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USE OF SYNTHETIC STREAMFLOW FOR FLOOD CONTROL IN A MULTIRESERVOIR SYSTEM

L'utilisation de débits synthétiques pour le contrôle des inondations dans un système à réservoirs multiples

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Abstract: A multivariate daily streamflow model produces thousands of synthetic sequences which are used to calculate the flood control storage in a hydropower multi-reservoir system. The model is briefly described, as well as the algorithm for flood control storage allocation. An application for the Parana River in Brazil is also described.

Résumé: Un modèle de débit quotidien multivarié engendre des milliers de séquences synthétiques qui sont utilisées pour calculer le stockage permettant de contrôler les inondations dans un système hydro-électrique à réservoirs multiples. Le modèle est brièvement décrit ainsi que l'algorithme permettant de déterminer le stockage de contrôle des inondations. La communication décrit également une application à la rivière Parana au Brésil.

1. INTRODUCTION

The efficient use of multireservoir systems requires careful operation planning. As an example, consider a simple system with one reservoir R_1 with two purposes

(i) reduction of the probability of causing downstream inundation, and

(ii) optimization of power production.

According to the flood control objective the available storage, K_1, should only be allowed to store water during a flood event. After its ocurrence, a complete drawdown should be accomplished. According to the power production objective the reservoir storage should be kept as full as possible and any drawdown only allowed during a dry period. This conflict is resolved by allocating a predetermined space for flood control. A careful calculation of this storage should consider the frequency distribution of flood peaks and volumes taking into account seasonal variation. The problem is made more complex if there are other reservoirs upstream of R_1. A succesful plan requires careful coordination of the tributary and mainstream reservoirs' flood control storages, and the calculation should consider the spatial pattern of floods in the valley.

In the next sections it will be seen the importance of stochastic multivariate short time interval streamflow models in the planning of flood control operation for multireservoir system. First it will be briefly described a stochastic multivariate daily streamflow model, the DIANA model, which was developed for flood control and dam-safety studies in Brazil (Kelman et al [1]). Second, it will be shown a methodology for planning the flood-control operation of multi-reservoir systems based on the use of synthetic sequences generated by stochastic models. Third it will be presented an application for the Parana river in Brazil.

2. DIANA MODEL

The runoff q(t) on day t is considered to be the sum of two components:

$$q(t) = u(t) + o(t); \; t=1, 2, \ldots \tag{1}$$

There are two aspects to consider in the modelling of the u(t) process:

i) Its marginal probability distribution has a probability mass p at u(t) = 0

ii) The external factors that govern the rising limbs of the hydrograph may result from persistent meteorological processes (e.q. cold fronts). The modelling of the u(t) process must be able to reproduce this induced time persistence.

In large basins, floods result from the coincidence of several events which are not necessarily exceptional. Indeed, a major flood in a large basin is usually shaped by the persistence of minor daily increments of flow. These increments can already be present in the sample. In this case using the empirical frequency distribution of u(t) one has no need to make any assumption regarding the shape of the distribution. This is the method adopted in the DIANA model. Persistence in the DIANA model is modelled through an AR(1) process with censoring. This process is transformed into u(t) using a non-parametric relationship that preserves the empirical distribution $F_U(.)$.

Let z(t) be the AR(1) process defined by:

$$z(t) = \rho\, z(t-1) + \sqrt{1-\rho^2}\;\;\varepsilon\,(t) \qquad (7)$$

where $\varepsilon(t)$ is a normally distributed white-noise and ρ is the lag one autocorrelation of z(t).

y(t) results from imposing a censoring in z(t) and is defined as:

$$y(t) = z(t) \quad \text{if} \quad z(t) > \beta \qquad (8a)$$

$$y(t) = \beta \quad \text{if} \quad z(t) \leq \beta \qquad (8b)$$

$$\beta = \Phi^{-1}(p) \qquad (8c)$$

where β defines the censoring interval $(-\infty, \beta)$, $\Phi(.)$ is the c.d.f. for the standard normal distribution, and $p = P[u(t) = 0]$.

The relationship between u(t) and y(t) is obtained solving the equation $F_U(u(t)) = \Phi(y(t))$.

