Simulation of the exploration of a cascade system combined by a multipurpose reservoir and a waterfall

André Nascimento

Instituto Superior Técnico, Universidade de Lisboa

May 2018

Abstract

Climate variability, population growth, increasing urbanization and pollution make clearer the urgency of optimising the integrated and sustainable management of available hydric resources.

This dissertation focuses on the study of a multiple purpose reservoir, through a simulation model in a case study of a developing country, Mozambique, whose intra-annual climate seasonality is considerably noticeable. The model to simulate contemplates two hydropower plants in cascade being the upstream comprised of a multipurpose reservoir (water used for irrigation, energy production and the capacity to regulate the flow) and the downstream of a run-of-the-river scheme (production of electric energy). The intention is for the model to simulate, 18 consecutive hydrologic years on a monthly basis, aimed at the economic and social optimisation of the available hydric resources. Thus, varying the area that is intended to be irrigated and the hydroelectric power to be installed, it is possible to obtain results concerning the economic benefits that each irrigation-energy pairing should supply, as well as the reliability achieved in terms of the water provided for irrigation, in order to elaborate an analysis for different scenarios.

Through the analysis of different scenarios, it is possible observe the impact that multipurpose reservoirs have in the context of the optimization in hydric resource management, being in the consumption regarding irrigation and in the usage in hydroelectric production, or in the regularization of natural streams, allowing for a larger use of resources throughout the year, fighting its seasonal character, in hydrological contexts as the ones seen in Mozambique.

Key-words: water resources; multipurpose reservoir; run-of-the-river; hydropower; irrigation; simulation model; Mozambique; Lúrio river.

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1. Introduction

“Water is an essential element for life and for the sustainable development of societies. Considered until recently as an inexhaustible resource, it is now known that it is a renewable but limited resource” (Hipólito & Vaz, 2013). Even though it occupies two-thirds of the Earth’s surface, the availability of water and its distribution are strongly influenced by several factors. Climate variability, population growth, increasing urbanization and the improvement of the population’s quality of life, pollution, waste and the availability of water in terms of the use of drinkable water make such an abundant liquid become scarce.

Nowadays, the urgency of optimising the integrated and sustainable management of available hydric resources is clearer, namely in developing countries where the aforementioned factors still have a considerable weight. A developing country is a country where the consumption and usage of hydric resources grow abundantly, which is why it is essential to have an efficient management which relates that demand to the availability and sustainability of the available hydric resources.

This dissertation focuses on the area of Hydraulics and Hydric Resources, addressing the scheme of a multiple purpose reservoir, through a case study of a developing country, Mozambique, whose intra-annual climate seasonality is considerably noticeable. The model to simulate contemplates two power stations in cascade being the upstream comprised of a multiple purpose reservoir (water used for irrigation, production of electric energy and the capacity to regulate) and the downstream of a pure run-of-the-river (production of electric energy).

The simulation models are mathematically simple and very versatile. They simulate or imitate a system's behaviour, in this case a reservoir and its several purposes throughout time. The simulation is no more than the sequential application, through several periods of time, of the reservoir's continuity equation. Although simple, these models may describe in detail the system's behaviour.

The case study on which this dissertation focuses is based on prior analyses on the River Lurio's hydrographic basin, in Mozambique, namely "Hidrotécnica Portuguesa", in 1980, and of the Black & Veatch International Company, in 2007, where the intention is to create a picture of sustainable management, development and conservation of the hydric resources of that basin, aimed at the improvement of living conditions (fighting poverty) and an increase in the population's economic and social benefits.

The intention is for the model to simulate, 18 consecutive hydrologic years on a monthly basis, aimed at the economic and social optimisation of the available hydric resources. Thus, varying the area that is intended to be irrigated and the hydroelectric power to be installed, it is possible to obtain results concerning the economic benefits that each irrigation-energy pairing should supply, as well as the reliability achieved in terms of the water provided for irrigation, in order to elaborate an analysis for different scenarios.

2. Hydric resources in the world

2.1. Hydric resources

Water is the most abundant liquid on Earth, occupying two-thirds of its surface, with an approximate volume of 1,600 million km^3. For hundreds of years, the impact of man on hydric resources was insignificant and local. Water's capacity to renew itself allowed for a sustainable balance between human consumption and its availability. However, that capacity ended up by creating a careless attitude towards the use of hydric resources. According to Shiklomanov (1998), it was in the last few decades that we started to feel that activity in the worldwide distribution of hydric resources, essentially due to the expansion of irrigated areas, the increase in water consumption for industrial usage, including energy production and the intensive creation of reservoirs.

