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THE METHODOLOGIES FOR THE FLOOD CONTROL PLANNING USING HYDROPOWER RESERVOIRS IN BRAZIL

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ABSTRACT: The continental dimension of Brazil, including basins with large hydropower potential took the option of an electrical matrix predominantly hydroelectric (approximately 70% of the Brazilian matrix). One of the particularities of the Interconnected Brazilian Hydrothermal System operation planning is the need of using part of the volumes of the hydroelectric plants reservoirs as waiting volumes for attenuation of possible floods, avoiding damages to hydro plant's downstream areas. The consideration of flood control in the reservoirs of hydropower plants is both an opportunity and a challenge, since the two uses of water (hydropower generation and flood control) are conflicting. While the first aims to keep the reservoirs filled at the end of the rainy season to use the water stored during the dry season, the flood control aims to keep the reservoirs empty to store the volume of large floods that may occur during the rainy season to avoid damage in downstream areas. To minimize this conflict, Brazil has been developing methodologies and computational tools for planning reservoir operation considering power generation and flood control. This paper focus on the methodologies and computational tools for planning the flood control operation in the Brazilian power system reservoirs addressing the methodology adopted to calculate the "Waiting Volumes". An application of the methodology and the computational tools will be presented, using as a case-example the Paraná River basin, located in the southeastern region of Brazil.

Key Words: Planning, Flood Control, Controllability Conditions, Multiple uses

1. INTRODUCTION

Due to Brazil's large hydro potential, the Brazilian energy matrix is basically hydroelectric, approximately 67.4% of Brazil's installed capacity is hydro (ANEEL, 2014), which makes it possible to generate electricity using an abundant, clean and renewable source.

Law no. 9,433/97 (BRAZIL , 1997) , known as " water law " - instituted the National Water Resources Policy and set up water as a public good with economic value, with priority uses the human supply and watering animals. This policy states that the management of water resources should allow multiple use of water, with the right of equal access to the use of water resources by all user sectors. With the increasing use of the Brazilian hydro resources for purposes other than electric power generation, several constraints on the operation of hydroelectric plants and their reservoirs comprising the Brazilian Interconnected Power System (BIPS) were imposed. For example , the use of hydroelectric plants reservoirs for flood control imposes constraints such as maximum outflows to prevent flooding in cities, highways and bridges downstream of the reservoir and maximum levels to prevent from flooding upstream of the reservoir. The protection of these constraints leads to the need to use part of the reservoirs volumes for floods "damping" and it may create a conflict between these two uses, considering that most of the hydroelectric plant reservoirs was not designed considering flood control.

Since, in view of power generation, the role of the reservoir is to store water (energy) in periods of abundance to be able to use it in times of scarcity, the operation of hydroelectric plants reservoirs must be held so that at the end of the rainy season, reservoirs volumes are full to be able to face the next dry season and use this water for power generation. Thus, it seeks to minimize deficit risks of and operating costs (e.g. the use of thermal power plants). On the other hand, for flood control, the function of the reservoir is to store the volume of floodwater that occur in the basin, to keep outflows below a limit that does not cause damage downstream (outflow constraint). Then, the reservoir should keep an empty volume (waiting volume) to be occupied when the flood occurs. From the foregoing, there is a conflict between the two uses, since the first seeks to keep the reservoirs filled and the second needs to keep part of them empty in the same period. This justifies the need for a carefully and optimized allocation of waiting volume, so that the conflict between the two uses is minimized.

The operation planning of the BIPS facilities seeks to minimize this conflict through the Floods Annual Plan (FAP) (ONS, 2013). In this plan, run by the Brazilian Power System Operator (ONS) every year, before the beginning of the rainy season, are set the waiting volumes for the reservoirs located in basins where there are flood control operational constraints. The definition of these volumes is associated with a certain protection risk to the valley downstream of the reservoir, in terms of recurrence time or the probability of flooding. Aiming to reduce the conflict between these two uses and seeking an allocation of optimal waiting volume, the electric power sector has been developing and improving methodologies for defining and using waiting volumes. The current methodology in use was developed by CEPEL (Electric Energy Research Center) (Costa et al, 1999) and adopts a number of features to better define the waiting volumes , such as: (i) seasonal allocation of waiting volumes during the rainy season. Thus, the necessity of waiting volume will be smaller in the beginning and at the end of the wet season, that means, the waiting volume will be higher at the moment that it requires more volume (Kelman, 1987); (ii) Stochastic approach to calculate the waiting volumes. Once the flood study is prepared before the beginning of the rainy season, it is not possible to know which inflow sequence will occur, then synthetic scenarios of possible daily flows in the basin during the rainy season are used; (iii) For the protection of a flood control point, it is not only considered the reservoir immediately upstream, but all upstream of the control point (where there is constraint) (DAMAZIO, 1988); and (iv) Consideration of macro-climatic information for the generation of synthetic daily inflow scenarios. The flood control uses as climate information ENSO (El Niño - South Oscillation) (Costa et al, 1996).

This paper aims to present the methodology for calculation of waiting volumes to be allocated in the reservoirs of hydroelectric plants to be used for flood control in the BIPS.