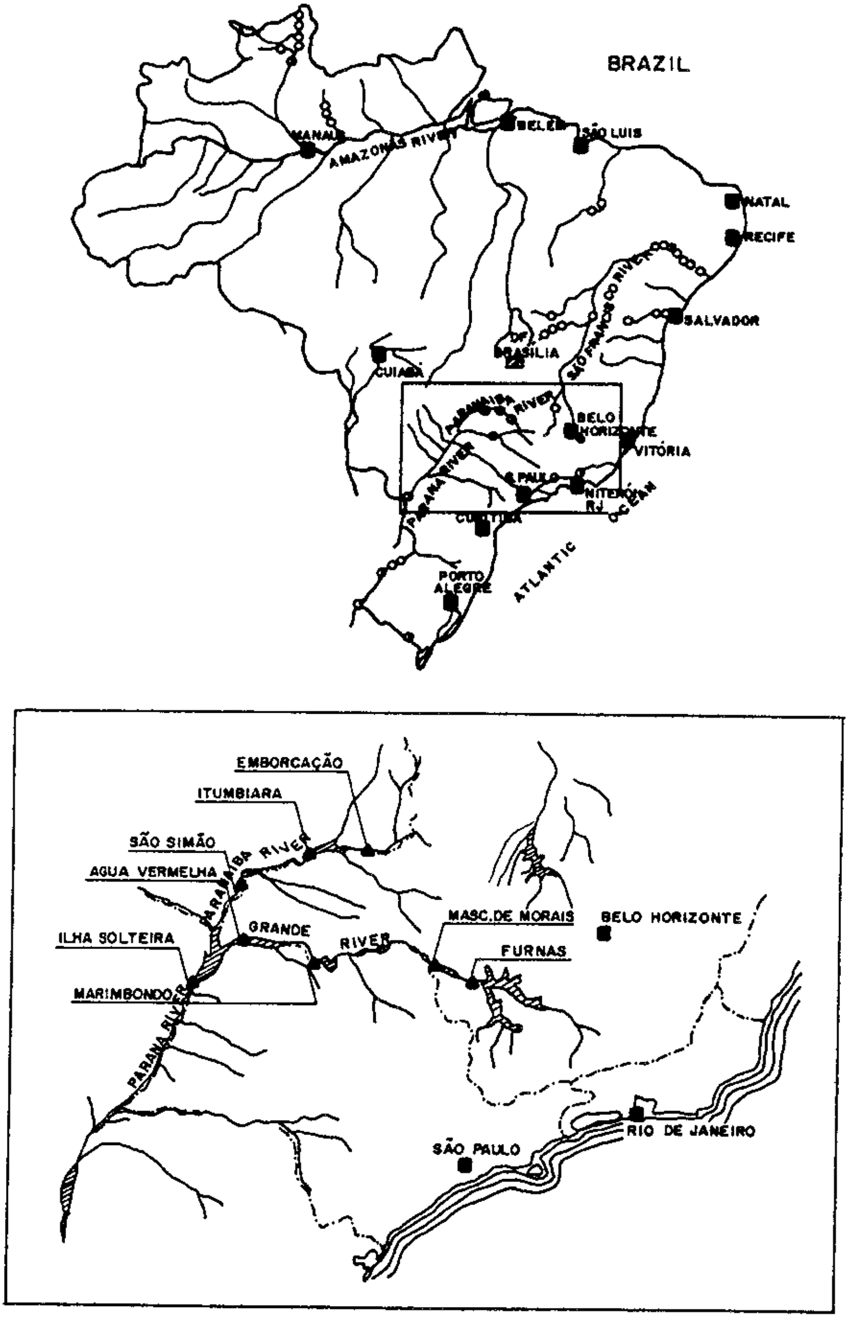

FIGURE 1 - RESERVOIR SYSTEM

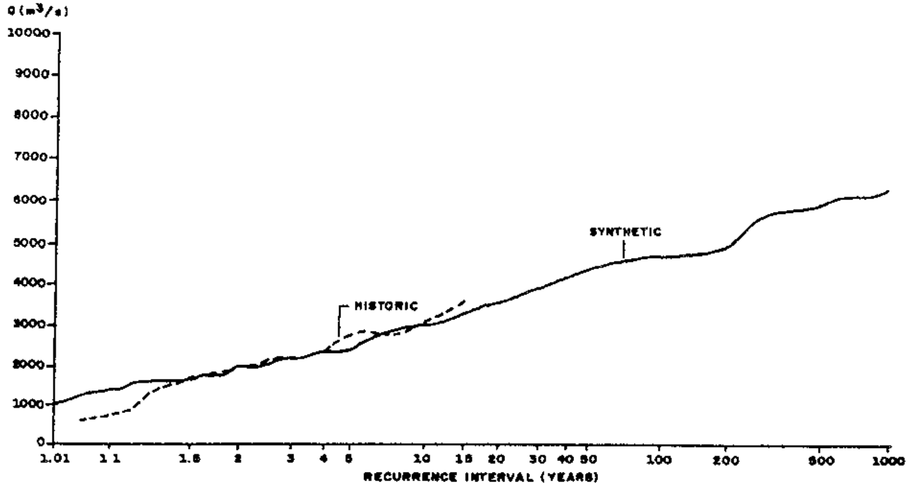

FIGURE 2 - FLOOD FREQUENCY CURVE FOR EMBORCAÇÃO

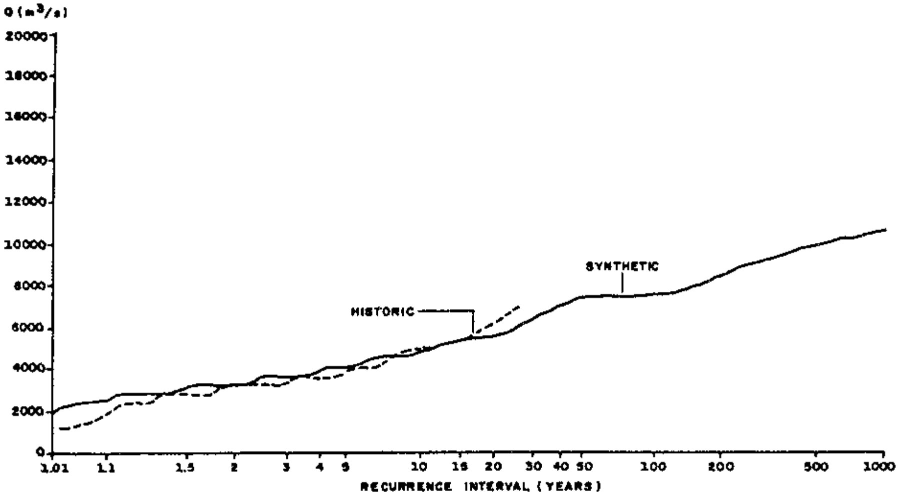

FIGURE 3 - FLOOD FREQUENCY CURVE FOR SÃO SIMÃO

$$VM_u(t)=\min[\sum_{j\varepsilon u} K_j;\ Q+VM_u(t+1)-\sum_{j\varepsilon u} q_j(t+1)],\ t=h-1,\ \dots,\ 0 \qquad (18)$$

The curves $VM_u(t)$ are called "critical paths". As an sample for the system of figure 4 the upper bounds in (16) are written as:

$$s_1(t) \leq VM_1(t) \qquad (19a)$$

$$s_1(t) + s_2(t) \leq VM_{1,2}(t) \qquad (19b)$$

$$s_1(t) + s_3(t) \leq VM_{1,3}(t) \qquad (19c)$$

$$s_1(t) + s_2(t) + s_3(t) \leq VM_{1,2,3}(t) \qquad (19d)$$

$$s_1(t) + s_3(t) + s_4(t) \leq VM_{1,3,4}(t) \qquad (19e)$$

$$s_1(t) + s_2(t) + s_3(t) + s_4(t) \leq VM_{1,2,3,4}(t) \qquad (19f)$$

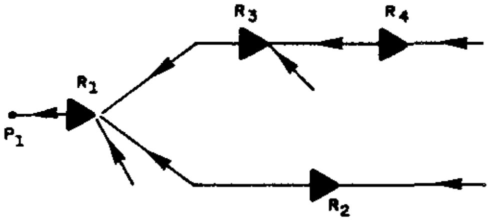

FIGURE 4 - EXAMPLE OF MULTIRESERVOIR SYSTEM

5. STOCHASTIC APPROACH

The critical paths provide upper-bounds for the stored volumes in the case of the occurence of a specific multivariate inflow sequence. However, during real operation one cannot forecast with sufficient precision the future inflow sequence. In the stochastic approach a large number of inflow sequences are taken as the set of all possible inflow sequence. As it is impossible, or uneconomical, protect P against all these sequences some of them are discarded.

Also, in order to take into account the time lag of the flow propagation in the system, the sequences $q_j(t)$ were back-shifted l_j days where l_j is the travel time between reservoirs j and P. The constraints in (16) and (20) should then be written as:

$$\sum_{j\varepsilon u} s_j(t-l_j) \leq VM_u(t) \tag{23}$$

$$\sum_{j\varepsilon u} s_j(t-l_j) \leq \min_i[VM_u(t,i)] \tag{24}$$

In the simulation tests, described in the following, shifted sequences were also used although the notation will not indicate this.

Table 1 shows for each reservoir the total volume, minimum outflow and travel time.

Table 1 - Reservoir System's Characteristics

INDEX	NAME	TOTAL VOLUME (10^6m^3)	TRAVEL TIME (Days)	MINIMUM-OUTFLOW (m^3/s)
8	Furnas	17217	3	859
7	Mascarenhas de Moraes	2500	3	929
6	Marimbondo	5260	1	1881
5	Agua Vermelha	5169	0	2637
4	Emborcação	13015	2	302
3	Itumbiara	12454	1	1504
2	São Simão	5580	0	1556
1	Ilha Solteira	12828	0	5524

7. SIMULATION TESTS

The calculated critical paths and envelope curves were tested by simulation.

The simulation confirmed the protection as the sequences which were not protected (at least one day with $\nu^* > 0$) are the same ones which were discarded.

8. CONCLUSION

This paper showed that it is possible to build multivariate stochastic daily streamflow models which produce synthetic sequences that are statistically indistinguishable from corresponding historical series. Also, it is shown that these synthetic sequences can be used to plan the flood control operation of multireservoir systems.

9. ACKNOWLEDGMENTS

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10. REFERENCES

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