2.2. Dams and reservoirs

All around the world, the climatic and hydrological variability restrict the availability of drinking water and, consequently, it translates into the rotation of periods of great inflow and drought. In this context, the dams and their respective reservoirs perform a fundamental role in efficient water management, by allowing its storage, in order to fight the variability of its availability, adopting streamflow to consumption needs.

Efficient water management is a key subject worldwide and reservoirs perform a crucial role in that management, being urgent a better optimization of the usage of available hydric resources, which support the economic, social and environmental sustainability. From the perspective of optimization and better exploration of resources, the reservoirs created by dams have been, ever more so, operating with several objectives of simultaneous usage of stored water such as the industrial and municipal supply, irrigation, hydroelectric energy production or flood control. Yet, management and the optimization of multi-purpose scheme is considerably complex due to the conflict generated by the necessity to evaluate the weight and the priority of each proposed objective (Lin & Rutten, 2016).

2.3. Irrigation and the production of hydroelectric energy

The irrigation and production of hydroelectric energy are the purposes for which the simulation model in the case study of this dissertation have been developed and they are of the utmost importance.

In the case of irrigation, it is estimated that around 20% of the cultivated area worldwide is irrigated, in a total of 300 million hectares in which a third of the world's food is produced, as well as non-food items (Hipólito & Vaz, 2013). Irrigation provides greater crop yield revenues and agricultural production at times of the year when precipitation is insufficient for the purpose. According to *Food and Agriculture Organization of the United Nations*, FAO (Bruinsma, 2009), the only hope to feed the world 's population in continuous expansion is to increase irrigated agriculture. Agriculture is the sector that consumes the most water worldwide, corresponding to the collection of water for irrigation to approximately 70% of all water abstraction.

Hydroelectricity, in its turn, is one of the most auspicious renewable energy sources, mainly for its storage capacity and immediate availability which guarantees the reliability of its supply. It is a simple and technologically advanced energy source with one of the best efficiency conversion rates of all-known sources.

2.4. Developing countries (Africa – Mozambique)

This dissertation’s case study focuses on the River Lúrio, in Mozambique, from which it has been deemed necessary the need to study the general overview of hydric resource management in developing countries, namely in the African context, and more specifically, in Mozambique.

The sustainable growth of a developing country depends significantly on the increase of the usage of its hydric resources without degrading the present ecosystems too much, which are also fundamental for the balance and well-being of humankind. In most parts of Africa development has fallen short from the rest of the world in the last half-century, making it unquestionable for the urgent need of better hydric management. Although, managing hydric resources in Africa, more precisely in Mozambique is particularly challenging due to the great spatial and temporal variability that characterizes its availability, together with water scarcity in certain semi-barren regions with a significant area. On this point and considering the actual levels of poverty but also the perspectives for future development, the government of Mozambique has been developing strategies for the development and integrated hydric resource management that will allow the country to grow in a healthier and more sustainable way

Nowadays, Mozambique is one of the poorest countries in the world. It is ranked 181 out of 188 analysed countries by the Human Development Report of the United Nations (UNDP, 2016), regarding its state of development. In this way, its hydric resources are also far from being reasonably exploited, being that water abstraction is extremely low and insufficient for the urban and rural water supply, for industrial usage and hydroelectric production, and mainly for irrigation, which falls considerably far from their needs. Yet, BMI Research presents, in *Mozambique Power Report* of 2017 (BMI Research, 2017), an up-to-date analysis of the country’s economic and energy situation with predictions for 2025, which points to a real GDP annual average growth rate of more than 7%, originating in a constant increase in the demand for electricity and this reaffirms the clear need to increase investment, mainly foreign, in the energy sector. Agriculture is also a key economic sector for Mozambique’s sustainable development where 80% of the population is involved in agriculture and job opportunities in non-agricultural sectors are very limited. According to Means (2016), agriculture represented about 28.1% of GDP in 2015 and most Mozambicans living in a rural environment support themselves on their own home-grown produce.

3. Case study: Lúrio river’s hydrographic basin

The source of the River Lúrio is located in the far south of the Niassa province, it flows for almost 500 km and drains between the cities of Pemba and Nacala. Being exclusively national and with a low usage (less than 1% of the available resources), it shows an enormous potential towards the development of the harnessing of its hydric resources.