2. FLOOD CONTROL AND ELECTRIC POWER GENERATION IN BRAZIL

2.1 Operation Planning of the Brazilian Hydrothermal Interconnected System

With size and characteristics that allow us to consider it singular worldwide, the interconnected system of production and transmission of electric power in Brazil is a large hydrothermal system, with a strong predominance of hydroelectric plants and multiple owners. The BIPS is formed by the basins of the Southern, Southeastern, Midwestern and Northeastern regions and part of the Northern region. Only 1.7% of the country's electricity production capacity is out of the BIPS, in small isolated systems located mainly in the Amazonian region (ONS, 2014). In May 2014, the installed capacity in Brazil reached a total of 128,286 MW, of which 86,420 MW in hydro power plants (including small hydro plants) and 38,700 MW in thermal power plants (ANEEL, 2014). Due to the magnitude of the system with large reservoirs spread over large geographic areas, any decision implies different spatial and temporal consequences, making the problem quite complex. Then, there is a relationship between the decision-making at any stage and its future consequences. If in the present, the option is to use lots of water for power generation, system reservoirs levels will be lower, so if a period of low inflows occurs, the deficit risk regarding demanded electric power supply will increase, which will drive to the necessity to operate the thermal power plants, increasing operation costs. Likewise, if in the present it is chosen to generate thermal energy in order to store hydraulic energy and if in the future a period of high flows occurs, system power spillage will be necessary, which leads to a more expensive and unnecessary operation. Therefore, it is necessary that the BIPS operation is preceded by a planning, in addition, the coordination of the operation of the reservoir system of the power sector, in conjunction with the operation of thermal power plants complementation allows the best use of the natural flows, avoiding the waste of water and excessive fuel costs. This coordination is done within the so-called Operation Planning of the Interconnected Power System, currently performed by ONS.

Today this planning is made in three steps, and in each of them the mathematical models used have different planning horizons, discretization of time and degree of detailing in the representation of the generating units and operational constraints. These models are linked through coupling, at the end of their horizons, of allocation policies of hydro and thermal resources produced by the modelof the previous step, forming a chain of models developed by CEPEL (MACEIRA et al, 2002). At the top of the chain is the medium-term planning, where the stochastic optimization model, NEWAVE, gets the allocation policy of hydro and thermal resources of minimum cost for each month considering a time horizon of five to ten years. The hydroelectric plant is represented in an aggregated way in four equivalent reservoirs of energy, representing the subsystems of the south, southeast, northeast and north. Next, in the short-term planning, the DECOMP model, also of stochastic optimization, determines a scheduling for each system's power plant for the weeks of the following month and for the next month. At the base of the chain, is the daily programming, under implementation, where the DESSEM_PAT model, of deterministic optimization, will calculate the generation dispatch for each half hour of the following day. In this planning, the main objective is to minimize the expected value of the operation cost (thermal generation spending and penalties for not meeting demand) over the planning horizon, taking into account physical constraints and system reliability. However, in the planning, one must consider a lot of activities related to the multiple use of water in reservoirs in conjunction with the generation dispatch and multiperiod optimization of reservoirs. It is highlighted water withdrawals for other uses and flood control.

2.2 Flood Control in the Brazilian Hydrothermal System

Currently, one of the activities of the Operation Planning of the BIPS is the Flood Prevention Study. This study can be divided into two stages: i) definition of empty volumes to be reserved in the reservoirs (named waiting volumes) during the rainy season, which will serve to damp the possible flooding that may occur in the basin, considering a particular risk and ii) planning the use (filling/emptying) of these volumes during the occurrence of flooding.

Just as in the Operation Planning of the BIPS, the Flood Prevention Studies are also conducted using mathematical models. In the first stage of these studies, to define the waiting volumes, the SPEC System (Costa et al, 1999) is used. It is formed by three connected models: DIANA, CAEV and VESPOT. Until the year 2012, in all basins where BIPS's reservoirs were also used for flood control, the SPEC System was adopted, with exception for the Paraiba do Sul River basin. On this basin, the methodology used was the Volume-Duration Curve (ONS, 2010). In 2013, it was included another model (SIMRESC) to the SPEC system to allow consideration of reservoirs that do not have outflow control, as is the case of two hydroelectric plants of the Paraiba do Sul River basin (Costa et al, 2013). In the second stage of studies, to aid decision making regarding filling / emptying of waiting volumes in the event of a flood the models used are OPCHEN (RAUPP et al, 2011), OPCHEND (Costa et al, 2014) and OPCHENS (COSTA et al, 2012).

3. METHODOLOGY FOR CALCULATING WAITING VOLUMES

The methodology for calculating the waiting volumes to be allocated in the reservoirs of hydroelectric plants can be divided into two phases: (i) generation of synthetic inflow scenarios and (ii) calculation of waiting volume curves.

