning and Management of Water Resources (SIGERH) in order to ensure the integrated and rational use of water resources, which in its art. 5 clarifies that this law has as its purpose the application of the State Water Resources Policy, being also responsible for forming, updating and applying the State Water Resources Plan, in agreement with the state and municipal agencies and entities, and organized civil society (AESA, 2019). To ensure the water demand that is of utmost importance for the whole society, it is necessary to know the reality of the reservoirs, starting with an analysis of the proportional balance of water inflows and outflows to be accumulated. In order to cooperate with the planning and management of water resources, we use simulation methods, through integrated models for the analysis of complex systems in water resources. These simulation models can narrow and facilitate the understanding and formulation of the problem, as well as the interpretation of the analysis results, since it provides a very detailed mathematical representation, assisting the decision making of managers (SANTOS, 2011).

Thus, it is possible to idealize scenarios with planned situations, whether in a region's drought or flood period, with the intention of contributing with managers in the most appropriate decision-making for each situation and possible scenarios, preventing erroneous decisions that can bring losses to all stakeholders and the population in general.

Based on this context, we also realize the continuous need for the use of tools that help the decision-making process in management units, such as simulation models, which are of great value for accurate and efficient planning and management of issues involving the multiple uses of water. Thus, it is possible to carry out simulations with different water availability scenarios through models, identifying the ideal water allocation scenario for each type of demand, thus enabling an efficient management of water resources.

Based on the above, the main objective of this study is to quantitatively analyze the water situation of the Coremas - Mãe D' Água system considering the multiple uses of water and the period of water crisis from 2012 to 2018.

Materials and methods

Characterization of the Study Area

The Coremas system, located in the municipality of Coremas-PB, in the interior of the sertão of Paraíba, belongs to the hydrographic basin of the Pianco River. According to LIMA (2004), the reservoirs were built for the following purposes: valley perennialization, flood control, irrigation, fish farming, crop growing in the areas where the waters arrive, water supply for urban populations and power generation, among other uses.

The sub-basin of the Pianco river is located in the southwest of the state of Paraiba, between parallels 6'43'51" and 7'58'15" south and meridians 37'27'41" and 38'42'49" west of Greenwich. It is bordered to the west by the state of Ceara, to the south by the state of Pernambuco, to the north by the Upper and Middle Piranhas sub-basins and to the east by the **Espinharas** River sub-basin, where its average annual temperature is above 24°C and the annual thermal amplitude is less than 40°C. It corresponds to one of the seven sub-basins of the Piranhas River in Paraiba State. (LIMA, 2004).

The Coremas - Mãe D' Água system has a maximum capacity of 1,358,000,000 m^3 of water, but currently operates with only 86,859,933 m^3, that is, it is at 14.9% of its total capacity, according to monitoring data from AESA - Executive Agency for Water Management of the State of Paraiba, (2019). The management of the Coremas - Mãe D'Água system becomes complex since it involves 24 units of reservoirs responsible for supplying several municipalities and six irrigation perimeters.

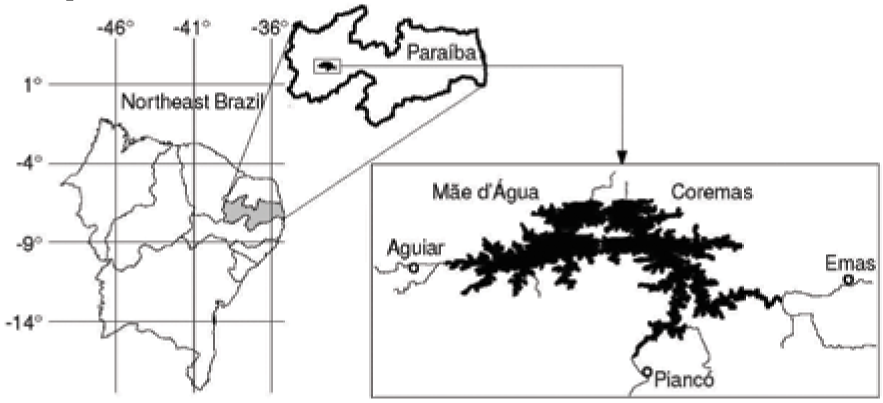

Figure 1. Location of the Coremas and Mãe D'Água reservoirs.
Source: Celeste *et. al* (2009).

The system also serves various downstream uses, such as: energy generation, perennialization of the Piancó River, the water demands of the State of Rio Grande do Norte, supply of the Sweepers Sousa irrigated perimeter, the Coremas/Sabugi feeder system and irrigation demands downstream of the system. In addition, the Coremas - Mãe D' Água system presents a water deficit, since the current demands a higher availability than the current, for this reason it needs a more efficient policy and integrated management of available resources (ANA, 2018).

Simulation Scenario 1 - Individualized Reservoirs

In this scenario the objective was to perform an analysis of the water behavior of the system, considering only the operation in the quota of the infrastructure that separates the reservoirs, that is, in the quota of the sill of the channel connecting the reservoirs.

Simulations were performed using the data resulting from the research, as the calculated flows found by calculation in the SMAP software, after that, inserted in ACQUANET along with the data of each reservoir as maximum, minimum and initial volume, *Quota x Area x Volume*, and the monthly evaporation rate of the reservoir. Soon after, the demands linked to each reservoir were inserted considering the level of priority, 1st - human supply and animal feeding, 2nd - irrigation, 3rd - industry and 4th - fish farming.