It is a hydrographic basin, increasingly valued by its hydroelectric potential, considering that the realisation of that potential would be a strong leverage for the development of Mozambique’s central and northern regions. Some of the hydroelectric schemes planned for the Lúrio’s basin has already been the object of study and projects with enough development to allow for its rapid construction. For the development of this dissertation’s simulation model, the studies carried out by Hidrotécnica Portuguesa (1980), by Norconsult and SwedPower (2004), and by Black & Veatch International Company (2007) were taken into account. These studies present thorough analysis of the basin’s hydric capacities, aimed at watering and electric energy production.

The data collected by these three studies enable the creation of a model that intends to optimise the scheme of a system based on a dam with a multi-purpose reservoir (which will be named Ocua Lúrio), located near the town of Ocua, approximately 119 km from the river’s estuary into the Indian Ocean. Those aims involve irrigation in the Lúrio’s basin, hydroelectric energy production and flow control that will allow for hydroelectric harnessing of the constant run-of-the-river from the waterfalls that can be found 49 km downstream from Ocua (identified as Quedas Lúrio).

4. Simulation model

4.1. Topology and structure

The model applied aims at simulating the exploration of a stretch of water of the River Lúrio in which we foresee a system composed of a multi-purpose reservoir (Ocua) and, its own downstream, a pure run-of-the-river scheme (Quedas do Lúrio). The reservoir's main objective is irrigation and hydroelectric energy production, and through the simulation of its harnessing, the intention being to increase the total benefits from an economic, environmental and social point of view, varying the hydroelectric power to be installed in the two power stations, as well as the farming area capable of being irrigated with a certain guarantee. In **Figure 1** the two power stations are simply represented in cascade, the object of simulation.

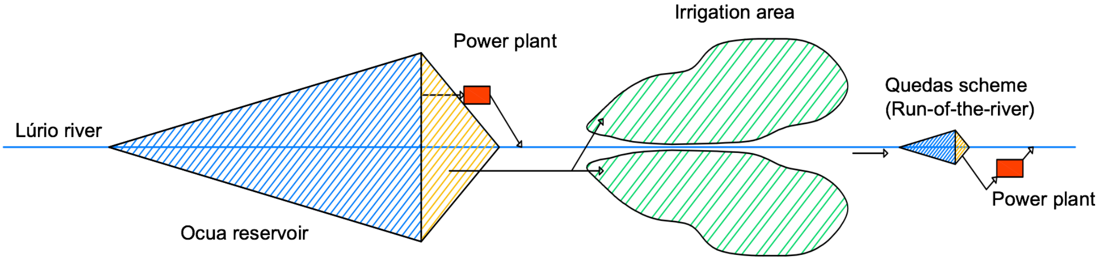

Figure 1 – Simplified diagram of the simulation model, with the two power stations in cascade.

The hydrological data collected (monthly affluent outflow, precipitation and evaporation) refer to a continuous period of 18 hydrologic years from 1963/64 to 1980/81. Thus, the simulation is done throughout that timeframe on a monthly basis. In its presentation as an Excel sheet, each line corresponds to a month, where we can see the gain and loss of the reservoir's water volume (affluent outflow, evaporation, precipitation, irrigation, hydroelectric production...), resulting in the final volume for the reservoir for that particular month, which will be the initial volume for the following month/line.

The simulation model is divided into five main components, applied sequentially over the course of each month which introduce the reservoir's water gain and loss. The first component is BASE, where artificial extraction is not taken into account (irrigation and energy production), having only grouped the following variables: initial volume, affluent outflow, precipitation, evaporation, ecologic water flow and final volume. The second component is concerned with IRRIGATION, whose monthly volume to be supplied is added to the BASE component. The third component refers to OCUA ENERGY, having its respective monthly volume used in hydroelectric production added to the IRRIGATION component. The fourth component regards the FINAL CONDITIONS of the Ocua reservoir, with all of the associated consumption, referring to the volume of discharged water at the time of flooding in relation to each month/line. The fifth, and final component is QUEDAS ENERGY, which identifies the total effluent outflow of Ocua (and affluent to the waterfalls) and analyses the hydroelectric production of the waterfalls at Quedas Lúrio. **Figure 2** represents a simplified diagram with the sequence of the model's different components and its input and output variables. The first four components are identified in blue, corresponding to the project of the multi-purpose reservoir, whilst in green we can see the reservoir's effluent volume and the fifth component, the scheme of (the Falls) Quedas do Lúrio.