3.1 Generation of Synthetic Inflow Scenarios

The first stage of the Flood Prevention Studies are conducted before the beginning of the rainy season, through the FAP. In this plan waiting volumes to be allocated in the reservoir throughout the rainy season are set, thus, when the rainy season starts, it is already known for each reservoir how much volume must be empty at each time interval of the rainy season. An assessment of energy impacts from the allocation of waiting volumes in the BIPS's reservoirs is also performed. Once the waiting volumes are defined before the beginning of the rainy season, it is not possible to know which will be the sequence of daily inflows that will occur during the season. This problem, due to the randomness of the flows is stochastic. A way to treat it is to consider a set of synthetic scenarios of possible daily inflows, for that it is used the DIANA model (KELMAN et al, 1983), a stochastic model for generating multivariate synthetic daily inflow scenarios. This model was developed to reproduce striking and difficult characteristics concerning daily inflow series, such as exaggerated asymmetry, strong seasonality and the diversity of rises and recessions of daily hidrogram.

In order to generate more credible synthetic scenarios, it is used the macroclimate trend, ENSO (El Niño - Southern Oscillation), represented by the Southern Oscillation Index (SOI). The way adopted to consider this information was to generate synthetic daily inflow scenarios conditioned to ENSO's phases (Wet, Dry and Normal). Through a criterion that relates wetter (greater occurrence of floods), drier or normal rainy seasons with SOI index values (ONS , 2013), for each river basin where flood control is considered, the sequences of daily inflows of historical rainy seasons are then classified into wet, dry or normal, forming three sets of historical inflows. Each of these sets is used to estimate the parameters of the stochastic model DIANA. From the three sets of parameters, three sets of synthetic scenarios of daily flows are generated. Figure 1 illustrates this procedure. As it is not possible to know in advance how to configure the subsequent rainy season will be, in the FAP for each of the three sets of synthetic daily flow, it is calculated the waiting volumes, as described in the next item, and before the beginning of the rainy season, it is checked the classification of the rainy season in question and according to the result, it is used the corresponding waiting volume curve.

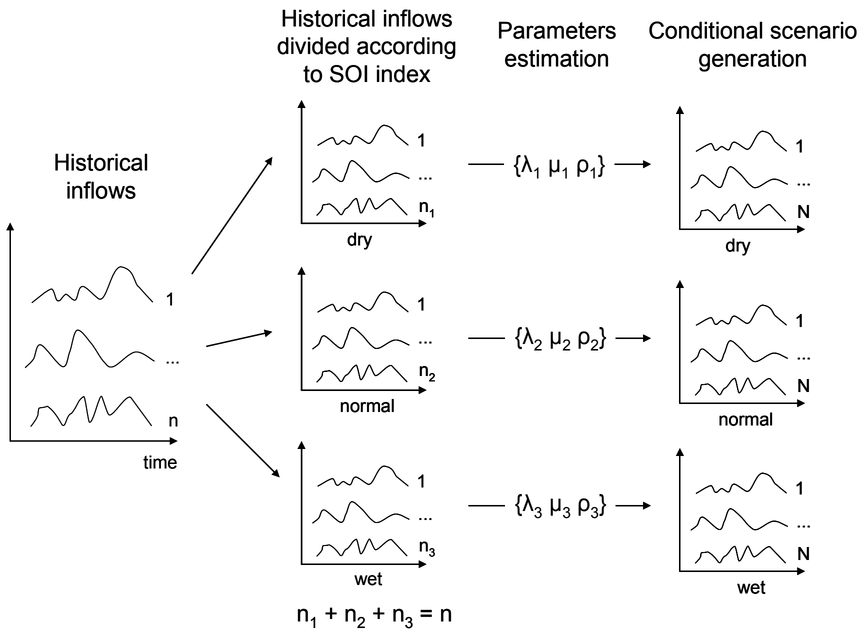


Figure 1: Conditioned generation of synthetic daily inflows scenarios.

3.2 Calculation of Waiting Volumes Curves

Since 1997, the methodology for calculating the waiting volumes to be allocated in the BIPS's reservoirs is based on the Theory of Controllability Conditions (DAMAZIO et al, 1994). This theory is an extension of the Critical Path method (KELMAN, 1987) for systems with multiple reservoirs and multiple flood control points.

3.2.1 Method of Critical Path

The critical path method consists of a water balance between the amount of water that arrives at the reservoir (inflow), the maximum outflow that can be thrown, according to the flood control point constrain (outflow constrains), and the waiting volumes allocated in the time step before. This method uses a backward algorithm in time, i.e., the calculation is done from the last day of the rainy season (T) until the first day, as eqn. 1, assuming the waiting volume on the last day of the season equal zero, VE(T,s)=0, since from the end of the season, it will no longer be necessary to allocate waiting volumes.

$$VE(t-1,s) = \max[0,(Q_{AFL}(t-1,s) - Q_{RESTR}) \times \Delta t + VE(t,s)],\ t = T,...,1 \qquad [1]$$

Where VE (t, s) is the waiting volume for the end of the t-th day of the s-th rainy season, T is the last day of the rainy season, Q_{AFL} (t, s) is the average daily inflow of t-th day of the s-th rainy season, Q_{RESTR} is the constraint outflow and Δt is the number of seconds in a day.

By equation 1, it is observed that for the penultimate day of the rainy season (T-1), the calculation is simply the difference between the inflow and the constraint flow, since the waiting volume of the Day "T" is previously defined by the methodology as equal to zero. From the penultimate day (T-2), calculating the waiting volume is influenced by the waiting volume allocated on the next day (T-1), previously calculated. Calculating the waiting volumes for all the days of the rainy season of a year, it is obtained the critical path (allocation of empty volume over the period considered) for this rainy season. This curve will ensure the protection of the valley downstream from the reservoir to a specific season, which means, for the sequence of inflows considered. For each of the synthetic scenarios generated in the previous stage, it is then calculated the corresponding critical path.