Finally, results were generated for a better conception of the water behavior and reservoir withdrawals. It is possible to analyze whether there were failures in some of the periods studied. The Figure 2 shows in more detail the location of the water intake of the Coremas reservoir, as well as the bleeder of the Mãe D' Água reservoir, both located in the city of Coremas/ PB.

Figure 2. Water intake for the Coremas reservoir and Bleeder for Mãe D'Água reservoir. Source: Lima (2004).

Figure 3 illustrates the layout of the system analyzed as two reservoirs without channel communication, which was designed using the tools available in ACQUANET.

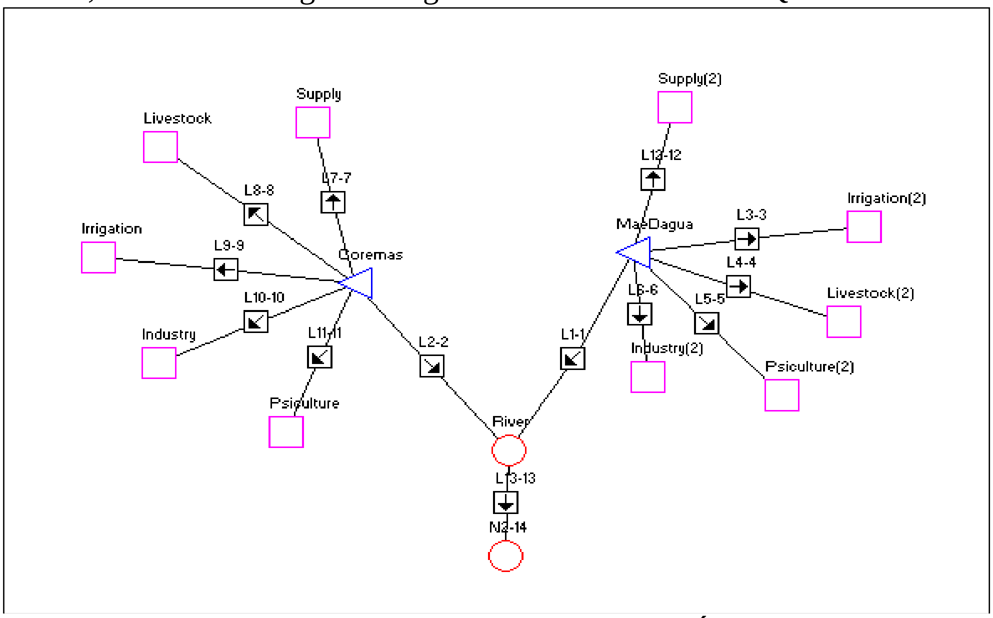

Figure 3. Layout of the Coremas and Mãe D’Água reservoir system in an individualized analysis.

Note: This plot illustrates the water path built through the ACQUANET simulation model and how the dynamics of the reservoirs work, as well as the withdrawals of the different uses from each reservoir separately.

Simulation scenario 2 - The water system as a single reservoir

In this scenario the objective was to perform an analysis of the water behavior of the system considering only the operation in the upper part of the reservoirs, that is, in the elevation of the upper sill of the connecting channel of the reservoirs (elevation equal to 237m).

Simulations were performed using the data resulting from the research, as the calculated flows found by calculation in the SMAP software, after that, inserted in ACQUANET together with the system data as maximum, minimum, and initial volume, and the monthly evaporation rate of the Coremas-Mãe de Água system, as a single reservoir. Soon after, the demands linked to the system were inserted, considering the level of priority, human supply no.1, animal watering nº.1, irrigation nº.2, industry nº.3, and pisciculture nº.4.

Finally, results were generated for a better conception of the water behavior and the withdrawals from the system, being able to analyze if there were failures in its water availability in some of the studied periods.

The Figure 4 shows the lake formed by the Coremas and Mãe de Água reservoirs when they reach a considerable volume of water, exceeding the maximum sill quota of the connecting channel, and also the bridge over the connecting channel between the reservoirs.

Figure 4. Lake formed by the reservoirs and bridge over the connecting Canal. Source: Lima (2004).

Figure 5 below illustrates the layout of the analyzed system of reservoirs connected to the canal, which was drawn using the tools available in ACQUANET. This layout illustrates the water path built through the model and how the dynamics of reservoirs interconnected by a canal work, as well as the multiple-use withdrawals.

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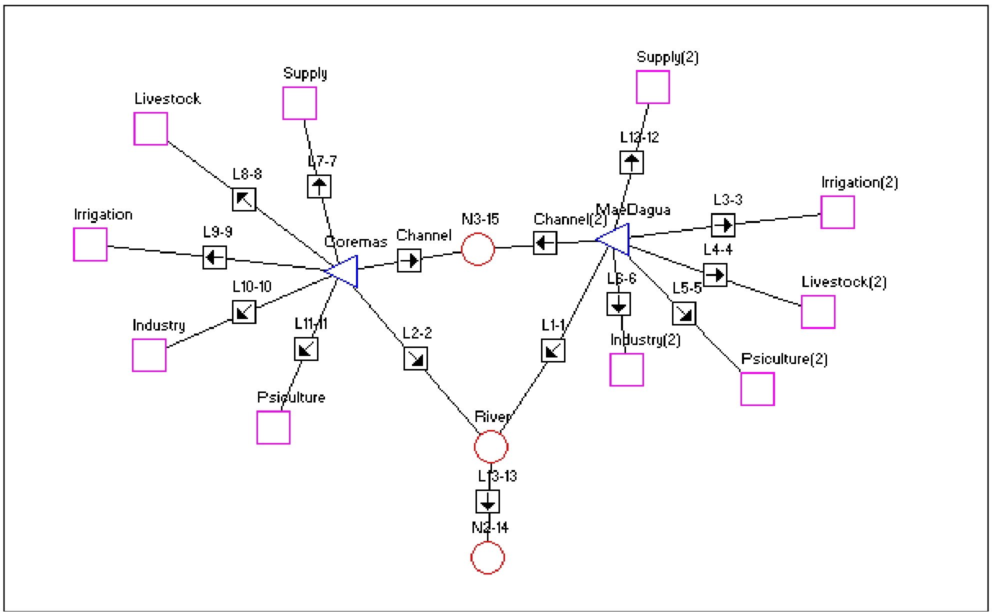

Figure 5. Layout of the water system as a single reservoir.