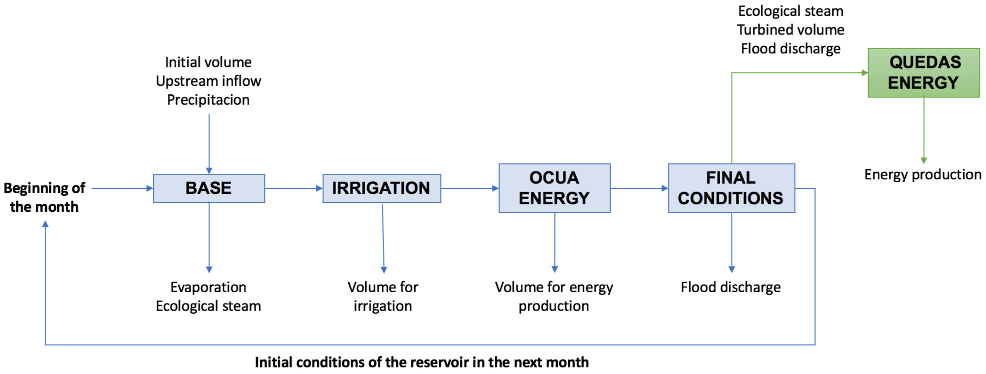

Figure 2 – Simplified diagram of simulation model's components and its sequence.

4.2. Input data

The input data of the simulation model serves the presented topology. However, it can be altered in order to adapt the model to a different case study, as long as the global topology is similar. These are the characteristics of the schemes that integrates the system, the hydrological data concerning the section of the River Lúrio being studied and the figures due to artificial extractions, in this case irrigation and hydroelectric energy production.

4.3. The model's equations and restrictions

Essentially, the model applies the continuity equation to the Ocua reservoir for a specific period of time, expressed in a function of the variables present. When considering a system for a specific period of time, the amount of water present abides by the conservation principles of mass, represented by the continuity equation:

$$I - O = \frac{dS}{dt} \text{, } in\ the\ continuous\ form \tag{1}$$

Where the I represents the volume of water that enters the system by unit of time, O, the volume that leaves the system also by unit of time and S, the volume stored inside the system.

The methodology of the continuity equation is frequently used to determine the value of a hydrologic variable when all the other remnants that are in the balance are known. In the system being studied, the continuity equation relative to the variation of the volume of water in the Ocua reservoir, each month, can be represented in the following way:

$$\begin{gathered} Final\ Vol. = Initial\ Vol. + Outflow\ Vol. + Precipitação\ Vol. - Evaporação\ Vol. - Ecologic\ Vol \\ - Irrigation\ Vol. - Energy\ Vol. - Flood\ discharge\ Vol. \end{gathered} \tag{2}$$

The variables relative to the continuity equation applied to the Ocua reservoir are: *Final Vol.*, being, the reservoir's total volume, at the end of each month, considering all the consumption, usage and water gain; *Initial Vol.*, which is the total volume of the reservoir, at the beginning of each month, equal to the final volume of the previous month; *Outflow Vol.*, which represents the month's affluent outflow; *Precipitation Vol.* and *Evaporation Vol.*, which identify the precipitated and evaporated volumes in the reservoir likewise in the month; the *Ecologic Vol.*, regarding the monthly discharge volume towards ecological purposes; *Irrigation Vol.* and *Energy Vol.*, that represent the consumed monthly volumes and used up volumes respectively for irrigation and hydroelectric energy production; and the *Flood discharge Vol.*, calculated for the end of each month and representing the volume that, after all consumption, usage and gains, exceeds the volume corresponding to the full level storage capacity.

The continuity equation is applied monthly to the fifth component, meaning, to the hydroelectric scheme of the water flow of the Quedas do Lúrio which is given by:

$$Ocua\ effluent\ Vol. = Ecologic\ Vol. + Energy\ Vol. + Flood\ discharge\ Vol. \tag{3}$$

In the previous equation, the *Ocua effluent Vol.* refers to the total monthly volume stemming from Ocua's reservoir and the Quedas do Lúrio affluent.