If the goal is to provide 100% protection, given this set of scenarios, it must defined the covering critical trajectory (envelope curve), calculated using equation 2, which provides the limit curve, which guarantees the protection of the control point for all scenarios considered. The envelope curve is defined mathematically as:

$$ENV(t) = \max[VE(t,c);c = 1,...,n];t = 1,...,T \qquad [2]$$

Where ENV(t) is the envelope curve for the t-th day and n is the number of scenarios considered in the calculation of the envelope curve.

If the valley protection is associated with a particular risk, then there is need to ensure that the outflow does not exceed the constraint outflow for all scenarios. The number of scenarios, for which will not be guaranteed that the outflow does not exceed the constraint outflow, is the risk function (return time):

$$TR = 1 / P \qquad [3]$$

$$N = N_{SS} / TR \qquad [4]$$

$$N_{PROT} = N_{SS} - N \qquad [5]$$

Where P is the risk associated with not protecting the control point, which means, the waiting volumes defined in the envelope curve are not able to protect the control point, TR is the return time (in years), N_{SS} is the total number of synthetic scenarios considered in the study, N is the number of synthetic scenarios that will not be protected and N_{PROT} is the number of synthetic scenarios that will be protected by the waiting volumes defined in the envelope curve.

It is worth noting that currently there is no legislation regarding the determination of the return time to be used. Thus, the return time used by the FAP, for each basin and control point, where the BIPS's reservoirs are used for flood protection, it is agreed among ONS, the basin's generating agents that have reservoirs that will be used for flood control, the Brazilian Water Agency (ANA) and the Brazilian Electricity Regulatory Agency (ANEEL).

Set the number of scenarios to be protected (N_{PROT}), it must be chosen a criterion for the disposal of N scenarios that will not be protected and, therefore will not be considered in calculating the envelope curve. This criterion considers the viewpoint of the electric power generation, since, for flood control, what matters is the associated risk, which is independent of the criterion for scenarios rejection. One of the most used criteria is the maximization of the waiting volumes recovery probability (FRANÇA & CANELLA, 1994), which is associated to maximize the probability of recovering the waiting volumes, since it does not consider the scenarios that require higher inflows to ensure that the reservoir is full at the end of the rainy season. The variable that will determine which scenario will be discarded is the maximum tangent, according to the expression:

$$TAN_{MAX}(c) = \max\left[\frac{VE(t,c)}{\Delta t}; t = 1,...,T\right]; c = 1,...,N_{SS} \qquad [6]$$

Where $\Delta t = (T + 1) - t$ and TAN_{MAX} (c) is the maximum tangent of the c-th scenario;

The N scenarios to be discarded will be those presenting higher values for maximum tangent. This criterion is most suitable for basins where there is a dry season and a rainy season, well defined, being desirable to terminate the rainy season with full reservoirs, in order to face the subsequent dry season.

3.2.2 Theory of Controllability Conditions

The method of critical paths was developed to determine the necessary waiting volume when considering just one reservoir and one flood control point. To solve the problem of determining the waiting volumes in systems with multiple reservoirs and flood control points, it was developed the Theory of Controllability Conditions (DAMAZIO et al, 1994). Controllability conditions are a set of linear constraints that establish the reservoirs' and set of reservoirs' necessary waiting volumes lower limit that ensure the protection of basin's flood control points, given a sequence of inflows. For the development of the Controllability Conditions, it was necessary to define the partial system (MARIEN, 1984). It is defined as a partial system, (s.p.) all reservoirs set having only one outflow point and this is a main point of the flood control. Thus, the reservoirs system of Figure 2, which has two flood control points P1 and P2 and two reservoirs R1 and R2, has three partial systems: SP1={R1}, SP2={R2} e SP3={R1, R2}.

The equations that represent the Controllability Conditions for the system of Figure 2, considering only one inflow scenario are, according Damazio et al (1994):

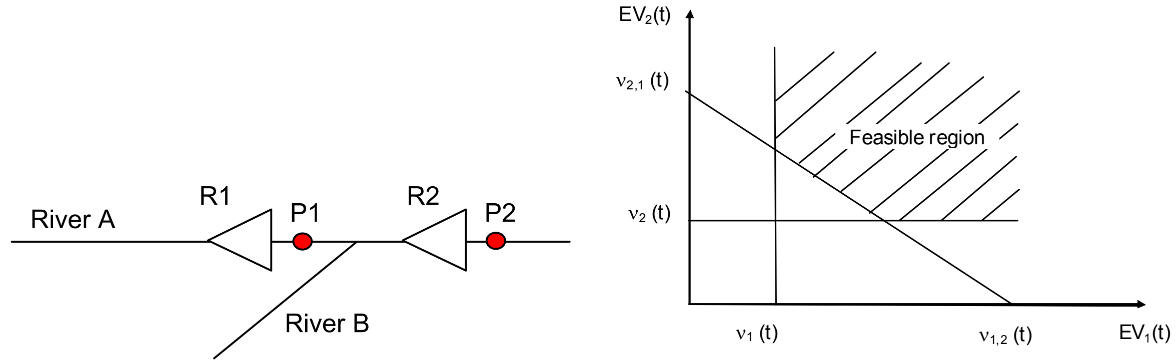
$$Vv_{R1} \geq VE_{SP1}(t); t = 1,...,T \qquad [7]$$