Input Data

Regarding the monthly natural flow series of the Coremas and Mãe de Água reservoirs in the years 1963 to the, yet to be determined, 2018, they were calculated through SMAP (Soil Moisture Accounting Procedure), a hydrological simulation model of the type of rainfall-flow transformation. To use the simulation, necessary data such as precipitation, evaporation, natural flows, existing demands and their withdrawals, maximum and minimum volumes, target volume, among other factors that influence the dynamics of the reservoirs under study was obtained.

Input data for the SMAP model

The SMAP model, which is based on a deterministic hydrological simulation model of the rainfall-flow transformation type, developed by Lopes et. al. (1982) was used to receive all input data. Alongside, specifically to this study, the SMAP.Net, Windows version (1.0.0.0 of 06/24/2015), available on the LabSid website, was the main model.

To calculate the monthly natural flows for the years 1963 to 2018, through the SMAP model, rainfall data, evapotranspiration data and average natural flows, are regarded as general data of the study area. The "initial data", such as drainage area (Ad), moisture rate (Tu), baseflow (Eb), field capacity and initial Abstraction, in addition to the use of specific parameters for the region in which the study area is located are recorded separately.

The initial data required in SMAP are presented in Table 1 and were used to calculate the inflows necessary for the following analysis of the reservoirs, these inputs being: drainage area (Ad) of the reservoirs, moisture rate (Tu), base flow (Eb), field capacity and initial abstraction (portion of the amount of rainfall produced before the onset of runoff). As shown in Table 1:

Table 1. Geoclimatic data of the Coremas-Mãe D'água system used in the SMAP model.

System[1]	Drainage Area (km²)	Moisture Content (%)	Base flow (m³/s)	Initial Abstraction (mm)	Field Capacity (%)
Coremas-Mãe D' água	9,207.00	19.00	17.00	9.00	40.00

[1] Source: IBGE (2019); PRHBH - Piancó-Piranhas-Açu River (2016).

Among these values, only the initial abstraction remained the default value found in the model. The drainage area of the two reservoirs was found in the IBGE - Brazilian Index of Geography and Statistics (2019). For the other items, the data available in the Water Resources Plan of the Hydrographic Basin of the Piancó-Piranhas-Açu River (2016) were used as reference, and that the others come from the software calibration itself.

The parameters used in the application of the model were also those provided in the Water Resources Plan of the Piancó-Piranhas-Açu River Hydrographic Basin (2016), applied for the period from January 1963 to December 2018. The parameters used were: saturation capacity of the soil (Sat); aquifer recharge coefficient (Crec); runoff generation rate (Pes); water level depletion rate of the underground aquifer (k), these shown in Table 2 below:

Table 2. Soil parameters of the Piancó-Piranhas-Açu River Basin.

System[1]	Period	Parameters			
		Sat (mm)	Pes	Crec	kkt
Coremas-Mãe D' água	January/63 to December/2018	1,284.70	2.514	4.794	20.00

[1] Source: PRHBH - Piancó-Piranhas-Açu River (2016).

These data are necessary to arrive at the final result of the calculated flows from 1983 to 2018, and thus can be inserted in the next analysis, of the ACQUANET model, for the analysis of the scenarios proposed in this research.

Data for the ACQUANET model

ACQUANET is a simulation model in a flow network that initially requires, for its application, the design of the topography of the water system to be studied. As input data, it requires demands and their withdrawal values, natural flow series, *Quota x Area x Volume*, maximum and minimum volumes, target volume, and average monthly evaporation.

The monthly precipitation data used are in millimeter and correspond to the period in which it was desired to obtain the monthly natural flows, i.e., it comprised the period from January 1963 to December 2018. These values were obtained from the ANA website from 1963 to 2007, and from the AESA rainfall monitoring website from 2008 to 2018, in which the data from the Coremas rainfall stations at Coremas Reservoir and Mãe D'Água were verified.

The values of the average monthly evaporations are also in millimeter and were observed in the Coremas and Mãe D'Água reservoirs, arranged in annex b of the National Water Agency's Piancó-Piranhas-Açu Master Plan (ANA, 2017). The high rate of water evaporation, common in arid and/or semi-arid climate regions, is a factor that significantly affects the quantitative aspects of water reservoirs, especially surface reservoirs.

According to the Piancó-Piranhas-Açu Water Resources Plan (2016), the main existing demands in the Coremas and Mãe D'Água reservoirs are essentially the same. These are: human supply, animal feeding, irrigation, industry and pisciculture. The types of demand, their withdrawal values, and the priority for meeting them are shown in Table 3.

Table 3. Withdrawals in m³/s for human supply, livestock, irrigation, industry, and pisciculture in Coremas and Mãe D'Água reservoirs, Paraíba, Brazil.