The sequential monthly application of the continuity equation allows us to understand the system's behaviour in each time period, for example, the volume stored, evaporated or linked to several uses and the energy produced. Once the volumes of consumption/usage have been determined regarding the needs for irrigation and hydroelectric production (depending on the number of hectares to be irrigated and the hydroelectric power to be installed, respectively). It is necessary to evaluate if the volume of water stored in the reservoir each month can guarantee the fulfilment of those consumptions/usages, in periods of insufficient natural affluences. At the end of each simulation it is possible to determine the reliability reached by the differing consumption, calculated from the registered flaws, energy produced, verified floods and a maximum flow discharge, the filling and emptying periods and the precipitated and evaporated volumes in the reservoir.

4.4. Components

The **base component** identifies the month that is being simulated in each line, in which the respective collected hydrological data is allocated (outflow, evaporation, precipitation and ecologic volume, considered for this study as 5% of the affluent outflow). The initial conditions of the reservoir are also calculated, being the initial volume equal to the final volume of the previous month (the reservoir's level is considered to be at full maximum storage in the first month) and that allows us to determine the level and area of the reservoir resorting to the curvature of the stored volumes and flooded areas. In this way, the continuity equation is applied to determine the final volume of the reservoir in this component, through the following equation:

$$Final\ Vol. = Initial\ Vol. + Outflow\ Vol. + Precipitation\ Vol. - Evaporation\ Vol. - Ecologic\ Vol. \qquad (4)$$

The intention of the **irrigation component** is to add this end to the continuity equation. However, it is necessary to guarantee that the minimum level of exploration is fulfilled. In this way, if the final level of the reservoir after the base component is inferior to that level (250 m), no volume in relation to irrigation is extracted. If, on the other hand, the level is superior, that end is added until the minimum level allows it or until that month's specified needs are satisfied. Therefore, it is possible to obtain a new final volume, where irrigation will be considered and the reservoir's corresponding level.

The Ocua energy component of the model presents an identical verification to the irrigation component, in function of the reservoir's level and if this fulfils the requisite relative to the minimum exploration level, 250 m. The volume to be charged each month is obtained based on the useful fall which that month presents and of the power installed. Thus, the new final volume is obtained already considering the volume used for the reservoir's energy production and its corresponding level.

The last component in relation to the Ocua reservoir is the **final conditions component**. This component determines the flood volume discharged each month, identifying the months where the reservoir's final level is higher than the full storage level (260 m), after the base, irrigation and energy components. In those months the real final level will be the full storage level, being the difference in volumes between that level and the discharge obtained.

The **Quedas energy component** harnesses the Ocua reservoir's monthly effluent outflow to produce energy in a pure run-of-the-river scheme. The determination of the affluent outflow of this scheme is the sum of the volume used for energy production, ecological volume and the volume of flood discharge regarding Ocua every month. The energy production of this waterfall is calculated based on the total power installed of 120 MW and the constant useful fall of 58.5 m.

4.5. Output data

The simulation model created has many variables which are to be changed in order to look for the best possible scenario for the scheme of this system: the number of hectares to be irrigated and the installed power. In this case the intention is to evaluate each scenario through the output data which will allow us to check the reservoir's condition each month, the compliance of harnessing requirements and the possible social and economic returns.

The output data possible for this simulation model may be obtained through graphs that analyse the monthly variation of specific variables throughout the study (reservoir level, affluent outflow, precipitation, evaporation, water volume consumed for irrigation or used for energy production...), but also through final analysis figures of the models' behaviour throughout the study period, such as the total economic benefits and the reliability regarding irrigation and the production of hydroelectric energy.

5. Use of the model

5.1. Identifying scenarios

The simulation model, created to explore the system, is composed of the Ocua storage reservoir and by the pure run-of-the-river scheme of Quedas', which can be applied bearing in mind different scenarios which differ in the areas to be irrigated and the power installed in Ocua. Therefore, five scenarios were defined in order to analyse the economic as well as the social optimization. In **Table 1** scenarios are differentiated by the consumption/usage considered in each one.

Table 1 – Identification for the simulation model's harnessing scenarios.

	Scenário 1	Scenário 2	Scenário 3	Scenário 4	Scenário 5
Ocua Irrigation	No	Yes	No	Yes	Yes
Ocua Energy	No	No	60 MW	25 MW	20 MW
Quedas Energy	120 MW	No	120 MW	120 MW	120 MW

Scenarios 1 and 2 determine the two extreme situations of harnessing in the model. The first doesn't consider the existence of the Ocua dam, only addressing the energy produced in the Quedas Lúrio scheme (120 MW) regarding the natural affluent outflow, with regularization promoted by Ocua. The second is the opposite, as it only considers the Ocua dam, having as its only purpose the supply of water for irrigation without any hydroelectric energy production.