$$Vv_{R2} \geq VE_{SP2}(t); t = 1,...,T \qquad [8]$$

$$Vv_{R1} + Vv_{R2} \geq VE_{SP3}(t); t = 1,...,T \qquad [9]$$

Where $Vv_{R1}(t)$ is the empty volume in the R1 reservoir to the t-th day, $Vv_{R2}(t)$ is the empty volume in the R2 reservoir to t-th day, $VE_{SP1}(t)$ is the waiting volume in the partial system 1, necessary to ensure the P1 flood control point protection in view of the inflows scenario to R1 on the t-th day; $VE_{SP2}(t)$ is the waiting volume in the partial system 2, necessary to ensure the protection of the P2 flood control point in view of the inflows incremental scenario to R2 on the t-th day; and VE_{SP3} (t) is the waiting volume of the partial system 3, necessary to ensure the protection of the P2 flood control point considering the inflow scenario to R1 and R2 on the t-th day. The right side of equations 7-9 are the minimum limits of waiting volumes required to ensure the protection of the basin's flood control points. These limits are obtained from the Theory of Controllability Conditions, an extension of the critical paths, equation 1. To consider the inflows uncertainty, the calculated values to the right side of the equations 7-9, should be replaced by their envelope curve.

To enable to allocate in the basin's hydroelectric plants reservoirs the waiting volumes defined for each time interval on partial systems envelope curves, it is necessary to distribute these volumes through the basin’s reservoir set. In the example shown in figure 2, the domain of (feasible) possible solutions to the spatial distribution of waiting volumes is shown graphically in figure 3.



(a) (b)

Figure 2: (a) Topology of the hypothetical river and (b) Region of feasible solutions to the allocation of figure 2 s.p. waiting volumes through R1 and R2 reservoirs.

The spatial distribution of partial systems waiting volumes through reservoirs is obtained by solving a linear stochastic problem whose objective function reflects the interests of electric power generation (COSTA et al, 1999), seeking to avoid unbalanced waiting volumes allocations where reservoirs exaggerated depletion may impair the system’s hydroelectric generation capacity. To this end, three options are considered to objective functions: proportional allocation of system reservoirs’ waiting volumes, allocating by priorities and bands, where it is started the allocation of waiting volumes for those reservoirs whose depletion causes less loss of the system productibility and, finally, allocations associated with the basin’s potential to flood exposure, in this case it is prioritized the allocation in the reservoirs where the occurrence of flooding is more frequent. The choice of the objective function depends on each basin’s characteristics. The solution technique adopted makes use of Benders decomposition and network flow algorithms, using the envelope curves of the partial systems as constraints of the problem, to accelerate the method convergence.

4. SPEC SYSTEM

The methodology to calculate waiting volumes to be allocated in hydro plants reservoirs flood protection, described in Section 3, was implemented in the computational system SPEC - Flood Control Studies System. This system consists of five modules:

- The historical daily flows sequences classification in wet, dry and normal - ENSOCLAS;
- Generation of synthetic multivariate daily inflows scenarios - DIANA;
- Decomposition of hydro plants reservoirs system in partial systems, calculation of daily inflows synthetic scenarios critical paths, and calculation of partial systems envelope curves - CAEV;
- Spatial distribution of the envelope curve of partial systems by basin’s reservoirs - VESPOT; and
- The SIMRESC module to deal with basins reservoirs with no outflow control, and these located upstream of the flood control system (COSTA et al, 2013).

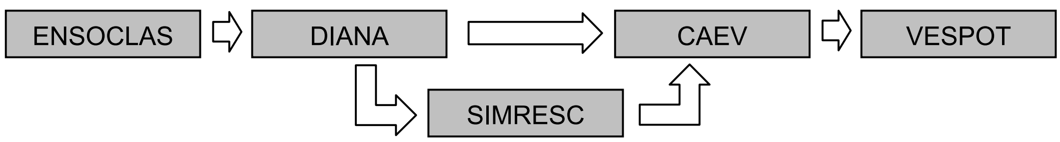


Figure 4: SPEC System

5. CASE STUDY: PARANÁ RIVER BASIN

The case study considered the Parana River Basin, chosen due to its major importance regarding energy production and significant need to allocate seasonal waiting volumes This basin covers part of the states of Sao Paulo, Minas Gerais, Goias, Mato Grosso do Sul and Parana, receiving contributions of the Paranaiba, the Grande, the Tiete and the Paranapanema River basins, as illustrated in Figure 5. The total storage capacity of the river basin hydropower reservoirs is about 106 km³ and the basin's generating capacity is 43,302 MW, which represents approximately 47% of Brazil's total generation (ELETROBRAS, 2013). The Parana River basin's rainy season comprises the months from November to April. As shown in Figure 5, the flood control system used in the study is composed of 19 hydropower plants that are used for energy generation and flood control, and 14 flood control points with maximum outflow constraints. Table 1 shows the main characteristics of the hydropower plants used for flood control.