Reservoirs[1]	Human supply	Livestock	Irrigation	Industry	Pisciculture	Total
Coremas	2.60	0.26	7.18	0.32	0.04	10.42
Mãe D' Água	0.51	0.13	7.77	0.23	0.04	8.70
Level of Priorities	1	1	2	3	4	-

[1] Source: PRHBH - Piancó-Piranhas-Açu River (2016).

The consumption of 4.0 m³/s for the Várzeas de Sousa irrigation project coming from the Mãe D'Água reservoir, through the Redenção Canal, was considered together with the demand for Rio Grande do Norte of 1.5 m³/s, and the consumption of 0.5 m³/s for the Piancó I irrigation project, coming from the Coremas reservoir.

Maximum and minimum volume values are presented according to Table 4. The target volume stipulated for application in the ACQUANET model was chosen as an operation rule, using the entire minimum volume of the reservoir, considering the minimum volume to be the target volume.

Table 5. Volumes of the Coremas and Mãe D'Água reservoirs in the channel integrated system.

Date[1]	Coremas	Mãe D' Água	System
Maximum Volume (hm³)	373.00	283.50	1.358,70
Minimum Volume (hm³)	69.00	130.50	199.50

[1] Source: ANA (2014); PRHBH – Piancó-Piranhas-Açu River (2016).

The natural flow series comprising the period from January 1963 to December 2018, and the values of quota/area/volume of the studied water system are available in Technical Note No. 001/2014 of the National Water Agency. With the bathymetry, a maximum volume of 158.23 hm³ was considered for the Coremas reservoir and 158.96 hm³ for the Mãe D'água reservoir. When simulated as an integrated system it was considered the volume of the minimum quota of the channel to be 656.50 hm³.

Operation Scenarios

The simulations were started with the SMAP model, in order to obtain the monthly natural flow values from 1963 to 2018. Subsequently, these values were used in the ACQUANET model, along with the other data mentioned so far, which was calculated using 56 years in the period between January 1963 and December 2018. This simulation allowed an analysis of the behavior of the two reservoirs in detriment of meeting each demand, and the situation of their initial and final volume. Thus, it was possible to visualize the systematics of this water system over time, going through situations of rainy periods and dry periods.

Results and discussion

In this topic, the quantitative results of the Coremas and Mãe D'água water system are exposed individually with their performance in meeting demands in the simulated period 2016.

Scenario 1

Behavior of the Coremas Reservoir

At the beginning of the simulation, an initial reservoir volume of 50% of its maximum capacity was set (Figure 6). Figure 7 illustrates the reservoir performance. It can be seen that there is a great variability in its volume, characterized by alternating years of high rainfall rates and dry periods, which is a characteristic of the region where it is located, and because they were simulated separately and with bathymetric data provided by ANA (2014).

It is possible to observe that periods of lower volumes began, reaching its minimum volume in several years, where the reservoir operated at its minimum capacity in some periods, a fact that has returned to occur in more recent years, where the natural flows were not sufficient for Coremas to have a significant increase in its volume, which directly affects the demands involved.

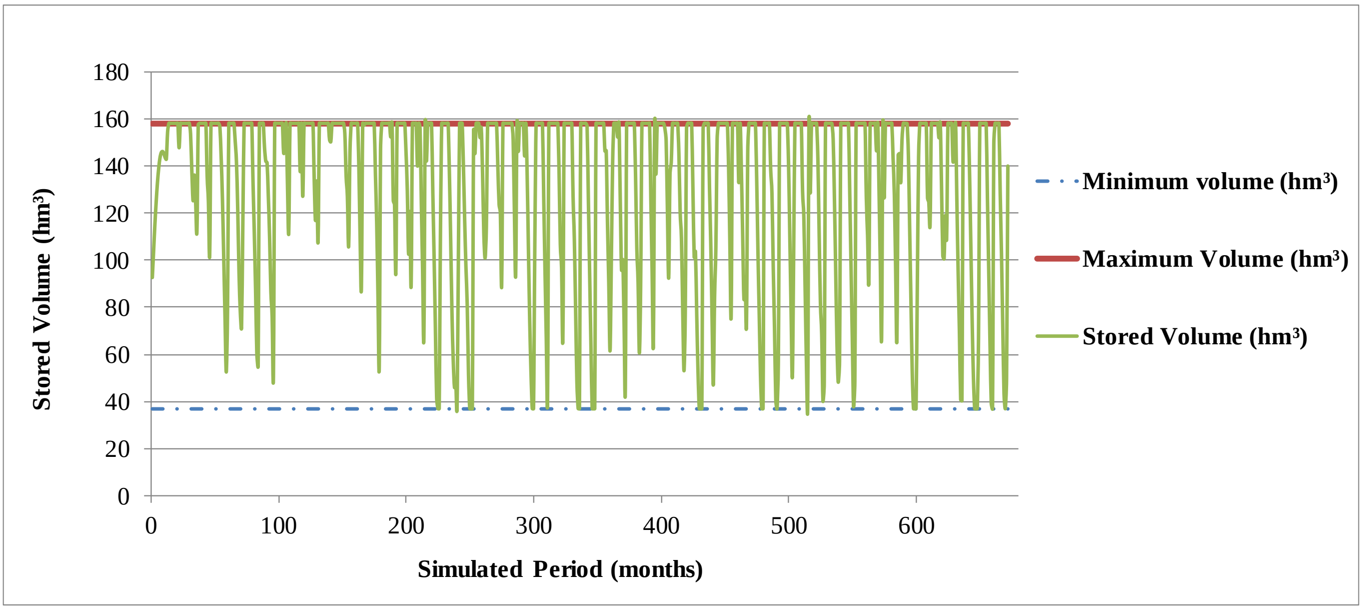

Figure 6. Storage volume behavior of the Coremas reservoir, Paraíba, Brazil.