Scenario 3, in turn, considers the complete system of the Ocua dam fall with the run-of-the-river scheme of Quedas', but aiming just at hydroelectric production without any consumption regarding irrigation. The power installed at Ocua and Quedas are defined by B&V (2007) and confirmed in this study, of being 60 and 120 MW respectively.

In scenarios 4 and 5 we intend to explore the system integrating all the intended purposes. However, in Ocua, in order to consider the consumption regarding irrigation and the usage referent to energy production, it is necessary to reduce the installed hydroelectric power. So, the installed power in Ocua in scenario 4 is of 25 MW and in scenario 5 of 20 MW. In Quedas, power remains at 120 MW.

5.2. Scenario 4

We opt to represent the results from scenario 4 as it simulates the model with all the integrated components, that is to say, with all the consumption and usage being considered throughout the 18 hydrologic years. Consequently, the Ocua reservoir will have multiple purposes for the usage of water for energy production and the consumption regarding the supply of water for irrigation, whilst Quedas will benefit from the regularization of its streams imposed by the upstream dam (Ocua), for the production of hydroelectric energy production in a pure run-of-the-river scheme.

With regards to irrigation, the maximum amount of area to be irrigated is determined, for which the Ocua reservoir guarantees the required assurance, in other words, with a maximum of three years being considered flaws (lack of volume higher than 5% of the total water consumption for watering in that year). After several simulations for different amounts of area to be irrigated, making the number of hectares vary every 1,000 until the required assurances are no longer fulfilled. We can conclude that the maximum area that guarantees assurance is of 32,000 ha. **Table 2** presents the results regarding this simulation, namely, that which concerns the volume that was effectively consumed monthly for irrigation purposes, of the total economic benefits in millions of dollars and the guarantee given to obtain those benefits.

Table 2 - Results of the simulation model applied to scenario 4, regarding the supply of water for irrigation purposes in Ocua Lúrio (power installed of 25 MW).

IRRIGATION EFFICIENCY OCUA LÚRIO – SCENARIO 4 (power 25 MW in Ocua)				**AREA TO BE IRRIGATED (ha)**
				32000
Total Nº of months to water (10 months/year)	Nº months to water 100%	Nº months to water 0%	Nº months to partly water	% volume effectively watered
180	172	6	2	96.9%
	95.6%	3.3%	1.1%	
Economic benefits			**Guarantee**	
Revenue $/ha/year		500	nº of flaws	3
Total revenue in millions $		279.16	Max nº of flaws	3

In what concerns hydroelectric energy production, the power installed in the scheme of the Ocua reservoir and in the pure run-of-the-river scheme of Quedas are respectively 25 and 120 MW. The results correspond to the effectiveness of the harnessing, to the percentage of water volume that was effectively turbined (which varies with the Ocua falls, with the sizing of streams...), to the total energy produced in kWh, and to the total economic benefits in millions of dollars, over the course of the 18 hydrological years studied. This is shown in **Table 3** (Ocua) and in **Table 4** (Quedas).

Table 3 - Results of the simulation model applied in scenario 4, regarding energy production

ENERGY EFFICIENCY OCUA LÚRIO – SCENARIO 4				POWER (MW)
				25
Total Nº of months to turbine	Nº of months to turbine 100%	Nº of months to turbine 0%	Nº months to partly turbine	% volume effectively turbined
216	193	9	14	93.2%
	89.4%	4.2%	6.5%	
Total energy produced (kWh)		**Total economic benefits (in millions $)**		
3.35E+09		334.64		

Table 4 - Results of the simulation model applied in scenario 4, regarding energy production

ENERGY EFFICIENCY QUEDAS LÚRIO – SCENARIO 4				POWER (MW)
				120
Total Nº of months to turbine	Nº of months to turbine 100%	Nº of months to turbine 0%	Nº months to partly turbine	% volume effectively turbined
216	34	9	173	48.4%
	15.7%	4.2%	80.1%	
Total energy produced (kWh)		**Total economic benefits (in millions $)**		
1.01E+10		1008.60		

Bearing in mind a more complex analysis of the system's behaviour throughout the simulation of the 18 hydrological years, it is possible, for example, to collect graphs with a monthly variation of the level of water in the Ocua reservoir, of the volume consumed for irrigation purposes, the volume of water used for energy production in Ocua and the production at Quedas. **Figures 3** and **4** present those graphs.