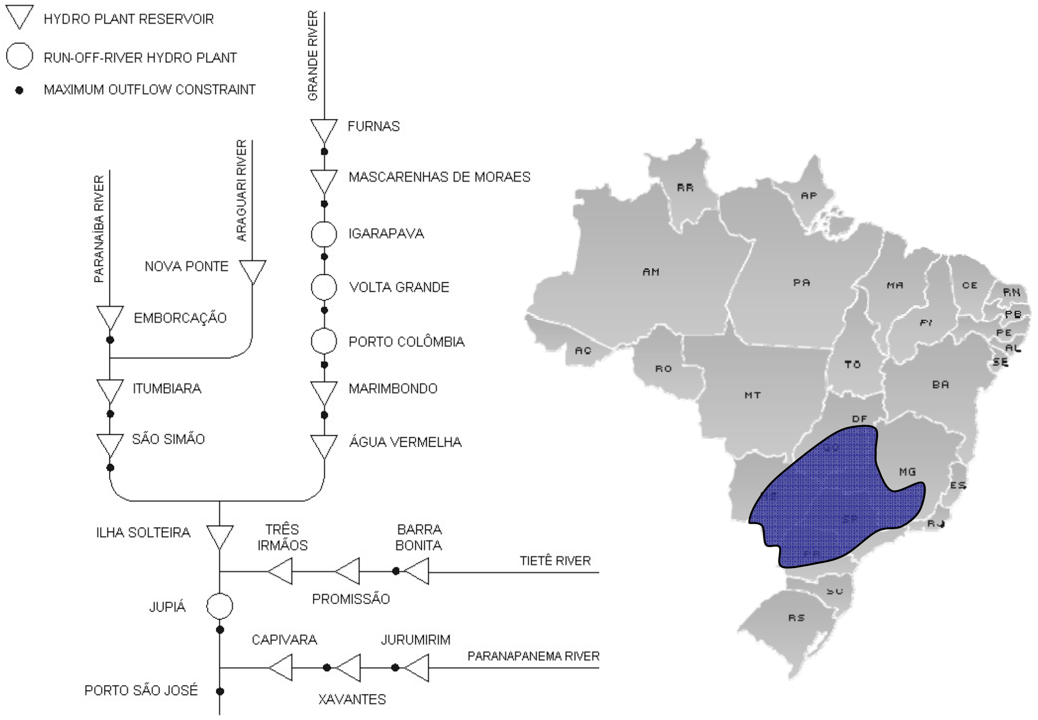


Figure 5: Parana River Basin topology and location.

The most striking constraint to calculate this basin's waiting volumes is the maximum outflow constraint (16,000 m3/s) of Jupia hydropower plant (HPP), since its return time associated is approximately 4 years and Jupia's HPP reservoir is run-of-river, so Jupia's upstream reservoirs are responsible for allocating waiting volumes to protect this constraint.

To present the result of using the methodology, it was considered the 2008/2009 rainy season (ONS, 2008), using the natural inflows historic series that encompassed the years 1949-2006. The classification of years (sequences of the rainy season historical daily inflows) according to ENSO's phases was based on the SOI index (South oscillation index), according to criteria described by Costa et al (1996). The 57 years of the historic were divided in 10 dry years, 34 normal years and 13 wet years. For each of the three sets of the historic series were generated 12,000 (N_{SS}) synthetic scenarios of daily inflows to the basin's hydroelectric plants through the DIANA model. For each set of scenarios CAEV model was used to calculate the critical paths of all scenarios. The return period considered was 30 years for all basin's control points, resulting in no protection of 400 synthetic scenarios (N = 400) of all the 12,000 scenarios. The calculation of the individual envelope curves for each reservoir used the VESPOT model.