Behavior of the Mãe D' Água Reservoir

This topic presents individually the simulation results of the historical series for the Mãe D'Água reservoir, its performance throughout the years and the fulfillment of its respective demands.

In the simulation carried out for the historical series in the reservoir Mãe D'Água, an initial volume of 50% of its maximum capacity was also adopted. Figure 7 presents the results obtained for the behavior of its stored volume.

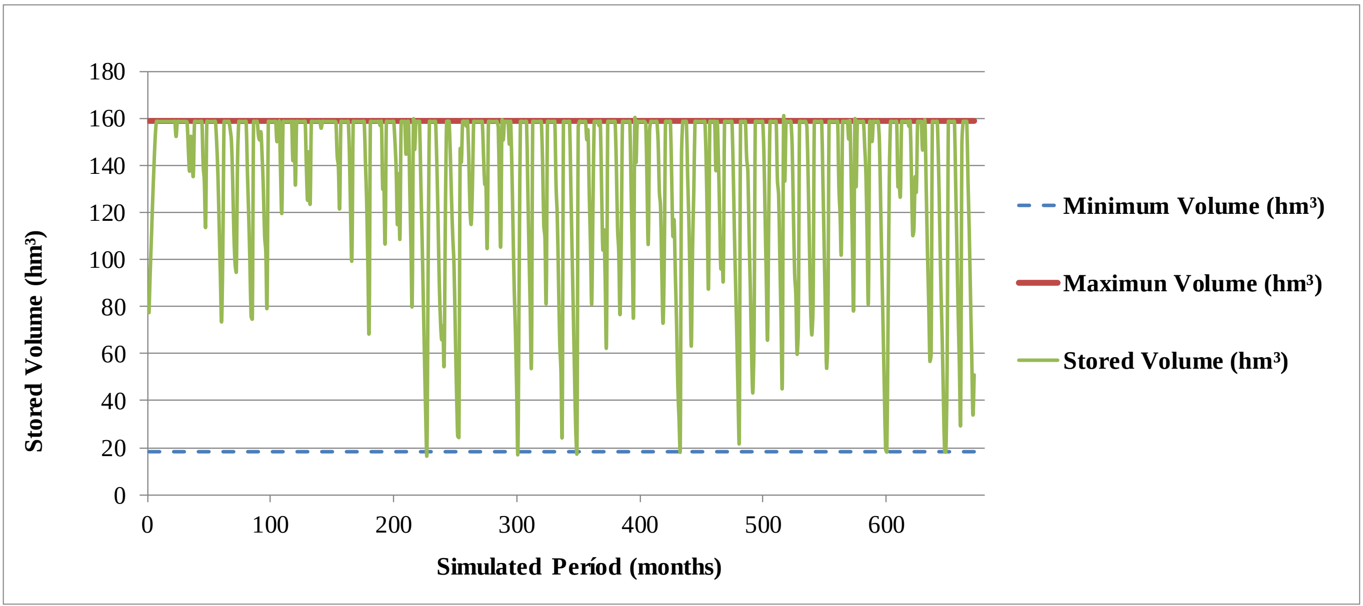

Figure 7. Storage volume behavior of the Mãe D' Água reservoir, Paraíba, Brazil.

Figure 7 also demonstrates the constancy of high volumes in the reservoir in some periods throughout the simulated years. It can also be verified that after a certain point, periods of low volumes occurred, reaching the limit of the minimum volume. The constancy of dry periods is also a point to be highlighted, intensifying the non-compliance with the target volume in several years, which brought inconvenience and lack of water for the population and all the demands involved.

Table 6 shows that the water demand for human supply, livestock, irrigation, industry and pisciculture were fully met in some periods, however, there were failures in an alternating manner, in other words, there was a deficit in the supply, especially in recent years, where the problem has worsened due to the recent years of low rainfall. The reliability calculation for human and animal supply demands was 99.7%, and for irrigation, industry and pisciculture, 99.5%, but with different average flow rates.

Table 6. Withdrawals for human supply, livestock, irrigation, industry, and pisciculture in the Coremas reservoir, Paraíba, Brazil.

MULTIPLE USES	Number of Failures	Guarantee (%)	Maximum Monthly Demand (m³/s)	Average Supplied Flow (m³/s)
Human Supply	2	99.7	2.609	2.569
Livestock	2	99.7	0.261	0.256
Irrigation	3	99.5	7.185	6.948
Industry	3	99.5	0.323	0.310
Pisciculture	3	99.5	0.049	0.047

It is possible to verify in Table 7 that, despite the periods in which the demand was successfully met, there were also failures, which were intensified due to the most occurring periods of low rainfall. It is important to emphasize that besides the periods of low rainfall, the demands tend to increase over the years, causing a greater withdrawal and lower volume of water accumulated in the reservoir. The reliability of service for human and animal supply demands was 99.7%, while for irrigation, industry and pisciculture was 99.5%, although the average flows provided were different.

Table 7. Withdrawals for human supply, livestock, irrigation, industry, and pisciculture in the Mãe D'água reservoir, Paraíba, Brazil.