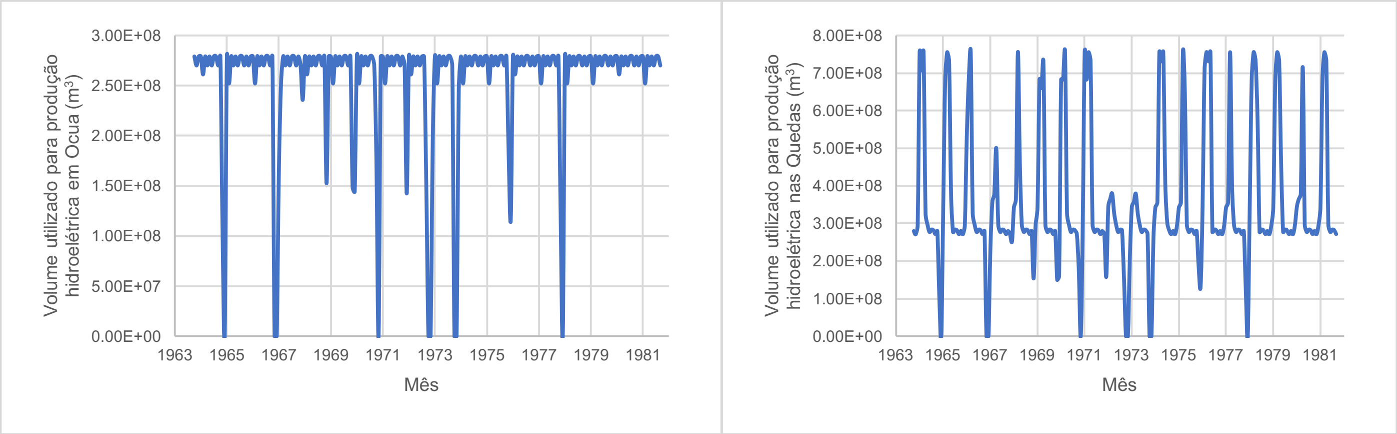

Figure 3 – Monthly variations of the water level in the Ocua reservoir (left) and monthly variation of the water used for irrigation in Ocua (right) – Scenario 4.

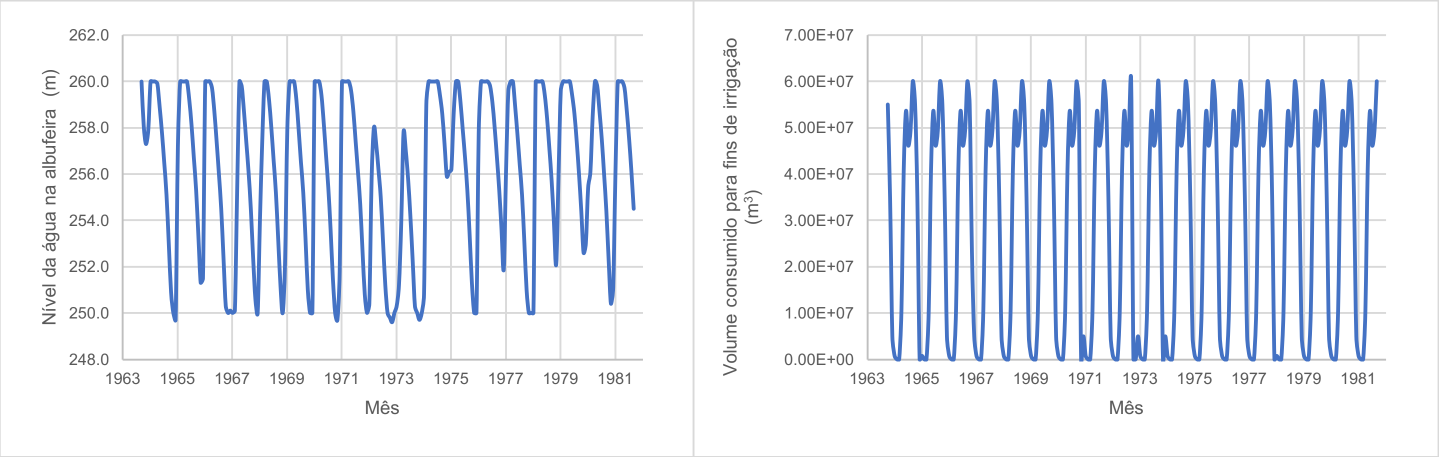

Figure 4 – Monthly variation of the volume of water used for hydroelectric energy production in Ocua (left) and the monthly variation of the volume of water used for hydroelectric energy production at Quedas (right) – Scenario 4.