Table 1: Hydropower plants on the Parana River Basin used for flood control

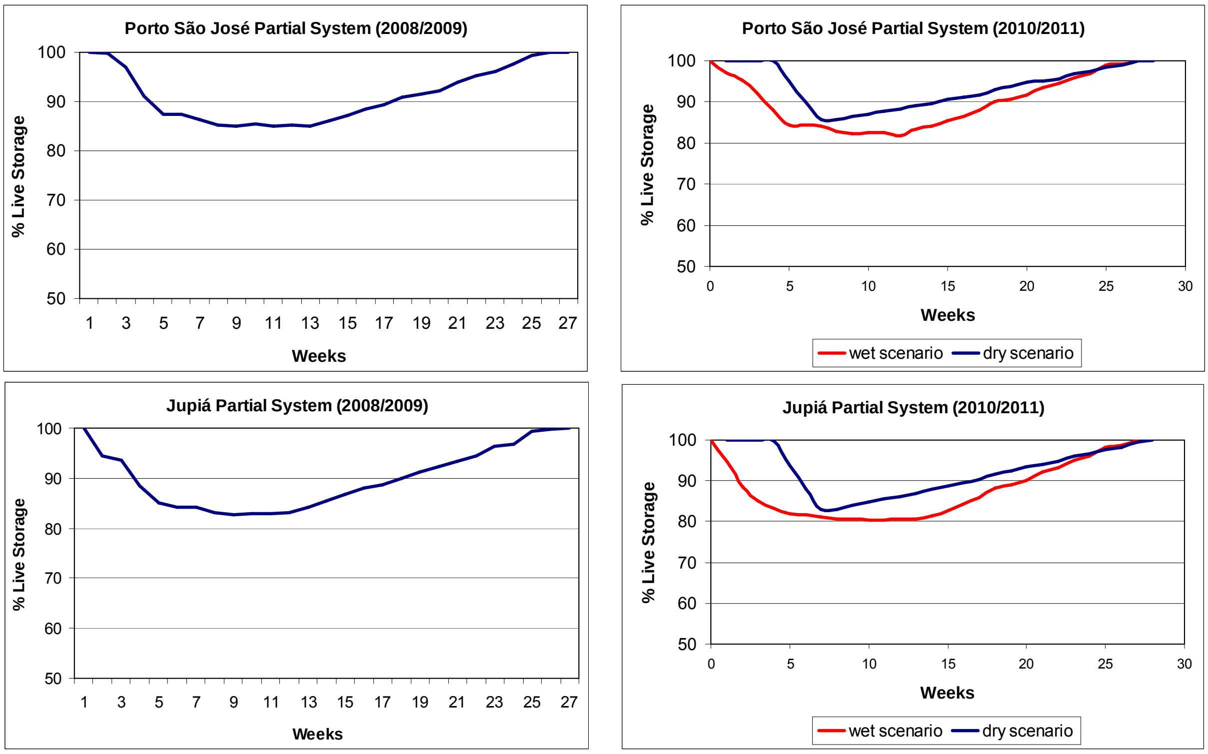
Hydropower Reservoir (HPR)	Maximum outflow constraint (m^3/s)	Storage Capacity (Km^3)
Furnas	4000	17.217
Mascarenhas de Moraes	4400	2.499
Igarapava	4500	0.035
Volta Grande	5000	0.268
Porto Colombia	7000	0.233
Marimbondo	8000	5.260
Água Vermelha	-----	5.169
Emborcação	5000	13.056
Nova Ponte	-----	10.380
Itumbiara	7000	12.454
São Simão	16000	5.540
Barra Bonita	2000	2.566
Promissão	-----	2.128
Jupiá	16000	0,903
Chavantes	2000	3.041
Capivara	-----	5.724
Ilha Solteira-Três Irmãos	-----	8.965
Jurumirim	1200	3.165
Porto São José(1)	24000	-----

(1) Porto São José is not a hydropower reservoir; it is only a flood control point

Figure 6a shows the envelope curve for normal scenario calculated by the CAEV for the basin's largest partial system, whose outflow point is the control point downstream of Porto Sao Jose. This partial system is formed by the reservoirs of all power plants in the basin, totaling 111 km^3 of storage capacity. Figure 6a also shows the envelope curve considering the control point downstream of Jupia power plant, whose maximum outflow constraint is the most restrictive of the basin. This partial system is formed by all hydroelectric plants reservoirs upstream Jupia, totaling 98 km^3 of storage capacity.

From the envelope curve presented, it can be observed the curves seasonality along the rainy season, with a higher allocation of waiting volume between weeks 5-11, representing the end of December, January and early February, the time inflows are higher. As the method of disposal was the maximization of the waiting volumes recovery probability, there is a slight decrease in waiting volume, to allow a higher probability of completing the rainy season with fuller reservoirs. If the waiting volumes were too big in the final weeks of the rainy season, it will be more difficult to fill the reservoir up to 100% in few weeks, especially in the end of the season when inflows are, in general, lower. Regarding the envelope curves related to single reservoirs, figures 7, 8 and 9 show the waiting volume curves calculated for three reservoirs of the basin (Furnas, Itumbiara and Barra Bonita, respectively) for the normal scenario (2008-2009 rainy season classification).

For the 2010-2011 rainy season (ONS, 2010), a new classification methodology began to be used, considering the non-standard SOI index, whose series begins in 1951, so the historic series used was from 1951 to 2008. Besides, it was changed the way to classify years in wet, normal and dry. The new classification divided the historic series in 11 wet years, 7 dry and 39 normal years. The rainy season was classified as a dry season and the envelope curve calculation used the methodology presented in this paper. The envelope curve considered for Jupia and Porto Sao Jose partial systems are presented in figure 6b and reservoirs envelope curves of Funil, Itumbiara and Barra Bonita are presented in figures 7, 8 and 9 respectively. Out of curiosity, to illustrate the difference in waiting volume allocation between dry and wet scenarios, in the figures, were also added the waiting volume curves for the wet scenario. One can note the difference with respect to waiting volume allocation between the dry and wet scenarios throughout the rainy season.



(a) (b)

Figure 6: Porto Sao Jose and Jupia partial systems envelope curve.