MULTIPLE USES	Number of Failures	Guarantee (%)	Maximum Monthly Demand (m³/s)	Average Supplied Flow (m³/s)
Human Supply	2	99,7	0,517	0,509
Livestock	2	99,7	0,134	0,132
Irrigation	3	99,5	7,773	7,656
Industry	3	99,5	0,232	0,228
Pisciculture	3	99,5	0,049	0,482

Scenario 2

Behavior of the Coremas Reservoir

As for the performance of the reservoirs as a single reservoir, most of them presented satisfactory results, but it is worth mentioning that the probable increase in water consumption of the demands brings more possibilities of availability deficit for this reservoir. It is important to emphasize, regarding the results provided by the model, that it did not recognize values below the minimum volume.

According to Figure 8, we notice that the reservoir volume varied very little. This is due to the fact that it was considered the quota up to the maximum channel sill, this way, the reservoir had a larger volume, meeting all the demands related to it.

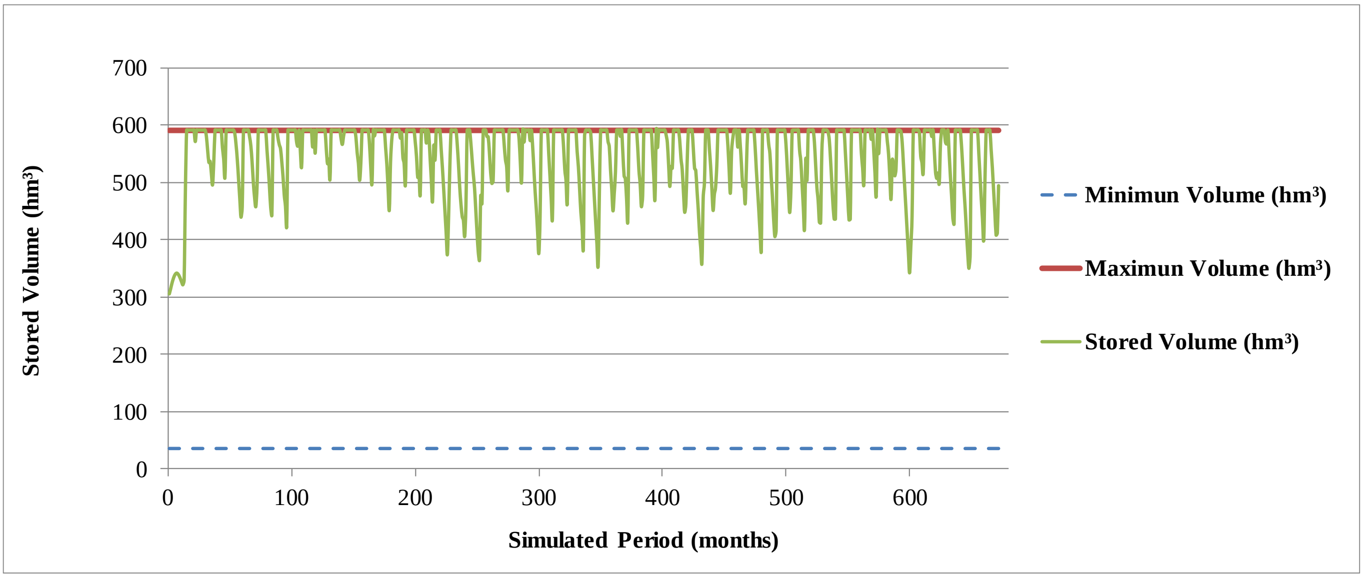

Figure 8. Behavior of the stored volume of the Coremas Reservoir, interconnected by the channel, Paraíba, Brazil.

It can be seen in Figure 9 that the demands were fully met, with no failures. This occurs because the quota up to the maximum channel sill was considered, thus, the reservoir had a larger volume, varying little along the years.

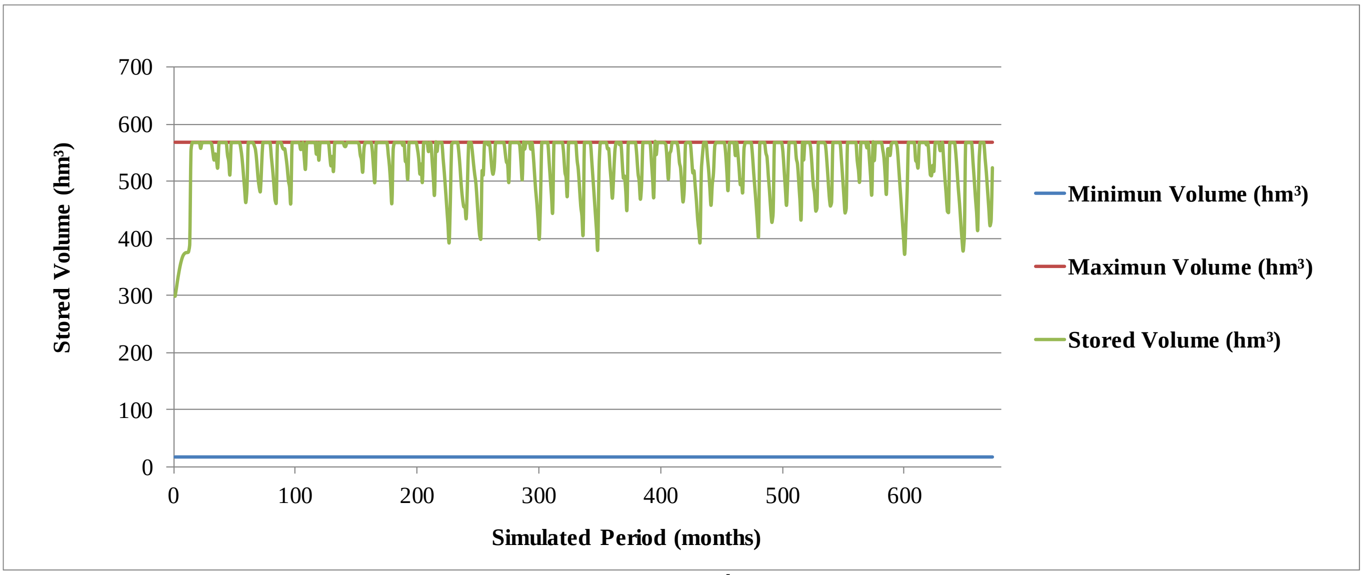

Figure9. Behavior of the stored volume of the Mãe D'Água Reservoir, interconnected by the channel, Paraíba, Brazil.