It is noticeable in the figures how the system reacts to the alternation between the dry season and the wet season. In the first graph in **Figure 3** it is possible to observe the situations where the reservoir level decreases to values below the minimum exploration level (250 m) and where it reaches the full storage level (260 m). The variation of the monthly volume used for irrigation is presented in the second, where we can see that the volume is higher when the reservoir level presented in the previous one allows it and lesser when that level is lower.

In the graphs referent to **Figure 4** it is possible to observe that in 1965, 1967, 1971, 1973, 1974 and 1978, there is a plunge where the energy production reaches very low levels. It can be observed that those years are years in which in the case of the first graph (variation of the water level in the Ocua reservoir) the water level presents the lowest values, exceeding the minimum exploration level of 250m. These are the critical years where situations of drought could be seen.

6. Conclusions

This dissertation addressed the importance of a good management of hydric resources on a global level, adopting a developing country as a case study, and brought about by the development of a simulation model for the exploration of a system composed of two power stations, one possessing a multi-purpose reservoir and the other a run-of-the-river scheme located in the hydrographic basin of the River Lúrio in Mozambique.

Through the analysis of the differing simulation scenarios of the model can we observe the impact that multi-purpose reservoirs have in the context of the optimization in hydric resource management, being in the consumption regarding irrigation and in the usage in hydroelectric production, or in the regularization of natural streams, allowing for a larger use of resources throughout the year, fighting its seasonal character, in hydrological contexts as the ones seen in Mozambique.

Table 5 presents a summary of the economic benefits corresponding to each scenario, regarding the water used for irrigation and hydroelectric energy production in Ocua and in Quedas downstream.

Table 5 – Table summary of the economic benefits of each scenario.

	Irrigation		**Energy**		**Total economic benefits (millions $)**
	Irrigated area (ha)	Economic benefits (millions $)	Installed power Ocua + Quedas (MW)	Economic benefits (millions $)	
Scenario 1	0	0	0 + 120	0 + 803	803
Scenario 2	207,000	1,822	0	0	1,822
Scenario 3	0	0	60 + 120	522 + 1,194	1,716
Scenario 4	32,000	279	25 + 120	335 + 1,009	1,622
Scenario 5	69,000	605	20 + 120	268 + 900	1,773

It is possible to understand by looking at the table that the total economic benefits are higher in scenario 2, which points exclusively towards irrigation. However, in developing countries it shouldn't just be the market and the economic benefits dictating the viability and interest to implement projects, bearing in mind the essential regional development component with the intent of social improvement and the population's quality of life. Although scenarios 4 and 5 do not present global economic benefits as high as in scenario 2, they allow for several purposes such as hydroelectric production and the regularization of the stream's exploration which the Ocua reservoir induces in the Lúrio river, which can be interpreted in a more integrated and sustainable hydric resource management.

It can also be noted what impact the storage and regularization of streams can have in a hydrological context with a great variability of resources, with increases in terms of energy production and economic benefits in Quedas do Lúrio, without upstream regularization (scenario 1) or taking advantage of the regularization of streams promoted by the Ocua reservoir (scenarios 3 and 5).

There are several aspects to this dissertation that could have been carried out in a more detailed way if this were a more in-depth study but would stray from the focus of the work. One of those aspects would be the creation of a generating model and stream propagation between the two power stations, Ocua and Quedas, as an alternative to the simplistic hypothesis considered that the losses and gains in that section would cancel each other out. Another aspect that would have to be improved would be the technical consistency of the data used for the economic evaluation of the relative benefits regarding, either irrigation or hydroelectric production. Note that, these possibilities exist to further deepen the study and are not connected to this dissertation, the simulation model created is prepared to receive this type of information, be it a model of domestic propagation, a variation of the economic evaluation or a modification in the equations of the reservoir's exploration.

Finally, it is essential to bear in mind that "nowadays it is unthinkable to plan a reservoir of a large or medium size without having the social and environmental impact duly analysed and foresee the respective mitigation measures and their costs" (Hipólito & Vaz, 2013). In considering the impact associated to dams we should analyse if the resulting economic benefits exceed the associated cost but also how these impacts are distributed socially (positively or negatively) and which are the environmental consequences of this type of project.

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