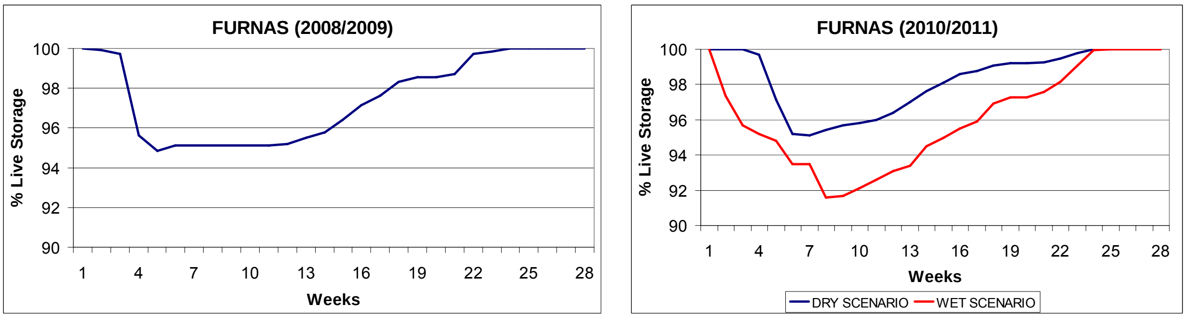


Figure 7: Furnas reservoirs' envelope curve: 2008/2009 normal scenario and 2010/2011 dry and wet scenarios.

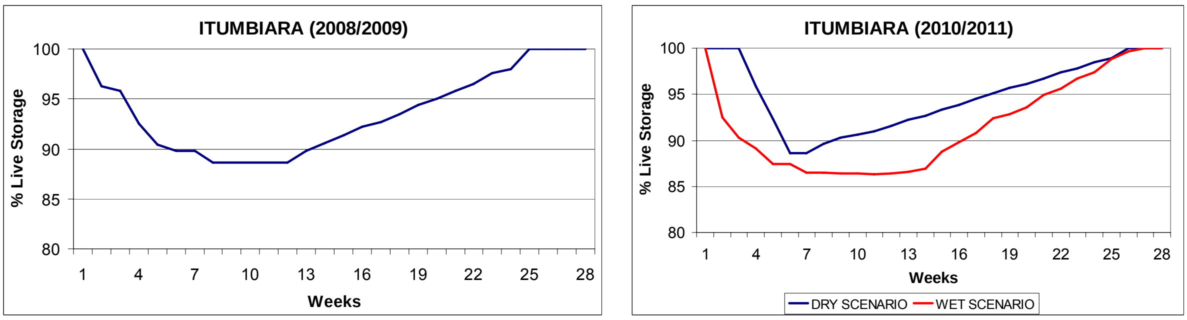


Figure 8: Itumbiara reservoirs' envelope curve: 2008/2009 normal scenario and 2010/2011 dry and wet scenarios.

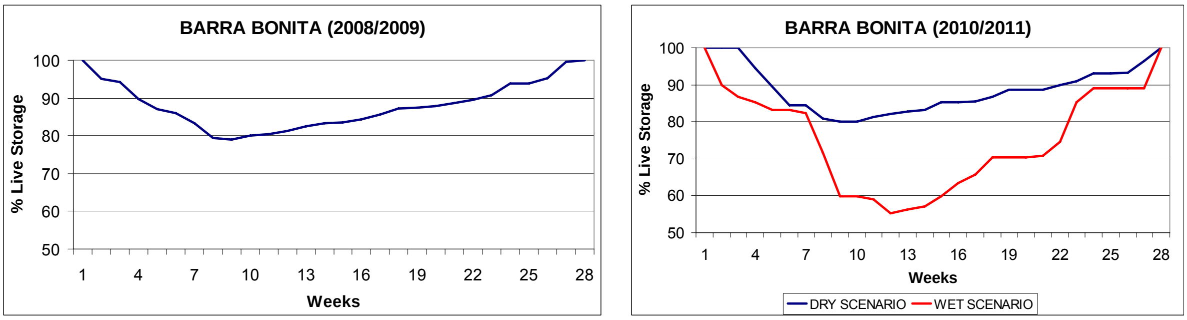


Figure 9: Barra Bonita reservoirs' envelope curve: 2008/2009 normal scenario and 2010/2011 dry and wet scenarios.

6. CONCLUSIONS

This paper presented the methodology currently in use to consider the flood control in reservoirs used for electric power generation, through the allocation of empty volumes during rainy seasons. In order to reduce the conflict between these two uses of the water in the reservoirs, waiting volumes calculation uses some rules in order to obtain more optimized volumes. They are: consideration of macroclimatic information (South Oscilation index), seasonal allocation of waiting volume during the rainy season, use of synthetic inflow scenarios and consideration of all reservoirs upstream of a flood control point for their protection. Besides the methodology, the SPEC system was also presented, which aims to calculate the waiting volumes to be allocated in the reservoirs.

As it could be observed in implementing the methodology undertaken in the Parana River Basin for two distinct rainy seasons: 2008-2009 (normal scenario) and 2010-2011 (dry scenario). For 2010-2011 season, were also presented the wet scenario. The waiting volumes allocation for wet and dry scenarios are very distinct, with a higher allocation of volume to wet scenarios, as expected. The dry scenario allocates lower volumes seeking a higher probability of getting 100% full reservoirs at the end of the rainy season in order to use this water for power generation during the subsequent dry season. Comparing the waiting volumes allocation of the two rainy seasons, the normal scenario (2008-2009) allocates more volume than the dry scenario (2010-2011), but less volume than the wet scenario (2010-2011), as expected.

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