As can be seen in Table 8, the Coremas reservoir was simulated interconnected by a canal. Considering the system working full, at the maximum quota of 245.00 (m), it can be seen that the system attended all withdrawals, whether for human supply where the withdrawal of 1.5 of water for Rio Grande do Norte through the Coremas reservoir was considered. The withdrawals for animal watering, irrigation, industry and pisciculture. The system was able to satisfy the demand in all months. Where the guarantee of service was 100% for all uses.

Table 8. Withdrawals for human supply, livestock, irrigation, industry, and pisciculture in the Coremas reservoir, Paraíba, Brazil.

MULTIPLE USES	Number of Failures	Guarantee (%)	Maximum Monthly Demand (m^3/s)	Average Supplied Flow (m^3/s)
Human Supply	0	100	2.609	2.609
Livestock	0	100	0.261	0.261
Irrigation	0	100	7.185	7.185
Industry	0	100	0.323	0.323
Pisciculture	0	100	0.049	0.049

In Table 9 it was simulated the Mãe D'Água reservoir interconnected by a canal. Considering the system working full, at the maximum quota of 245.00 (m), it can be seen that the system met all withdrawals, whether for human supply where the withdrawal of 1.5 of water for Rio

Grande do Norte – Brazil through the Coremas reservoir was considered. The withdrawals for animal watering, irrigation, industry and pisciculture.

Table 9. Withdrawals for human supply, livestock, irrigation, industry, and pisciculture in the Mãe D'água reservoir, Paraíba, Brazil.

MULTIPLE USES	Number of Failures	Guarantee (%)	Maximum Monthly Demand (m³/s)	Average Supplied Flow (m³/s)
Human Supply	0	100	0,517	0,517
Livestock	0	100	0,134	0,134
Irrigation	0	100	7,773	7,773
Industry	0	100	0,232	0,232
Pisciculture	0	100	0,049	0,049

Conclusions

The climatological conditions characterized by the semi-arid region bring challenges to the watershed committees in the management of water resources. The low rainfall rates concentrated in a few months of the year, as well as the great alternation of rainy and dry years bring a complex context for the maintenance of the target volume of reservoirs, which often cannot fully meet their demands, which tend to increase over time.

Within this context, this work aimed to analyze quantitatively the water situation of the Coremas-Mãe D'Água system and the fulfillment of its demands, through simulations of the historical series from 1963 to the recent year of 2018, as well as to analyze the situation of reservoirs such as the Coremas-Mãe D'água system joined by the canal. Finally, the results obtained with the analysis of the reservoirs, proposed in this work, combined optimization, and simulation techniques, through the SMAP and ACQUANET models. The operational requirements were maintaining a target volume within which the entire useful capacity of each reservoir is used, and maintenance of the minimum volume. Regarding the priorities for meeting the demands, they were firstly water withdrawals for water supply and animal watering, secondly for irrigation, thirdly for industrial use, and fourthly for pisciculture.

In the allocation analysis done in the ACQUANET Model, for the simulation of the historical series from 1963 to 2018 for the two reservoirs separately, what can be concluded is that, for the reservoirs, in most months, the target volume was respected, working below the channel quota and due to the sharper flows coming from periods of more abundant rainfall, the maximum volume was reached. There were periods in which the reservoirs' capacity reached the minimum volume, in detriment of the few rains and due to silting, which became more present in the last years, making these reservoirs still far from reaching their maximum water storage capacity until the present moment.

As for the demands of the two reservoirs, the behavior was similar. Human and animal water supply presented guarantees of 99.7%, while irrigation, industry and pisciculture presented guarantees of 99.5%.

In the simulation of the historical series from 1963 to 2018 for the two reservoirs as one, what can be concluded is that because the quota up to the maximum channel sill was considered, the reservoir had a higher value, varying very little. With this, it was possible to meet the demands related to the system, with similar behavior, human supply, animal feeding, irrigation, industry and fish farming, where the reliability of service was 100% in scenario 2.

Therefore, this research proved to be important for presenting a diagnosis of the reality of the Coremas-Mãe D' água system, and the way the system operates reflects directly on meeting the demands of multiple uses.

Supplementary materials

Supplementary material is available and can be requested by e-mail from the corresponding author.

Data availability

- The dataset generated from (or analyzed in) the study can be found at {Water resources plan for the Piancó-Piranhas-Açu river basin and link: http://piranhasacu.ana.gov.br/produtos/PRH_PiancoPiranhasAcu_ResumoExecutivo_30062016.pdf}.
- The dataset of the study is available from the authors upon reasonable request.

Author contributions

The acquanet model is unique in the world and was created throughout Brazilian database Sao Paulo University (USP). The author Andrade de Amorin designed the study considering simulations and experimental test in the acquanet model. The authors Sarmento Vieira & Fontgalland supervised the paper as well sponsored the research group and general administrative support; All the writing assistance, technical editing, language checking, are in charge of the authorship.

Conflicts of interest

The authors declare that there is no conflict of interest.

References

1. ACQUANET. Modelo para alocação de água em sistemas complexos de recursos hídricos - Manual do Usuário. Escola Politécnica da Universidade de São Paulo - Departamento de Engenharia Hidráulica e Sanitária - Laboratório de Sistemas de Suporte a Decisões (LabSid). São Paulo. 2013
2. AESA. Agência Executiva de Gestão de Águas do Estado da Paraíba. Disponível em: <http://www.aesa.pb.gov.br/aesa-website/documentos/gestao-das-aguas> Acessado em: 14 de jun. de 2019.
3. ANA. Agência Nacional de Águas. Disponibilidade e Demandas de Recursos Hídricos no Brasil. Cadernos de Recursos Hídricos. 2005. Disponível em:<http://arquivos.ana.gov.br/planejamento/planos/pnrh/VF%20DisponibilidadeDemanda.pdf> Acessado em: 20 de jun. 2018.
4. _____. Estudo da Agência Nacional de Águas aborda uso da água no setor industrial. Disponível em:<http://www3.ana.gov.br/portal/ANA/noticias/estudo-da-agencia-nacional-de-aguas-aborda-uso-da-agua-no-setor-industrial> Acessado em: 19 de out. de 2018.
5. _____. Irrigação. Disponível em: <http://www3.ana.gov.br/portal/ANA/usos-da-agua/irrigacao/irrigacao-1> Acessado em: 21 de out. de 2018.

6. _____. Indústria. Disponível em: <http://www3.ana.gov.br/portal/ANA/usos-da-agua/industria> Acessado em: 22 de out. de 2018.
7. _____. Abastecimento. Disponível: em:http://www3.ana.gov.br/portal/ANA/textos-das-paginas-do-portal/abastecimento> Acessado em: 22 de out. de 2018.
8. _____. Sistema Hídrico Curema-Mãe D’Água e rios Piancó e Piranhas. Disponível em: <http://www3.ana.gov.br/portal/ANA/sala-de-situacao/acudes-do-semiarido/sistema-curema-mae-dagua> Acessado em: 05 de nov. de 2018.
9. _____. Saiba mais – Açudes Nordeste. Disponível em: <http://www3.ana.gov.br/portal/ANA/sala-de-situacao/acudes-do-semiarido/saiba-mais> Acessado em: 18 de nov. de 2018.
10. _____. Reservatórios do Semiárido Brasileiro, Hidrologia, Balanço Hídrico e Operação. Anexo b – Piancó-Piranhas-Açu. 2017. Disponível em: <https://www.ana.gov.br/noticias/estudo-reservatorios/anexo-b-pianco-piranhas-acu.pdf/view> Acessado em: 18 de jun. de 2019.
11. _____. Curvas Cota x Área x Volume do complexo dos Açudes Coremas e Mãe d´Água. Nota Técnica nº 001/2014/ SGI-ANA. Disponível em: <http://cbhpiancopiranhasacu.org.br/Docs/Notas%20tecnicas/NT%20001_2014_SGI.pdf> Acessado em: 01 de jun. de 2019.
12. BUCHIANERI, V. C. Geração da série histórica de vazão por meio do modelo SMAP: subsídio para o plano de manejo da bacia do Rio Grande de Ubatuba / Viviane Coelho Buchianeri. - - Piracicaba, 2004.
13. Alcigeimes B. CelesteWilson F. CuriRosires C. Curi; Implicit Stochastic Optimization for deriving reservoir operating rules in semiarid Brazil; Pesquisa Operacional, v.29, n.1, p.223-234, 2009.
14. EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. Disponível em: <https://www.embrapa.br> Acessado em 06 de jul. de 2019.
15. IBGE. Índice Brasileiro de Geografia e Estatística. Disponível em: <https://cidades.ibge.gov.br/> Acessado em: 14 de jun. de 2019.
16. LIMA, C. A. G. Análise e sugestões para diretrizes de uso das disponibilidades hídricas superficiais da bacia hidrográfica do rio Piancó, situada no estado da Paraíba.2004.Tese (Doutorado em Recursos Naturais) – Programa de Pós-Graduação em Recursos Naturais, Centro de Tecnologia e Recursos Naturais, Universidade Federal de Campina Grande, Paraíba, Brasil, 2004.
17. LOPES, J. E. G.; BRAGA, B. P. F.; CONEJO, J. G. L. SMAP - A Simplified Hydrological Model, Applied Modelling in Catchment Hydrology, Ed. V.P.Singh, Water Resources Publications, 1982.
18. PRH – PPA Plano de Recursos Hídricos da Bacia Hidrográfica do Rio Piancó- Piranhas-Açu: Resumo Executivo. Brasília, 2016.
19. SANTOS, V. da S. Modelo de otimização quali-quantitativo multiobjetivo para o planejamento dos recursos hídricos superficiais, com aplicação à Bacia do Rio Paraíba.2011.Tese (Doutorado em Recursos Naturais) – Programa de Pós-Graduação em Recursos Naturais, Centro de Tecnologia e Recursos Naturais, Universidade Federal de Campina Grande, Paraíba, Brasil, 2011.
20. SÃO PAULO (Estado). Secretaria do Meio Ambiente / Coordenadoria de Educação Ambiental. Cadernos de Educação Ambiental. Recursos hídricos. Vários autores. São Paulo: SMA / CEA, 2014.